CHAPTER 44

Human–Computer Interaction

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1. OVERVIEW 1193
2. ERGONOMICS 1194
- 2.1. Components of the Work System 1194
- 2.2. Critical Ergonomics Issues in Human–Computer Interaction 1195
- 2.3. Ergonomics of Computer Interfaces 1195
  - 2.3.1. The Screen and Viewing 1195
  - 2.3.2. Screen Character Features 1196
  - 2.3.3. Viewing Distance 1197
  - 2.3.4. Screen Flicker and Image Stability 1197
  - 2.3.5. Screen Swivel and Tilt 1197
- 2.4. The Visual Environment 1198
  - 2.4.1. Lighting 1198
  - 2.4.2. Illumination 1198
  - 2.4.3. Luminance 1199
  - 2.4.4. Glare 1199
- 2.5. The Auditory Environment 1200
  - 2.5.1. Noise 1200
  - 2.5.2. Heating, Ventilating, and Air Conditioning (HVAC) 1200
- 2.6. Computer Interfaces 1201
  - 2.6.1. The Keyboard 1201
  - 2.6.2. Accessories 1202
  - 2.6.3. The Mouse 1202
- 2.7. The Workstation 1202
  - 2.7.1. Working Surfaces 1202
  - 2.7.2. The Chair 1204
  - 2.7.3. Other Workstation Considerations 1204
- 2.8. Work Practices 1205
  - 2.8.1. Work Breaks 1205

3. COGNITIVE DESIGN 1205
- 3.1. Overview 1205
- 3.2. Requirements Definition 1206
- 3.3. Contextual Task Analysis 1206
  - 3.3.1. Background Information 1206
  - 3.3.2. Characterizing Users 1207
  - 3.3.3. Collecting and Analyzing Data 1208
  - 3.3.4. Constructing Models of Work Practices 1210
  - 3.3.5. Task Allocation 1210
- 3.4. Competitive Analysis and Usability Goal Setting 1212
- 3.5. User Interface Design 1212
  - 3.5.1. Initial Design Definition 1212
  - 3.5.2. Detailed Design 1213
  - 3.5.3. Prototyping 1216
- 3.6. Usability Evaluation of Human–Computer Interaction 1216

4. SOCIAL, ORGANIZATIONAL, AND MANAGEMENT FACTORS 1217
- 4.1. Social Environment 1217
- 4.2. Organizational Factors 1222
- 4.3. Management Factors 1225
- 4.4. An International Perspective 1228

5. ITERATIVE DESIGN 1228
REFERENCES 1230

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1. OVERVIEW

The utilities of information technology are spreading into all walks of life, from the use of self-standing personal computers and networking to Internet and intranet. This technology has allowed for tremendous growth in Web-based collaboration and commerce and has expanded into information appliances (e.g., pagers, cellular phones, two-way radios) and other consumer products. It is important that these interactive systems be designed so that they are easy to learn and easy to operate, with minimal errors and health consequences and maximal speed and satisfaction. Yet it can be challenging to achieve an effective design that meets these criteria.

The design of interactive systems has evolved through several paradigm shifts. Initially, designers focused on functionality. The more a system could do, the better the system was deemed to be. This resulted in system designs whose functionality often could not be readily accessed or utilized, or tended to physically stress users (Norman 1988). For example, how many homes have you walked into where the VCR is flashing 12:00? This example shows that even devices that should be simple to configure can be designed in such a manner that users cannot readily comprehend their use. Further, the occurrence of repetitive strain injuries rose as users interacted with systems that engendered significant physical stress. The development of such systems led to a shift in design focus from functionality to usability. Usability engineering (Nielsen 1993) focuses on developing interactive systems that are ergonomically suitable for the users they support (Grandjean 1979; Smith 1984), as well as cognitively appropriate (Vicente 1999). This approach aims to ensure the ease of learning, ease of use, subjective satisfaction, and physical comfort of interactive systems. While these design goals are appropriate and have the potential to engender systems that are effective and efficient to use, system designers have found that this focus on usability does not always lead to the most user-acceptable system designs. In recent years, environmental concerns (i.e., social, organizational, and management factors) have led to design practices that incorporate a greater emphasis on studying and understanding the semantics of work environments (Vicente 1999), often through ethnographic approaches (Nardi 1997; Takahashi 1998). Through participant-observation practices, efforts are made to understand more completely the tasks, work practices, artifacts, and environment that the system will become a part of (Stanney et al. 1997). This is often achieved by designers immersing themselves in the target work environment, thereby becoming accustomed to and familiar with the various factors of interactive system design. These factors include users' capabilities and limitations (both cognitive and physical), organizational factors (e.g., management and social issues), task requirements, and environmental conditions that the work environment supports (see Figure 1). Through the familiarity gained by this involvement, designers can develop systems that are more uniquely suited to target users and the organizations for which they work.

This chapter provides guidelines and data on how to achieve these objectives through the effective design of human–computer interaction, which takes into account the human's physical, cognitive, and social abilities and limitations in reference to interacting with computers and/or computer based appliances. In doing so, it relies on the available standards, practices, and research findings. Much of it is guided by currently available technology but may also be applicable as technology changes and new applications evolve.

The overall thrust of the chapter is that good physical design of the workplace will minimize the probabilities of the occurrence of health consequences; good cognitive design will maximize the utility of interactive systems; and good social and organizational design will effectively integrate these systems into existing work domains. In general, it is suggested that human–computer interaction will be optimized when the following are observed:

- The system design is ergonomically suited to the user.
- Interactive design matches the mental models of users.
- Only information needed for decision making is presented.
- Information of a similar nature is chunked together.
- The interface is adaptive to individual differences due to innate, acquired, or circumstantial reasons.
- The system design supports existing work practices and related artifacts.

Interactive system design is thus about many interfaces; it considers how users relate to each other, how they physically and cognitively interact with systems, how they inhabit their organizations, and how these interfaces can best be supported by mediating technologies. Focusing on each of these areas highlights the need for a multidisciplinary interactive system design team. As Duffy and Salvendy (1999) have documented, in teams that consist of design and manufacturing engineers, marketing specialists, and a team leader, even when they have common goals, each member retrieves and uses different information and has a different mental model that focuses on unique aspects in achieving the same design objectives.

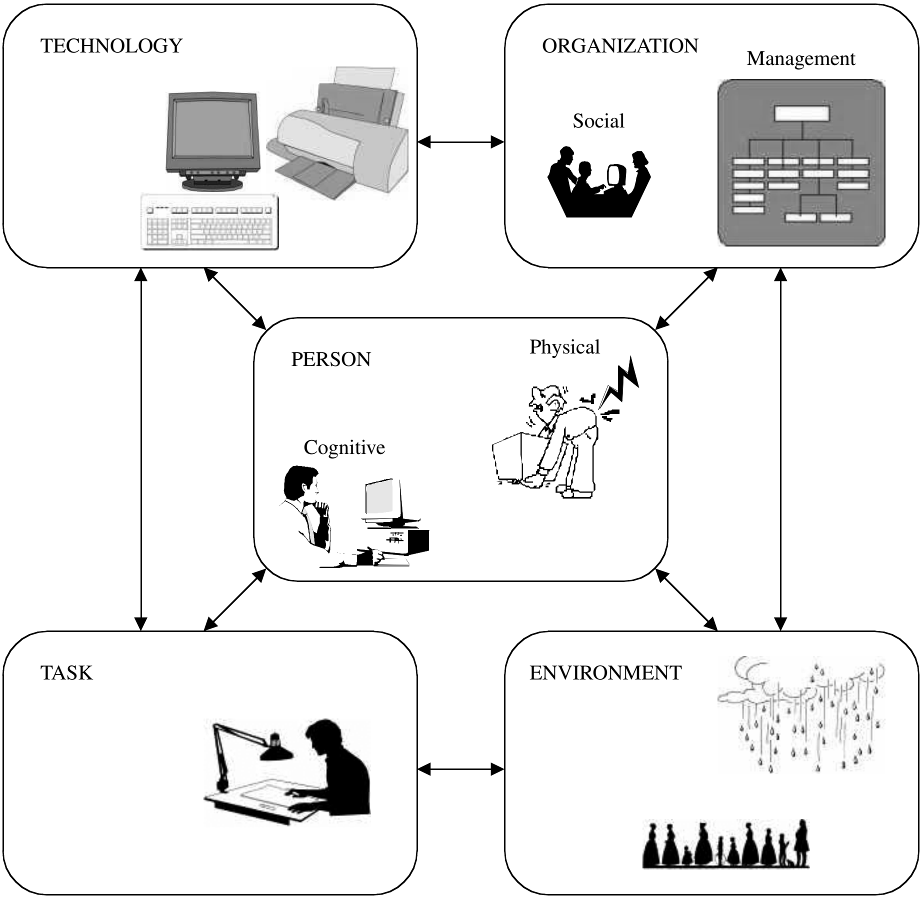


Figure 1 Model of the Work System. (Adapted from Smith and Sainfort 1989)

The following sections will focus on different aspects of interactive system design, including ergonomics, cognitive design, and social, organizational, and management factors.

2. ERGONOMICS

Ergonomics is the science of fitting the environment and activities to the capabilities, dimensions, and needs of people. Ergonomic knowledge and principles are applied to adapt working conditions to the physical, psychological, and social nature of the person. The goal of ergonomics is to improve performance while at the same time enhancing comfort, health, and safety. In particular, the efficiency of human–computer interaction, as well as the comfort, health, and safety of users, can be improved by applying ergonomic principles (Grandjean 1979; Smith 1984). However, no simple recommendations can be followed that will enhance all of these aspects simultaneously. Compromise is sometimes necessary to achieve a set of balanced objectives while ensuring user health and safety (Smith and Sainfort 1989; Smith and Cohen 1997). While no one set of rules can specify all of the necessary combinations of proper working conditions, the use of ergonomic principles and concepts can help in making the right choices.

2.1. Components of the Work System

From an ergonomic point of view, the different components of the work system (e.g., the environment, technology, work tasks, work organization, and people) interact dynamically with each other and function as a total system (see Figure 1). Since changing any one component of the system influences the other aspects of the system, the objective of ergonomics is to *optimize the whole system* rather than maximize just one component. In an ergonomic approach, the person is the central focus and the other factors of the work system are designed to help the person be effective, motivated, and comfortable. The consideration of physical, physiological, psychological, and social needs of the person is necessary to ensure the best possible workplace design for productive and healthy human–computer interaction. Table 1 shows ergonomic recommendations for fixed desktop video display terminal (VDT) use that improve the human interface characteristics. Ergonomic conditions for laptop computer use should conform as closely as possible to the recommendations presented in Table 1.

2.2. Critical Ergonomics Issues in Human–Computer Interaction

A major feature of the ergonomics approach is that *the job task characteristics will define the ergonomic interventions* and the priorities managers should establish for workplace design requirements. The following discussion of critical areas—the technology, sensory environment, thermal environment, workstation design, and work practices—will highlight the major factors that engineers and managers should be aware of in order to optimize human–computer interaction and protect user health. Specific recommendations and guidelines will be derived from these discussions, but please be advised that the recommendations made throughout this chapter may have to be modified to account for differences in technology, personal, situational, or organizational needs at your facility, as well as improved knowledge about human–computer interaction. It cannot be overstated that these considerations represent recommendations and guidelines and not fixed specifications or standards. The realization that any one modification in any single part of the work system will affect the whole system and particularly the person (see Figure 1) is essential for properly applying the following recommendations and specifications.

2.3. Ergonomics of Computer Interfaces

Today, the primary display interfaces in human–computer interaction are the video display with a cathode ray tube and the flat panel screen. In the early 1980s, the US Centers for Disease Control (CDC 1980) and the U.S. National Academy of Sciences defined important design considerations for the use of cathode ray tubes (NAS 1983). The Japan Ergonomics Society (JES) established a Committee for Flat Panel Display Ergonomics in 1996, which proposed ergonomic guidelines for use of products with flat panels, such as liquid crystal displays (LCDs) (JES 1996). These Japanese guidelines were subsequently reviewed by the Committee on Human–Computer Interaction of the International Ergonomics Association (IEA). The JES guidelines addressed the following issues: (1) light-related environmental factors, (2) device use and posture factors, (3) environmental factors, (4) job design factors, and (5) individual user factors. These guidelines will be discussed in appropriate sections of this chapter.

The use of CRTs and flat panel displays has been accompanied by user complaints of visual fatigue, eye soreness, general visual discomfort, and various musculoskeletal complaints and discomfort with prolonged use (Grandjean 1979; Smith et al. 1981; NIOSH 1981; NAS 1983; Smith 1984; JES 1996). Guidelines for providing the proper design of the VDT and the environment in which it is used have been proposed by the Centers for Disease Control (CDC 1980) and the Human Factors and Ergonomics Society (ANSI 1988), and for the laptop and palm computer, by the Japan Ergonomics Society (JES 1996). The following sections deal with the visual environment for using desktop computers, but the discussion can be extrapolated to other types of computer use.

The major interfaces of employees with computers are the screen (CRT, flat panel), the keyboard, and the mouse. Other interfaces are being used more and more, such as voice input, pointers, hand-actuated motion devices, and apparatuses for virtual environment immersion.

2.3.1. The Screen and Viewing

Poor screen images, fluctuating and flickering screen luminances, and screen glare cause user visual discomfort and fatigue (Grandjean 1979; NAS 1983). There are a range of issues concerning readability and screen reflections. One is the adequacy of contrast between the characters and screen background. Screens with glass surfaces have a tendency to pick up glare sources in the environment and reflect them. This can diminish the contrast of images on the screen. To reduce environmental glare, the luminance ratio within the user's near field of vision should be approximately 1:3, and within the far field approximately 1:10 (NIOSH 1981). For luminance on the screen itself, the character-to-screen background luminance contrast ratio should be at least 7:1 (NIOSH 1981). To give the best readability for each operator, it is important to provide VDTs with adjustments for character contrast and brightness. These adjustments should have controls that are obvious to observe and manipulate and easily accessible from normal working position (e.g., located at the front of the screen) (NIOSH 1981).

TABLE 1 Ergonomic Recommendations for the VDT Technology, Work Environment, and Workstation

Ergonomic Consideration	Recommendation
1. Viewing screen	
a. Character/screen contrast	7:1 minimum
b. Screen character size	height = 20–22 min of visual arc width = 70–80% of height
c. Viewing distance	Usually 50 cm or less, but up to 70 cm is acceptable
d. Line refresh rate	70 hz minimum
e. Eye viewing angle from horizon	10–40° (from top to bottom gaze)
2. Illumination	
a. No hardcopy	300 lux minimum
b. With normal hard copy	500 lux
c. With poor hard copy	700 lux
d. Environmental luminance contrast	
• Near objects	1:3
• Far objects	1:10
e. Reflectance from surfaces	
• Working surface	40–60%
• Floor	30%
• Ceiling	80–90%
• Walls	40–60%
3. HVAC	
a. Temperature—winter	20–24°C (68–75°F)
b. Temperature—summer	23–27°C (73–81°F)
c. Humidity	50–60%
d. Airflow	0.15–0.25 m/sec
4. Keyboard	
a. Slope	0–15° preferred, 0–25° acceptable
b. Key top area	200 mm^2
c. Key top horizontal width	12 mm (minimum)
d. Horizontal key spacing	18–19 mm
e. Vertical key spacing	18–20 mm
f. Key force	0.25N–1.5N (0.5–0.6N preferred)
5. Workstation	
a. Leg clearance	51 cm minimum (61 cm preferred minimum)
b. Leg depth	38 cm minimum
c. Leg depth with leg extension	59 cm minimum
d. Work surface height—nonadjustable	70 cm
e. Work surface height—adjustable for one surface	70–80 cm
f. Work surface height—adjustable for two surfaces	Keyboard surface 59–71 cm Screen surface 70–80 cm
6. Chair	
a. Seat pan width	45 cm minimum
b. Seat pan depth	38–43 cm
c. Seat front tilt	5° forward to 7° backward
d. Seat back inclination	110–130°
e. Seat pan height adjustment range	38–52 cm
f. Backrest inclination	Up to 130°
g. Backrest height	45–51 cm above seat pan surface

2.3.2. Screen Character Features

Good character design can help improve image quality, which is a major factor for reducing eyestrain and visual fatigue. The proper size of a character is dependent on the task and the display parameters (brightness, contrast, glare treatment, etc.) and the viewing distance. Character size that is too small can make reading difficult and cause the visual focusing mechanism to overwork. This produces eyestrain and visual fatigue (NAS 1983). Character heights should preferably be at least 20–22 min of visual arc, while character width should be 70–80% of the character height (Smith 1984; ANSI 1988). This approximately translates into a minimum lowercase character height of 3.5 mm with a width of 2.5 mm at a normal viewing distance of 50 cm.

Good character design and proper horizontal and vertical spacing of characters can help improve image quality. To ensure adequate discrimination between characters and good screen readability, the character spacing should be in the range of 20–50% of the character width. The interline spacing should be 50–100% of the character height (Smith 1984; ANSI 1988).

The design of the characters influences their readability. Some characters are hard to decipher, such as lowercase *g*, which looks like numeral *8*. A good font design minimizes character confusion and enhances the speed at which characters can be distinguished and read. Two excellent fonts are Huddleston and Lincoln-Mitre (NAS 1983). Most computers have a large number of fonts to select from. Computer users should choose a font that is large enough to be easy for them to read.

2.3.3. Viewing Distance

Experts have traditionally recommended a viewing distance between the screen and the operator's eye of 45–50 cm but no more than 70 cm (Grandjean 1979; Smith 1984). However, experience in field studies has shown that users may adopt a viewing distance greater than 70 cm and are still able to work efficiently and not develop visual problems. Thus, viewing distance should be determined in context with other considerations. It will vary depending on the task requirements, CRT screen characteristics, and individual's visual capabilities. For instance, with poor screen or hard copy quality, it may be necessary to reduce viewing distances for easier character recognition. Typically, the viewing distance should be 50 cm or less due to the small size of characters on the VDT screen. LNCs are often used in situations where the computer is placed on any convenient surface, for example a table at the airport waiting room. Thus, the viewing distance is defined by the available surface, not a fixed workstation. When the surface is farther away from the eyes, the font size used should be larger.

Proper viewing distance will be affected by the condition of visual capacity and by the wearing of spectacles/lenses. Persons with myopia (near-sightedness) may find that they want to move the screen closer to their eyes; while persons with presbyopia (far-sightedness) or bifocal lenses may want the screen farther away from their eyes. Many computer users who wear spectacles have a special pair of spectacles with lenses that are matched to their particular visual defect and a comfortable viewing distance to the screen. Eyecare specialist can have special spectacles made to meet computer users' screen use needs.

2.3.4. Screen Flicker and Image Stability

The stability of the screen image is another characteristic that contributes to CRT and LCD quality. Ideally, the display should be completely free of perceptible movements such as flicker or jitter (NIOSH 1981). CRT screens are refreshed a number of times each second so that the characters on the screen appear to be solid images. When this refresh rate is too low, users perceive screen flicker. LCDs have less difficulty with flicker and image stability than CRT displays. The perceptibility of screen flicker depends on illumination, screen brightness, polarity, contrast, and individual sensitivity. For instance, as we get older and our visual acuity diminishes, so too does our ability to detect flicker. A screen with a dark background and light characters has less flicker than screens with dark lettering on a light background. However, light characters on a dark background show more glare. In practice, flicker should not be observable, and to achieve this a screen refresh rate of at least 70 cycles per second needs to be achieved for each line on the CRT screen (NAS 1983; ANSI 1988). With such a refresh rate, flicker should not be a problem for either screen polarity (light on dark or dark on light). It is a good idea to test a screen for image stability. Turn the lights down, increase the screen brightness/contrast settings, and fill the screen with letters. Flickering of the entire screen or jitter of individual characters should not be perceptible, even when viewed peripherally.

2.3.5. Screen Swivel and Tilt

Reorientation of the screen around its vertical and horizontal axes can reduce screen reflections and glare. Reflections can be reduced by simply tilting the display slightly back or down or to the left or right, depending on the angle of the source of glare. These adjustments are easiest if the screen can be tilted about its vertical and horizontal axes. If the screen cannot be tilted, it should be approximately vertical to help eliminate overhead reflections, thus improving legibility and posture.

The perception of screen reflection is influenced by the tilt of the screen up or down and back and forth and by the computer user's line of sight toward the screen. If the screen is tilted toward sources of glare and these are in the computer user's line of sight to the screen, the screen images will have poorer clarity and reflections can produce disability glare (see Section 2.4.4). In fact, the line of sight can be a critical factor in visual and musculoskeletal discomfort symptoms. When the line of sight can observe glare or reflections, then eyestrain often occurs. For musculoskeletal considerations, experts agree that the line of sight should never exceed the straight-ahead horizontal gaze, and in fact it is best to provide a downward gaze of about 10–20° from the horizontal when viewing the top of the screen and about 40° when viewing the bottom edge of the screen (NIOSH 1981; NAS 1983; Smith 1984; ANSI 1988). This will help reduce neck and shoulder fatigue and pain. These gaze considerations are much harder to obtain when using LNCs because of the smaller screen size and workstation features (eg., airport waiting room table).

2.4. The Visual Environment

2.4.1. Lighting

Lighting is an important aspect of the visual environment that influences readability and glare on the screen and viewing in the general environment. There are four types of general workplace illumination of interest to the computer user's environment:

1. *Direct radiants:* The majority of office lighting is direct radiants. These can be incandescent lights, which are most common in homes, or fluorescent lighting, which is more prevalent in workplaces and stores. Direct radiants direct 90% or more of their light toward the object(s) to be illuminated in the form of a cone of light. They have a tendency to produce glare.
2. *Indirect lighting:* This approach uses reflected light to illuminate work areas. Indirect lighting directs 90% or more of the light onto the ceiling and walls, which reflect it back into the room. Indirect lighting has the advantage of reducing glare, but supplemental lighting is often necessary, which can be a source of glare.
3. *Mixed direct radiants and indirect lighting:* In this approach, part of the light (about 40%) radiates in all directions while the rest is thrown directly or indirectly onto the ceiling and walls.
4. *Opalescent globes:* These lights give illumination equally in all directions. Because they are bright, they often cause glare.

Modern light sources used in these four general approaches to workplace illumination are typically of two kinds: electric filament lamps and fluorescent tubes. Following are the advantages and drawbacks of these two light sources:

1. *Filament lamps:* The light from filament lamps is relatively rich in red and yellow rays. It changes the apparent colors of objects and so is unsuitable when correct assessment of color is essential. Filament lamps have the further drawback of emitting heat. On the other hand, employees like their warm glow, which is associated with evening light and a cozy atmosphere.
2. *Fluorescent tubes:* Fluorescent lighting is produced by passing electricity through a gas. Fluorescent tubes usually have a low luminance and thus are less of a source of glare. They also have the ability to match their lighting spectrum to daylight, which many employees find preferable. They may also be matched to other spectrums of light that can fit office decor or employee preferences. Standard-spectrum fluorescent tubes are often perceived as a cold, pale light and may create an unfriendly atmosphere. Fluorescent tubes may produce flicker, especially when they become old or defective.

2.4.2. Illumination

The intensity of illumination or the illuminance being measured is the amount of light falling on a surface. It is a measure of the quantity of light with which a given surface is illuminated and is measured in lux. In practice, this level depends on both the direction of flow of the light and the spatial position of the surface being illuminated in relation to the light flow. Illuminance is measured in both the horizontal and vertical planes. At computer workplaces, both the horizontal and vertical illuminances are important. A document lying on a desk is illuminated by the horizontal illuminance, whereas the computer screen is illuminated by the vertical illuminance. In an office that is illuminated from overhead luminaires, the ratio between the horizontal and vertical illuminances is usually between 0.3 and 0.5. So if the illuminance in a room is said to be 500 lux, the horizontal illuminance is 500 lux while the vertical illuminance is between 150 and 250 lux (0.3 and 0.5 of the horizontal illuminance).

The illumination required for a particular task is determined by the visual requirements of the task and the visual ability of the employees concerned. In general, an illuminance in the range of 300–700 lux measured on the horizontal working surface (not the computer screen) is normally preferable (CDC 1980; NAS 1983). The JES (1996) recommends office lighting levels ranging from 300–1,000 lux for flat panel displays. Higher illumination levels are necessary to read hard copy and lower illumination levels are better for work that just uses the computer screen. Thus, a job in which hard copy and a computer screen are both used should have a general work area illumination level of about 500–700 lux, while a job that only requires reading the computer screen should have a general work area illumination of 300–500 lux. Conflicts can arise when both hardcopy and computer screens are used by different employees who have differing job task requirements or differing visual capabilities and are working in the same area. As a compromise, room lighting can be set at the recommended lower (300 lux) or intermediate level (500 lux) and additional task lighting can be provided as needed. Task lighting refers to localized lighting at the workstation to replace or supplement ambient lighting systems used for more generalized lighting of the workplace. Task lighting is handy for illuminating hardcopy when the room lighting is set at a low level, which can hinder document visibility. Such additional lighting must be carefully shielded and properly placed to avoid glare and reflections on the computer screens and other adjacent working surfaces of other employees. Furthermore, task lighting should not be too bright in comparison to the general work area lighting since looking between these two different light levels may produce eyestrain.

2.4.3. Luminance

Luminance is a measure of the brightness of a surface, that is, the amount of light leaving the surface of an object, either reflected by the surface (as from a wall or ceiling), emitted by the surface (as from the CRT or LCD characters), or transmitted (as light from the sun that passes through translucent curtains). Luminance is expressed in units of candelas per square meter. High-intensity luminance sources (such as windows) in the peripheral field of view should be avoided. In addition, the balance among the luminance levels within the computer user's field of view should be maintained. The ratio of the luminance of a given surface or object to another surface or object in the central field of vision should be around 3:1, while the luminance ratio in the peripheral field of vision can be as high as 10:1 (NAS 1983).

2.4.4. Glare

Large differences in luminance or high-luminance lighting sources can cause glare. Glare can be classified with respect to its effects (disability glare vs. discomfort glare) or the source of glare (direct glare vs. reflected glare). Glare that results in an impairment of vision (e.g., reduction of visual acuity) is called disability glare, while discomfort glare is experienced as a source of discomfort to the viewer but does not necessarily interfere with visual performance. With regard to the source, direct glare is caused by light sources in the field of view of the computer user, while reflected glare is caused by reflections from illuminated, polished, or glossy surfaces or by large luminance differences in the visual environment. In general, glare is likely to increase with the luminance, size, and proximity of the lighting source to the line of sight.

Direct and reflected glare can be limited through one or more of the following techniques:

1. Controlling the light from windows: This can be accomplished by closing drapes, shades, and/or blinds over windows or awnings on the outside, especially during sunlight conditions.
2. Controlling the view of luminaires:
   - **(a)** By proper positioning of CRT screen with regard to windows and overhead lighting to reduce direct or reflected glare and images. To accomplish this, place VDTs parallel to windows and luminaires and between luminaires rather than underneath them.
   - **(b)** Using screen hoods to block luminaires from view.
   - **(c)** Recessing light fixtures.
   - **(d)** Using light-focusing diffusers.
3. Controlling glare at the screen surface by:
   - **(a)** Adding antiglare filters on the VDT screen.
   - **(b)** Proper adjustment up or down/left or right of the screen.
4. Controlling the lighting sources using:
   - **(a)** Appropriate glare shields or covers on the lamps.
   - **(b)** Properly installed indirect lighting systems.

Glare can also be caused by reflections from surfaces, such as working surfaces, walls, or the floor covering. These surfaces do not emit light themselves but can reflect it. The ratio of the amount of light reflected by a surface (luminance) to the amount of light striking the surface (illuminance) is called reflectance. Reflectance is unitless. The reflectance of the working surface and the office machines should be on the order of 40–60% (ANSI 1988). That is, they should not reflect more than 60% of the illuminance striking their surface. This can be accomplished if surfaces have a matte finish.

Generally, floor coverings should have a reflectance of about 30%, ceilings, of 80–90%, and walls, 40–60%. Reflectance should increase from the floor to the ceiling. Although the control of surface reflections is important, especially with regard to glare control, it should not be at the expense of a pleasant working environment where employees feel comfortable. Walls and ceilings should not be painted dark colors just to reduce light reflectance, nor should windows be completely covered or bricked up to keep out sunlight. Other, more reasonable luminance control approaches can give positive benefits while maintaining a psychologically pleasing work environment.

2.5. The Auditory Environment

2.5.1. Noise

A major advantage of computer technology over the typewriter is less noise at the workstation. However, it is not unusual for computer users to complain of bothersome office noise, particularly from office conversation. Noise levels commonly encountered in offices are below established limits that could cause damage to hearing (i.e., below 85 dBA). The JES (1996) proposed that the noise level should not exceed 55 dBA. The expectations of office employees are for quiet work areas because their tasks often require concentration. Annoying noise can disrupt their ability to concentrate and may produce stress.

Actually, there are many sources of annoyance noise in computer operations. Fans in computers, printers, and other accessories, which are used to maintain a favorable internal device temperature, are a source of noise. Office ventilation fans can also be a source of annoyance noise. The computers themselves may be a source of noise (e.g., the click of keys or the high-pitched squeal of the CRT). The peripheral equipment associated with computers, such as printers, can be a source of noise. Problems of noise may be exacerbated in open-plan offices, in which noise is harder for the individual employee to control than in enclosed offices.

Acoustical control can rely upon ceiling, floor and wall, furniture, and equipment materials that absorb sound rather than reflect it. Ceilings that scatter, absorb, and minimize the reflection of sound waves are desirable to promote speech privacy and reduce general office noise levels. The most common means of blocking a sound path is to build a wall between the source and the receiver. Walls are not only sound barriers but are also a place to mount sound-absorbent materials. In open-plan offices, free-standing acoustical panels can be used to reduce the ambient noise level and also to separate an individual from the noise source. Full effectiveness of acoustical panels is achieved in concert with the sound-absorbent materials and finishes applied to the walls, ceiling, floor, and other surfaces. For instance, carpets not only cover the floor but also serve to reduce noise. This is achieved in two ways: (1) carpets absorb the incident sound energy and (2) gliding and shuffling movements on carpets produce less noise than on bare floors. Furniture and draperies are also important for noise reduction.

Acoustical control can also be achieved by proper space planning. For instance, workstations that are positioned too closely do not provide suitable speech privacy and can be a source of disturbing conversational noise. As a general rule, a minimum of 8–10 ft between employees, separated by acoustical panels or partitions, will provide normal speech privacy.

2.5.2. Heating, Ventilating, and Air Conditioning (HVAC)

Temperature, humidity, air flow, and air exchanges are important parameters for employees' performance and comfort.

It is unlikely that offices will produce excessive temperatures that could be physically harmful to employees. However, thermal comfort is an important consideration in employee satisfaction that can influence performance. Satisfaction is based not on the ability to tolerate extremes but on what makes an individual happy. Many studies have shown that most office employees are not satisfied with their thermal comfort. The definition of a comfortable temperature is usually a matter of personal preference. Opinions as to what is a comfortable temperature vary within an individual from time to time and certainly among individuals. Seasonal variations of ambient temperature influence perceptions of thermal comfort. Office employees sitting close to a window may experience the temperature as being too cold or hot, depending on the outside weather. It is virtually impossible to generate one room temperature in which all employees are equally well satisfied over a long period of time.

As a general rule, it is recommended that the temperature be maintained in the range of 20–24°C (68–75°F) in winter and 23–27°C (73–81°F) in summer (NIOSH 1981; Smith 1984). The JES (1996) recommends office temperatures of 20–23°C in winter and 24–27°C in summer.

Air flows across a person's neck, head, shoulders, arms, ankles, and knees should be kept low (below 0.15 m/sec in winter and below 0.25 m/sec in summer). It is important that ventilation not produce currents of air that blow directly on employees. This is best handled by proper placement of the workstation.

Relative humidity is an important component of office climate and influences an employee's comfort and well being. Air that is too dry leads to drying out of the mucous membranes of the eyes, nose, and throat. Individuals who wear contact lenses may be made especially uncomfortable by dry air. In instances where intense, continuous near-vision work at the computer is required, very dry air has been shown to irritate the eyes. As a general rule, it is recommended that the relative humidity in office environments be at least 50% and less than 60% (NIOSH 1981; Smith 1984). The JES (1996) recommends humidity levels of 50–60%. Air that is too wet enhances the growth of unhealthy organisms (molds, fungus, bacteria) that can cause disease (legionnaires', allergies).

2.6. Computer Interfaces

Computer interfaces are the means by which users provide instructions to the computer. There are a wide variety of devices for interfacing, including keyboards, mice, trackballs, joy sticks, touch panels, light pens, pointers, tablets, and hand gloves. Any mechanical or electronic device that can be tied to a human motion can serve as a computer interface. The most common interfaces in use today are the keyboard and the mouse. The keyboard will be used as an example to illustrate how to achieve proper human–computer interfaces.

2.6.1. The Keyboard

In terms of computer interface design, a number of keyboard features can influence an employee's comfort, health, and performance. The keyboard should be detachable and movable, thus providing flexibility for independent positioning of the keyboard and screen. This is a major problem with LNCs because the keyboard is built into the top of the computer case for portability and convenience. It is possible to attach a separate, detachable keyboard to the LNC, and this should be done when the LNC is used at a fixed workstation in an office or at home. Clearly, it would be difficult to have a separate keyboard when travelling and the LNC portability feature is paramount.

The keyboard should be stable to ensure that it does not slide on the tabletop. This is a problem when an LNC is held in the user's lap or some other unstable surface. In order to help achieve a favorable user arm height positioning, the keyboard should be as thin as possible. The slope or angle of the keyboard should be between 0° and 15°, measured from the horizontal. LNCs are limited in keyboard angle because the keyboard is often flat (0°). However, some LNCs have added feet to the computer case to provide an opportunity to increase the keyboard angle. Adjustability of keyboard angle is recommended. While the ANSI standard (ANSI 1988) suggests 0–25°, we feel angles over 15° are not necessary for most activities.

The shape of the key tops must satisfy several ergonomic requirements, such as minimizing reflections, aiding the accurate location of the operator's finger, providing a suitable surface for the key legends, preventing the accumulation of dust, and being neither sharp nor uncomfortable when depressed. For instance, the surface of the key tops, as well as the keyboard itself, should have a matte finish. The key tops should be approximately 200 mm (ANSI 1988) with a minimum horizontal width of 12 mm. The spacing between the key centers should be about 18–19 mm horizontally and 18–20 mm vertically (ANSI 1988). There should be slight protrusions on select keys on the home row to provide tactile information about finger position on the keyboard.

The force to depress the key should ideally be between 0.5 N and 0.6 N (ANSI 1988). However, ranges from 0.25–1.5 N have been deemed acceptable (ANSI 1988). The HFES/ANSI-100 standard is currently being revised, and this recommendation may change soon. Some experts feel that the keying forces should be as low as feasible without interfering with motor coordination. Research has shown that light-touch keys require less operator force in depressing the key (Rempel and Gerson, 1991; Armstrong et al. 1994; Gerard et al. 1996). The light-touch force keyboards vary between 0.25–0.40 N.

Feedback from typing is important for beginning typists because it can indicate to the operator that the keystroke has been successfully completed. There are two main types of keyboard feedback: tactile and auditory. Tactile feedback can be provided by a collapsing spring that increases in tension as the key is depressed or by a snap-action mechanism when key actuation occurs. Auditory feedback (e.g., "click" or "beep") can indicate that the key has been actuated. Of course, there is also visual feedback on the computer screen. For experienced typists, the feedback is not useful, as their fingers are moving in a ballistic way that is too fast for the feedback to be useful for modifying finger action (Guggenbuhl and Krueger 1990, 1991; Rempel and Gerson 1991; Rempel et al. 1992).

The keyboard layout can be the same as that of a conventional typewriter, that is, the QWERTY design, or some other proven style, such as the DVORAK layout. However, it can be very difficult for operators to switch between keyboards with different layouts. Traditional keyboard layout has straight rows and staggered columns. Some authors have proposed curving the rows to provide a better fit for the hand to reduce biomechanical loading on the fingers (Kroemer 1972). However, there is no research evidence that such a design provides advantages for operator's performance or health.

Punnett and Bergqvist (1997) have proposed that keyboard design characteristics can lead to upper-extremity musculoskeletal disorders. There is controversy about this contention by Punnett and Bergqvist because there are many factors involved in computer typing jobs independent of the keyboard characteristics that may contribute to musculoskeletal disorders. Some ergonomists have designed alternative keyboards in attempts to reduce the potential risk factors for musculoskeletal disorders (Kroemer 1972; Nakaseko et al. 1985; Ilg 1987). NIOSH (1997) produced a publication that describes various alternative keyboards. Studies have been undertaken to evaluate some of these alternative keyboards (Swanson et al. 1997; Smith et al. 1998). The research results indicated some improvement in hand/wrist posture from using the alternative keyboards, but no decrease in musculoskeletal discomfort.

2.6.2. Accessories

The use of a wrist rest when keying can help to minimize extension (backward bending) of the hand. A wrist rest should have a fairly broad surface (approximately 5 cm) with a rounded front edge to prevent cutting pressures on the wrist and hands. Padding further minimizes skin compression and irritation. Height adjustability is important so that the wrist rest can be set to a preferred level in concert with the keyboard height and slope. Some experts are concerned that resting the wrist on a wrist rest during keying could cause an increase in intercarpal canal pressure. They prefer that wrist rests be used only when the user is not keying for the purpose of resting the hands and wrist. Thus, they believe users need to be instructed (trained) about when and how to use a wrist rest. Arm holders are also available to provide support for the hands, wrists, and arms while keyboarding. However, these may also put pressure on structures that may produce nerve compression. As with a wrist rest, some experts feel these devices are best used only during rest from keying.

2.6.3. The Mouse

The most often-used computer pointing device is the mouse. While there are other pointing devices, such as the joystick, touch panel, trackball, and light pen, the mouse is still the most universally used of these devices. An excellent discussion of these pointing devices can be found in Bullinger et al. (1977). The mouse provides for an integration of both movement of the cursor and action on computer screen objects, simultaneously. Many mice have multiple buttons to allow for several actions to occur in sequence. The ease of motion patterns and multiple-function buttons give the mouse an advantage over other pointing devices. However, a disadvantage of the mouse is the need for tabletop space to achieve the movement function. Trankle and Deutschmann (1991) conducted a study to determine which factors influenced the speed of properly positioning a cursor with a mouse. The results indicated that the most important factors were the target size and the distance traveled. Also of lesser importance was the display size arc. The control/response ratio or the sensitivity of the control to movement was not found to be important. Recently, studies have indicated that operators have reported musculoskeletal discomfort due to mouse use (Karlqvist et al. 1994; Armstrong et al. 1995; Hagberg 1995; Fogelman and Brogmus 1995; Wells et al. 1997).

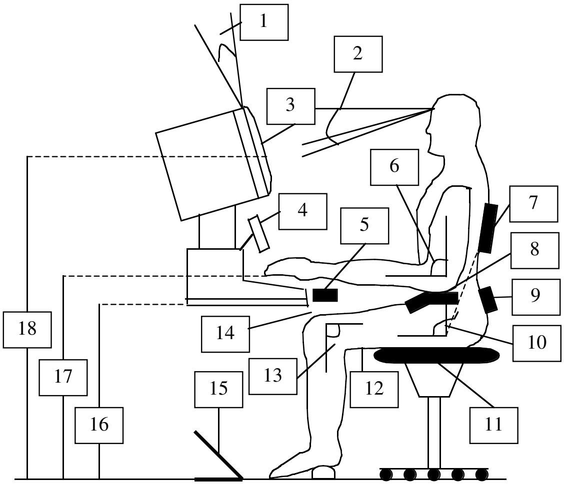
2.7. The Workstation

Workstation design is a major element in ergonomic strategies for improving user comfort and particularly for reducing musculoskeletal problems. Figure 2 illustrates the relationships among the working surface, VDT, chair, documents, and various parts of the body. Of course, this is for a fixed workstation at the office or home. Use of LNCs often occurs away from fixed workstations where it is difficult to meet the requirements described below. However, efforts should be made to meet these requirements as much as possible, even when using LNCs.

The task requirements will determine critical layout characteristics of the workstation. The relative importance of the screen, keyboard, and hard copy (i.e., source documents) depends primarily on the task, and this defines the design considerations necessary to improve operator performance, comfort, and health. Data-entry jobs, for example, are typically hard copy oriented. The operator spends little time looking at the screen, and tasks are characterized by high rates of keying. For this type of task it is logical for the layout to emphasize the keyboard, mouse, and hard copy, because these are the primary tools used in the task, while the screen is of lesser importance. On the other hand, data-acquisition operators spend most of their time looking at the screen and seldom use hard copy. For this type of task, the screen and the keyboard layout should be emphasized.

2.7.1. Working Surfaces

The size of the work surface is dependent on the task(s), documents, and technology. The primary working surface (e.g., supporting the keyboard, display, and documents) should be sufficient to: (1) permit the screen to be moved forward or backward to a comfortable viewing distance for a range



1. Screen tilt angle
2. Visual angle between the horizontal and the center of the display
3. Eye-screen distance
4. Document holder and source document
5. Wrist wrest
6. Elbow angle
7. Backrest
8. Elbow rest
9. Lumbar support
10. Seat back angle (from horizontal)
11. Seat pan angle (from horizontal)
12. Clearance between leg and seat
13. Knee angle
14. Clearance between leg and table
15. Footrest
16. Table height
17. Home row (middle row height)
18. Screen height to center of screen

Figure 2 Definitions of VDT Workstation Terminology. (Adapted from Helander 1982)

of users, (2) allow a detachable keyboard to be placed in several locations, and (3) permit source documents to be properly positioned for easy viewing. Additional working surfaces (i.e., secondary working surfaces) may be required in order to store, lay out, read, and/or write on documents or materials. Often users have more than one computer, so a second computer is placed on a secondary working surface. In such a situation, workstations are configured so that multiple pieces of equipment and source materials can be equally accessible to the user. In this case, additional working surfaces are necessary to support these additional tools and are arranged to allow easy movement while seated from one surface to another.

The tabletop should be as thin as possible to provide clearance for the user's thighs and knees. Moreover, it is important to provide unobstructed room under the working surface for the feet and legs so that users can easily shift their posture. Knee space height and width and leg depth are the three key factors for the design of clearance space under working surfaces (see Figure 2). Recommendations for minimum width for leg clearance is 51 cm, while the preferred minimum width is 61 cm (ANSI, 1988). The minimum depth under the work surface from the operator edge of the work surface should be 38 cm for clearance at the knee level and 60 cm at the toe level (ANSI 1988). A good workstation design accounts for individual body sizes and often exceeds minimum clearances to allow for free postural movement.

Table height has been shown to be an important contributor to computer user musculoskeletal problems. In particular, tables that are too high cause the keyboard to be too high for many operators. The standard desk height of 30 in. (76 cm) is often too high for most people to attain the proper arm angle when using the keyboard. This puts undue pressure on the hands, wrists, arms, shoulders, and neck. It is desirable for table heights to vary with the trunk height of the operator. Height-adjustable tables are effective for this. Adjustable multisurface tables enable good posture by allowing the keyboard and display to be independently adjusted to appropriate keying and viewing heights for each individual and each task. Tables that cannot be adjusted easily are not appropriate when used by several individuals of differing sizes. If adjustable tables are used, ease of adjustment is essential. Adjustments should be easy to make and operators should be instructed (trained) about how to adjust the workstation to be comfortable and safe.

Specifications for the height of working surfaces vary by whether the table is adjustable or fixed in height and depending on a single working surface or multiple working surfaces. Remember that adjustable-height working surfaces are strongly recommended. However, if the working surface height is not adjustable, the proper height for a nonadjustable working surface is about 70 cm (floor to top of surface) (ANSI 1988). Adjustable tables allow vertical adjustments of the keyboard and display. Some allow for independent adjustment of the keyboard and display. For single adjustable working surfaces, the working surface height adjustment should be 70–80 cm. For independently adjustable working surfaces for the keyboard and screen, the appropriate height range for the keyboard surface is 59–71 cm, and 70–80 cm for the screen (ANSI 1988).

2.7.2. The Chair

Poorly designed chairs can contribute to computer user discomfort. Chair adjustability in terms of height, seat angle, lumbar support, and armrest height and angle reduces the pressure and loading on the musculoskeleture of the back, legs, shoulders, neck, and arms. In addition, how the chair supports the movement of the user (the chair's action) helps to maintain proper seated posture and encourages good movement patterns. A chair that provides swivel action encourages movement, while backward tilting increases the number of postures that can be assumed. The chair height should be adjustable so that the feet can rest firmly on the floor with minimal pressure beneath the thighs. The minimum range of adjustment for seat height should be 38–52 cm (NAS 1983; Smith 1984; ANSI 1988). Modern chairs also provide an action that supports the back (spine) when seated. Examples of such chairs are the Leap by Steelcase, Inc. and the Aeron by Herman Miller.

To enable shorter users to sit with their feet on the floor without compressing their thighs, it may be necessary to add a footrest. A well-designed footrest has the following features: (1) it is inclined upward slightly (about 5–15°), (2) it has a nonskid surface, (3) it is heavy enough that it does not slide easily across the floor, (4) it is large enough for the feet to be firmly planted, and (5) it is portable.

The seat pan is where the user's buttocks sits on the chair. It is the part that directly supports the weight of the buttocks. The seat pan should be wide enough to permit operators to make slight shifts in posture from side to side. This not only helps to avoid static postures but also accommodates a large range of individual buttock sizes with a few seat pan widths. The minimum seat pan width should be 45 cm and the minimum depth 38–43 cm (ANSI 1988). The front edge of the chair should be well rounded downward to reduce pressure on the underside of the thighs, which can affect blood flow to the legs and feet. The seat needs to be padded to the proper firmness that ensures an even distribution of pressure on the thighs and buttocks. A properly padded seat should compress about one-half to one inch when a person sits on it.

Some experts feel that the seat front should be elevated slightly (up to 7°), while others feel it should be lowered slightly (about 5°) (ANSI 1988). There is little agreement among the experts about which is correct (Grandjean 1979, 1984). Many chair manufacturers provide adjustment of the front angle so the user can have the preferred tilt angle, either forward or backward.

The tension for leaning backward and the backward tilt angle of the backrest should be adjustable. Inclination of chair backrest is important for users to be able to lean forward or back in a comfortable manner while maintaining a correct relationship between the seat pan angle and the backrest inclination. A back seat inclination of about 110° is considered as the best position by many experts (Grandjean 1984). However, studies have shown that operators may incline backward as much as 125°. Backrests that tilt to allow an inclination of up to 125–130° are a good idea. The advantage of having an independent tilt angle adjustment is that the backrest tilt will then have little or no effect on the front seat height. This also allows operators to shift postures easily and often.

Chairs with full backrests that provide lower back (lumbar) support and upper back (lower shoulder) support are preferred. This allows employees to lean backward or forward, adopting a relaxed posture and resting the back muscles. A full backrest with a height around 45–51 cm is recommended (ANSI 1988). However, some of the newer chair designs do not have the bottom of the backrest go all the way to the seat pan. This is acceptable as long as the lumbar back is properly supported. To prevent back strain with such chairs, it is recommended that they have midback (lumbar) support since the lumbar region is one of the most highly loaded parts of the spine.

For most computer workstations, chairs with rolling castors (or wheels) are desirable. They are easy to move and facilitate the postural adjustment of users, particularly when the operator has to access equipment or materials that are on secondary working surfaces. Chairs should have a five-star base for tipping stability (ANSI 1988).

Another important chair feature is armrests. Pros and cons for the use of armrests at computer workstations have been advanced. On the one hand, some chair armrests can present problems of restricted arm movement, interference with keyboard operation, pinching of fingers between the armrest and table, restriction of chair movement such as under the work table, irritation of the arm or elbows, and adoption of awkward postures.

On the other hand, well-designed armrests or elbow rests can provide support for resting the arms to prevent or reduce fatigue, especially during breaks from typing. Properly designed armrests can overcome the problems mentioned because they can be raised, lowered, and angled to fit the user's needs. Removable armrests are an advantage because they provide greater flexibility for individual user preference, especially for users who develop discomfort and pain from the pressure of the armrest on their arms.

2.7.3. Other Workstation Considerations

An important component of the workstation that can help reduce musculoskeletal loading is a document holder. When properly designed and proportioned, document holders reduce awkward inclinations, as well as frequent movements up and down and back and forth of the head and neck. They permit source documents to be placed in a central location at approximately the same viewing distance and height as the computer screen. This eliminates needless head and neck movements and reduces eyestrain. In practice, some flexibility about the location, adjustment, and position of the document holder should be maintained to accommodate both task requirements and operator preferences. The document holder should have a matte finish so that it does not produce reflections or a glare source.

Privacy requirements include both visual and acoustical control of the workplace. Visual control prevents physical intrusions and distractions, contributes to protecting confidential/private conversations, and prevents the individual from feeling constantly watched. Acoustical control prevents distracting and unwanted noise—from machine or conversation—and permits speech privacy. While certain acoustical methods and materials such as free-standing panels are used to control general office noise level, they can also be used for privacy. In open-office designs they can provide workstation privacy. Generally, noise control at a computer workstation can be achieved through the following methods:

- Use of vertical barriers, such as acoustical screens or panels.
- Selection of floor, ceiling, wall, and workstation materials and finishes according to their power to control noise.
- Placement of workstations to enhance individual privacy.
- Locating workstations away from areas likely to generate noise (e.g., printer rooms, areas with heavy traffic).

Each of these methods can be used individually or combined to account for the specific visual and acoustical requirements of the task or individual employee needs. Planning for privacy should not be made at the expense of visual interest or spatial clarity. For instance, providing wide visual views can prevent the individual from feeling isolated. Thus, a balance between privacy and openness enhances user comfort, work effectiveness, and office communications. Involving the employee in decisions of privacy can help in deciding the compromises between privacy and openness.

2.8. Work Practices

Good ergonomic design of computer workstations has the potential to reduce visual and musculoskeletal complaints and disorders as well as increase employee performance. However, regardless of how well a workstation is designed, if operators must adopt static postures for a long time, they can still have performance, comfort, and health problems. Thus, designing tasks that induce employee movement in addition to work breaks can contribute to comfort and help relieve employees' fatigue.

2.8.1. Work Breaks

As a minimum, a 15-minute break from working should be taken after 2 hours of continuous computer work (CDC 1980; NIOSH 1981). Breaks should be more frequent as visual, muscular, and mental loads are high and as users complain of visual and musculoskeletal discomfort and psychological stress. With such intense, high-workload tasks, a work break of 10 minutes should be taken after 1 hour of continuous computer work. More frequent breaks for alternative work that does not pose demands similar to the primary computer work can be taken after 30 minutes of continuous computer work. Rest breaks provide an opportunity for recovery from local visual, musculoskeletal, and mental fatigue, to break from monotonous activities, or to engage in activities that provide variety in sensory, motor, and cognitive requirements.

While ergonomics considers users' physiological interface with interactive systems, cognitive design focuses on the psychological interface between users and computers. This will be addressed in the next section.

3. COGNITIVE DESIGN

3.1. Overview

Cognitive design, also referred to as cognitive engineering, is a multidisciplinary approach to system design that considers the analysis, design, and evaluation of interactive systems (Vicente 1999). Cognitive design involves developing systems through an understanding of human capabilities and limitations. It focuses on how humans process information and aims to identify users' mental models, such that supporting metaphors and analogies can be identified and designed into systems (Eberts 1994). The general goal of cognitive design is thus to design interactive systems that are predictable (i.e., respond to the way users perceive, think, and act). Through the application of this approach, human–computer interaction has evolved into a relatively standard set of interaction techniques, including typing, pointing, and clicking. This set of ‘‘standard’’ interaction techniques is evolving, with a transition from graphical user interfaces to perceptual user interfaces that seek to more naturally interact with users through multimodal and multimedia interaction (Turk and Robertson 2000). In either case, however, these interfaces are characterized by interaction techniques that try to match user capabilities and limitations to the interface design.

Cognitive design efforts are guided by the requirements definition, user profile development, tasks analysis, task allocation, and usability goal setting that result from an intrinsic understanding gained from the target work environment. Although these activities are listed and presented in this order, they are conducted iteratively throughout the system development life cycle.

3.2. Requirements Definition

Requirements definition involves the specification of the necessary goals, functions, and objectives to be met by the system design (Eberts 1994; Rouse 1991). The intent of the requirements definition is to specify what a system should be capable of doing and the functions that must be available to users to achieve stated goals. Karat and Dayton (1995) suggest that developing a careful understanding of system requirements leads to more effective initial designs that require less redesign. Ethnographic evaluation can be used to develop a requirements definition that is necessary and complete to support the target domain (Nardi 1997).

Goals specify the desired system characteristics (Rouse 1991). These are generally qualitatively stated (e.g., automate functions, maximize use, accommodate user types) and can be met in a number of ways. Functions define what the system should be capable of doing without specifying the specifics of how the functions should be achieved. Objectives are the activities that the system must be able to accomplish in support of the specified functions. Note that the system requirements, as stated in terms of goals, functions, and objectives, can be achieved by a number of design alternatives. Thus, the requirements definition specifies what the system should be able to accomplish without specifying how this should be realized. It can be used to guide the overall design effort to ensure the desired end is achieved. Once a set of functional and feature requirements has been scoped out, an understanding of the current work environment is needed in order to design systems that effectively support these requirements.

3.3. Contextual Task Analysis

The objective of contextual task analysis is to achieve a user-centered model of current work practices (Mayhew 1999). It is important to determine how users currently carry out their tasks, which individuals they interact with, what tools support the accomplishment of their job goals, and the resulting products of their efforts. Formerly this was often achieved by observing a user or set of users in a laboratory setting and having them provide verbal protocols as they conducted task activities in the form of use cases (Hackos and Redish 1998; Karat 1988; Mayhew 1999; Vermeeren 1999). This approach, however, fails to take into consideration the influences of the actual work setting. Through an understanding of the work environment, designers can leverage current practices that are effective while designing out those that are ineffective. The results of a contextual task analysis include work environment and task analyses, from which mental models can be identified and user scenarios and task-organization models (e.g., use sequences, use flow diagrams, use workflows, and use hierarchies) can be derived (Mayhew 1999). These models and scenarios can then help guide the design of the system. As depicted in Figure 3, contextual task analysis consists of three main steps.

Effective interactive system design thus comes from a basis in direct observation of users in their work environments rather than assumptions about the users or observations of their activities in contrived laboratory settings (Hackos and Redish 1998). Yet contextual tasks analysis is sometimes overlooked because developers assume they know users or that their user base is too diverse, expensive, or time consuming to get to know. In most cases, however, observation of a small set of diverse users can provide critical insights that lead to more effective and acceptable system designs. For usability evaluations, Nielsen (1993) found that the greatest payoff occurs with just three users.

3.3.1. Background Information

It is important when planning a task analysis to first become familiar with the work environment. If analysts do not understand work practices, tools, and jargon prior to commencing a task analysis, they can easily get confused and become unable to follow the task flow. Further, if the first time users see analysts they have clipboard and pen in hand, users are likely to resist being observed or change their behaviors during observation. Analysts should develop a rapport with users by spending time with them, participating in their task activities when possible, and listening to their needs and concerns. Once users are familiar and comfortable with analysts and analysts are likewise versed on work practices, data collection can commence. During this familiarization, analysts can also capture data to characterize users.

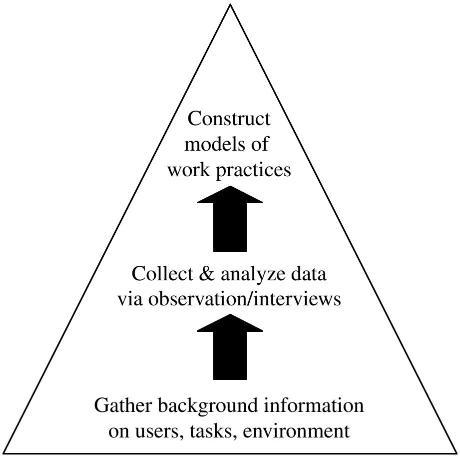


Figure 3 The Steps of Contextual Task Analysis.

3.3.2. Characterizing Users

It is ultimately the users who will determine whether a system is adopted into their lives. Designs that frustrate, stress, or annoy users are not likely to be embraced. Based on the requirements definition, the objective of designers should be to develop a system that can meet specified user goals, functions, and objectives. This can be accomplished through an early and continual focus on the target user population (Gould et al. 1997). It is inconceivable that design efforts would bring products to market without thoroughly determining who the user is. Yet developers, as they expedite system development to rush products to market, are often reluctant to characterize users. In doing so, they may fail to recognize the amount of time they spend speculating upon what users might need, like, or want in a product (Nielsen 1993). Ascertaining this information directly by querying representative users can be both more efficient and more accurate.

Information about users should provide insights into differences in their computer experience, domain knowledge, and amount of training on similar systems (Wixon and Wilson 1997). The results can be summarized in a narrative format that provides a user profile of each intended user group (e.g., primary users, secondary users, technicians and support personnel). No system design, however, will meet the requirements of all types of users. Thus, it is essential to identify, define, and characterize target users. Separate user profiles should be developed for each target user group. The user profiles can then feed directly into the task analysis by identifying the user groups for which tasks must be characterized (Mayhew 1999).

Mayhew (1999) presents a step-by-step process for developing user profiles. First, a determination of user categories is made by identifying the intended user groups for the target system. When developing a system for an organization, this information may come directly from preexisting job categories. Where those do not exist, marketing organizations often have target user populations identified for a given system or product. Next, the relevant user characteristics must be identified. User profiles should be specified in terms of psychological (e.g., attitudes, motivation), knowledge and experience (e.g., educational background, years on job), job and task (e.g., frequency of use), and physical (e.g., stature, visual impairments) characteristics (Mayhew 1999; Nielsen 1993; Wixon and Wilson 1997). While many of these user attributes can be obtained via user profile questionnaires or interviews, psychological characteristics may be best identified via ethnographic evaluation, where a sense of the work environment temperament can be obtained. Once this information is obtained, a summary of the key characteristics for each target user group can be developed, highlighting their implications to the system design. By understanding these characteristics, developers can better anticipate such issues as learning difficulties and specify appropriate levels of interface complexity. System design requirements involve an assessment of the required levels of such factors as ease of learning, ease of use, level of satisfaction, and workload for each target user group (see Table 2)

Individual differences within a user population should also be acknowledged (Egan 1988; Hackos and Redish 1998). While users differ along many dimensions, key areas of user differences have been identified that significantly influence their experience with interactive systems. Users may differ

TABLE 2 Example of a User Profile

Characteristic	Questionnaire Response	System Design Requirement
Attitude	Negative	System should be subjectively pleasing
Motivation	Generally low	Usefulness of system should be readily apparent
Education level	High school	Simplicity important; training requirements should be minimal
Computer experience	Low	High ease of learning required
Frequency of computer use	Discretionary	High ease of use required; system workload should be minimized
Typing skills	Poor	Minimize typing; use icons and visual displays
Gender	Mostly males	Consider color blindness
Age	Average = 42.5 (s.d. = 3.6)	Text and symbol size should be readily legible

in such attributes as personality, physical or cognitive capacity, motivation, cultural background, education, and training. Users also change over time (e.g., transitioning from novice to expert). By acknowledging these differences, developers can make informed decisions on whether or not to support them in their system designs. For example, marketing could determine which group of individuals it would be most profitable to target with a given system design.

3.3.3. Collecting and Analyzing Data

Contextual task analysis focuses on the behavioral aspects of a task, resulting in an understanding of the general structure and flow of task activities (Mayhew 1999; Nielsen 1993; Wixon and Wilson 1997). This analysis identifies the major tasks and their frequency of occurrence. This can be compared to cognitive task analysis, which identifies the low-level perceptual, cognitive, and motor actions required during task performance (Card et al. 1983; Corbett et al. 1997). Beyond providing an understanding of tasks and workflow patterns, the contextual task analysis also identifies the primary objects or artifacts that support the task, information needs (both inputs and outputs), workarounds that have been adopted, and exceptions to normal work activities. The result of this analysis is a task flow diagram with supporting narrative depicting user-centered task activities, including task goals; information needed to achieve these goals; information generated from achieving these goals; and task organization (i.e., subtasks and interdependencies).

Task analysis thus aims to structure the flow of task activities into a sequential list of functional elements, conditions of transition from one element to the next, required supporting tools and artifacts, and resulting products (Sheridan 1997a). There are both formal and informal techniques for task analysis (see Table 3). Such an analysis can be driven by formal models such as TAKD (task analysis for knowledge description; see Diaper 1989) or GOMS (goals, operators, methods, and selection rules; see Card et al. 1983) or through informal techniques such as interviews, observation and shadowing, surveys, and retrospectives and diaries (Jeffries 1997). With all of these methods, typically

TABLE 3 Task-Analysis Techniques for Interactive System Design

Design Objective	Task-Analysis Technique
Detailed description of task	TAKD, GOMS, interviews
Detailed description of task (when difficult to verbalize task knowledge)	Observation, shadowing
Task description for tasks with significant performance variation; determine specific task characteristics (e.g., frequency)	Surveys, observation, shadowing
Clarify task areas	Surveys, observation, shadowing, retrospectives and diaries

a domain expert is somehow queried about their task knowledge. It may be beneficial to query a range of users, from novice to expert, to identify differences in their task practices. In either case, it is important to select individuals that can readily verbalize how a task is carried out to serve as informants (Ebert 1994).

When a very detailed task analysis is required, formal techniques such as TAKD (Diaper 1989; Kirwan and Ainsworth 1992) or GOMS (Card et al. 1983) can be used to delineate task activities (see Chapter 39), TAKD uses knowledge-representation grammars (i.e., sets of statements used to described system interaction) to represent task-knowledge in a task-descriptive hierarchy. This technique is useful for characterizing complex tasks that lack fine-detail cognitive activities (Eberts 1994). GOMS is a predictive modeling technique that has been used to characterize how humans interact with computers. Through a GOMS analysis, task goals are identified, along with the operators (i.e., perceptual, cognitive, or motor acts) and methods (i.e., series of operators) to achieve those goals and the selection rules used to elect between alternative methods. The benefit of TAKD and GOMS is that they provide an in-depth understanding of task characteristics, which can be used to quantify the benefits in terms of consistency (TAKD) or performance time gains (GOMS) of one design vs. another (see Gray et al. 1993; McLeod and Sherwood-Jones 1993 for examples of the effective use of GOMS in design). This deep knowledge, however, comes at a great cost in terms of time to conduct the analysis. Thus, it is important to determine the level of task analysis required for informed design. While formal techniques such as GOMS can lead to very detailed analyses (i.e., at the perceive, think, act level), often such detail is not required for effective design. Jeffries (1997) suggests that one can loosely determine the right level of detail by determining when further decomposition of the task would not reveal any "interesting" new subtasks that would enlighten the design. If detailed task knowledge is not deemed requisite, informal task-analysis techniques should be adopted.

Interviews are the most common informal technique to gather task information (Jeffries 1997; Kirwan and Ainsworth 1992; Meister 1985). In this technique, informants are asked to verbalize their strategies, rationale, and knowledge used to accomplish task goals and subgoals (Ericsson and Simon 1980). As each informant's mental model of the tasks they verbalize is likely to differ, it is advantageous to interview at least two to three informants to identify the common flow of task activities. Placing the informant in the context of the task domain and having him or her verbalize while conducting tasks affords more complete task descriptions while providing insights on the environment the task is performed within. It can sometimes be difficult for informants to verbalize their task performance because much of it may be automatized (Eberts 1994). When conducting interviews, it is important to use appropriate sampling techniques (i.e., sample at the right time with enough individuals), avoid leading questions, and follow up with appropriate probe questions (Nardi 1997). While the interviewer should generally abstain from interfering with task performance, it is sometimes necessary to probe for more detail when it appears that steps or subgoals are not being communicated. Eberts (1994) suggests that the human information-processing model can be used to structure verbal protocols and determine what information is needed and what is likely being left out.

Observation during task activity or shadowing workers throughout their daily work activities are time-consuming task-analysis techniques, but they can prove useful when it is difficult for informants to verbalize their task knowledge (Jeffries 1997). These techniques can also provide information about the environment in which tasks are performed, such as tacit behaviors, social interactions, and physical demands, which are difficult to capture with other techniques (Kirwan and Ainsworth 1992).

While observation and shadowing can be used to develop task descriptions, surveys are particularly useful task-analysis tools when there is significant variation in the manner in which tasks are performed or when it is important to determine specific task characteristics, such as frequency (Jeffries 1997; Nielsen 1993). Surveys can also be used as a follow-on to further clarify task areas described via an interview. Focused observation, shadowing, retrospectives, and diaries are also useful for clarifying task areas. With retrospectives and diaries, an informant is asked to provide a retrospective soon after completing a task or to document his or her activities after several task events, the latter being a diary.

Whether formal or informal techniques are used, the objective of the task analysis is to identify the goals of users and determine the techniques they use to accomplish these goals. Norman (1988) provides a general model of the stages users go through when accomplishing goals (see Figure 4). Stanton (1998) suggests that there are three main ways in which this process can go awry: by users forgetting a required action, executing an errant action, or misperceiving or misinterpreting the current state of the system. In observing users of a vending machine, Verhoef (1988) indeed found that these types of errors occur during system interaction. In this case study, users of the vending machine failed to perceive information presented by the machine, performed actions in the wrong order, and misinterpreted tasks when they were not clearly explained or when incomplete information was provided.

By understanding the stages of goal accomplishment and the related errors that can occur, developers can more effectively design interactive systems. For example, by knowing that users perceive and interpret the system state once an action has been executed, designers can understand why it is

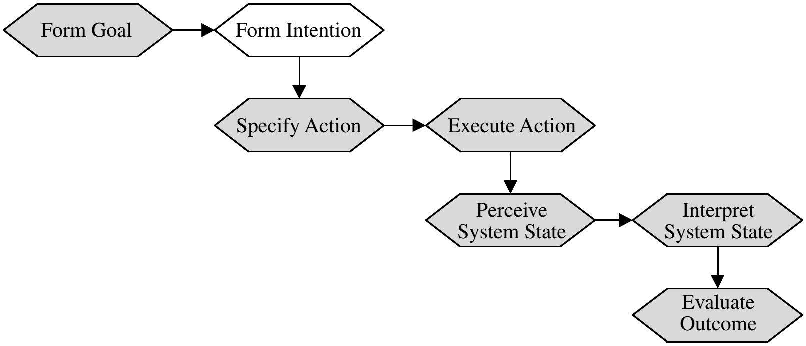


Figure 4 Stages of Goal Accomplishment.

essential to provide feedback (Nielsen 1993) to the executed action. Knowing that users often specify alternative methods to achieve a goal or change methods during the course of goal seeking, designers can aim to support diverse approaches. Further, recognizing that users commit errors emphasizes the need for undo functionality.

The results from a task analysis provide insights into the optimal structuring of task activities and the key attributes of the work environment that will directly affect interactive system design (Mayhew 1999). The analysis enumerates the tasks that users may want to accomplish to achieve stated goals through the preparation of a task list or task inventory (Hackos and Redish 1998; Jeffries 1997). A model of task activities, including how users currently think about, discuss, and perform their work, can then be devised based on the task analysis. To develop task-flow models, it is important to consider the timing, frequency, criticality, difficulty, and responsible individual of each task on the list. In seeking to conduct the analysis at the appropriate level of detail, it may be beneficial initially to limit the task list and associated model to the primary 10–20 tasks that users perform. Once developed, task models can be used to determine the functionality necessary to support in the system design. Further, once the task models and desired functionality are characterized, use scenarios (i.e., concrete task instances, with related contextual [i.e., situational] elements and stated resolutions) can be developed that can be used to drive both the system design and evaluation (Jeffries 1997).

3.3.4. Constructing Models of Work Practices

While results from the task analysis provide task-flow models, they also can provide insights on the manner in which individuals model these process flows (i.e., mental models). Mental models synthesize several steps of a process into an organized unit (Allen 1997). An individual may model several aspects of a given process, such as the capabilities of a tool or machine, expectations of coworkers, or understandings of support processes (Fischer 1991). These models allow individuals to predict how a process will respond to a given input, explain a process event, or diagnose the reasons for a malfunction. Mental models are often incomplete and inaccurate, however, so understandings based on these models can be erroneous.

As developers design systems, they will develop user models of target user groups (Allen 1997). These models should be relevant (i.e., able to make predictions as users would), accurate, adaptable to changes in user behavior, and generalizable. Proficient user modeling can assist developers in designing systems that interact effectively with users. Developers must recognize that users will both come to the system interaction with preconceived mental models of the process being automated and develop models of the automated system interaction. They must thus seek to identify how users represent their existing knowledge about a process and how this knowledge fits together in learning and performance so that they can design systems that engender the development of an accurate mental model of the system interaction (Carroll and Olson 1988). By understanding how users model processes, developers can determine how users currently think and act, how these behaviors can be supported by the interactive system design when advantageous, and how they can be modified and improved upon via system automation.

3.3.5. Task Allocation

In moving toward a system design, once tasks have been analyzed and associated mental models characterized, designers can use this knowledge to address the relationship between the human and the interactive system. Task allocation is a process of assigning the various tasks identified via the task analysis to agents (i.e., users), instruments (e.g., interactive systems) or support resources (e.g., training, manuals, cheat sheets). It defines the extent of user involvement vs. computer automation in system interaction (Kirwan and Ainsworth 1992). In some system-development efforts, formal task allocation will be conducted; in others, it is a less explicit yet inherent part of the design process.

While there are many systematic techniques for conducting task analysis (see Kirwan and Ainsworth 1992), the same is not true of task allocation (Sheridan 1997a). Further, task allocation is complicated by the fact that seldom are tasks or subtasks truly independent, and thus their interdependence must be effectively designed into the human–system interaction. Rather than a deductive assignment of tasks to human or computer, task allocation thus becomes a consideration of the multitude of design alternatives that can support these interdependencies. Sheridan (1997a,b) delineates a number of task allocation considerations that can assist in narrowing the design space (see Table 4).

In allocating tasks, one must also consider what will be assigned to support resources. If the system is not a walk-up-and-use system but one that will require learning, then designers must identify what knowledge is appropriate to allocate to support resources (e.g., training courses, manuals, online help).

Training computer users in their new job requirements and how the technology works has often been a neglected element in office automation. Many times the extent of operator training is limited to reading the manual and learning by trial and error. In some cases, operators may have classes that go over the material in the manual and give hands-on practice with the new equipment for limited periods of time. The problem with these approaches is that there is usually insufficient time for users to develop the skills and confidence to adequately use the new technology. It is thus essential to determine what online resources will be required to support effective system interaction.

Becoming proficient in hardware and software use takes longer than just the training course time. Often several days, weeks, or even months of daily use are needed to become an expert depending on the difficulty of the application and the skill of the individual. Appropriate support resources should be designed into the system to assist in developing this proficiency. Also, it is important to remember that each individual learns at his or her own pace and therefore some differences in proficiency will be seen among individuals. When new technology is introduced, training should tie in skills from the former methods of doing tasks to facilitate the transfer of knowledge. Sometimes new skills clash with those formerly learned, and then more time for training and practice is necessary to achieve good results. If increased performance or labor savings are expected with the new technology, it is prudent not to expect results too quickly. Rather, it is wise to develop the users' skills completely if the most positive results are to be achieved.

TABLE 4 Considerations in the Task-Allocation Process

Considerations in Task Allocation	Design Issue
Check task-analysis constraints	Strict task requirements can complicate or make infeasible appropriate task allocation
Identify obvious allocations	Highly repetitive tasks are generally appropriate for automation; dealing with the unexpected or cognitively complex tasks are generally appropriate for humans
Identify expected allocations	Users' mental models may uncover expected allocation schemes
Identify the extremes	Bound the design space by assessing total computer automation vs. total human manual control solutions
Consider points between the extremes	Sheridan (1997a,b) offers a 10-point scale of allocation between the extremes that assists in assessing intermediate solutions
Consider level of specificity required by allocation	Strict assignments are ineffectual; a general principle is to leave the big picture to the human and the details to the computer
Consider sequential vs. parallel processing	Will the computer and user trade outputs of their processing or will they concurrently collaborate in task performance?
Consider the range of criteria that can be used to judge appropriate allocation	While many criteria affect overall system interaction, a small number of criteria are generally important for an individual task

3.4. Competitive Analysis and Usability Goal Setting

Once the users and tasks have been characterized, it is sometimes beneficial to conduct a competitive analysis (Nielsen 1993). Identifying the strengths and weaknesses of competitive products or existing systems allows means to leverage strengths and resolve identified weaknesses.

After users have been characterized, a task analysis performed, and, if necessary, a competitive analysis conducted, the next step in interactive system design is usability goal setting (Hackos and Redish 1998; Mayhew 1999; Nielsen 1993; Wixon and Wilson 1993). Usability objectives generally focus around effectiveness (i.e., the extent to which tasks can be achieved), intuitiveness (i.e., how learnable and memorable the system is), and subjective perception (i.e., how comfortable and satisfied users are with the system) (Eberts 1994; Nielsen 1993; Shneiderman 1992; Wixon and Wilson 1997). Setting such objectives will ensure that the usability attributes evaluated are those that are important for meeting task goals; that these attributes are translated into operational measures; that the attributes are generally holistic, relating to overall system/task performance; and that the attributes relate to specific usability objectives.

Because usability is assessed via a multitude of potentially conflicting measures, often equal weights cannot be given to every usability criterion. For example, to gain subjective satisfaction, one might have to sacrifice task efficiency. Developers should specify usability criteria of interest and provide operational goals for each metric. These metrics can be expressed as absolute goals (i.e., in terms of an absolute quantification) or as relative goals (i.e., in comparison to a benchmark system or process). Such metrics provide system developers with concrete goals to meet and a means to measure usability. This information is generally documented in the form of a usability attribute table and usability specification matrix (see Mayhew 1999).

3.5. User Interface Design

While design ideas evolve throughout the information-gathering stages, formal design of the interactive system commences once relevant information has been obtained. The checklist in Table 5 can be used to determine whether the critical information items that support the design process have been addressed. Readied with information, interactive system design generally begins with an initial definition of the design and evolves into a detailed design, from which iterative cycles of evaluation and improvement transpire (Martel 1998).

3.5.1. Initial Design Definition

Where should one commence the actual design of a new interactive system? Often designers look to existing products within their own product lines or competitors' products. This is a sound practice because it maintains consistency with existing successful products. This approach may be limiting, however, leading to evolutionary designs that lack design innovations. Where can designers obtain the ideas to fuel truly innovative designs that uniquely meet the needs of their users? Ethnographic evaluations can lead to many innovative design concepts that would never be realized in isolation of the work environment (Mountford 1990). The effort devoted to the early characterization of users and tasks, particularly when conducted in the context of the work environment, often is rewarded in terms of the generation of innovative design ideas. Mountford (1990) has provided a number of techniques to assist in eliciting design ideas based on the objects, artifacts, and other information gathered during the contextual task analysis (see Table 6).

To generate a multitude of design ideas, it is beneficial to use a parallel design strategy (Nielsen 1993), where more than one designer sets out in isolation to generate design concepts. A low level

TABLE 5 Checklist of Information Items

Identified necessary goals, functions, and objectives to be met by system design
Became familiar with practices, tools, and vernacular of work environment
Characterized user profiles in terms of psychological characteristics, knowledge and experience, job and task characteristics, and physical attributes
Acknowledged individual differences within target user population
Developed user models that are relevant, accurate, adaptable to changes in user behavior, and generalizable
Developed a user-centered model of current work practices via task analysis
Defined extent of user involvement vs. computer automation in system interaction, as well as required support resources (e.g., manuals)
Conducted a competitive analysis
Set usability goals

TABLE 6 Design Idea Generation Checklist

Are there new uses for objects and artifacts identified in the task analysis?
Could objects and artifacts be adapted to be like something else? How would this change the organizational structure of the system interaction?
Could objects and artifacts be modified to serve a new purpose?
Can tools or other features be added to objects and artifacts?
Can interaction be streamlined by subtracting from objects and artifacts?
Are there alternative metaphors that would be more appropriate for the task domain being automated? Can the basic layout of a metaphor be modified or somehow rearranged?
Can a design scheme be reversed or transposed for alternative interaction approaches?
Are there large, encompassing metaphors that could be used to characterize more of the task domain?

of effort (e.g., a few hours to a few days) is generally devoted to this idea-generation stage. Storyboarding via paper prototypes is often used at this stage because it is easy to generate and modify and is cost effective (Martel 1998). Storyboards provide a series of pictures representing how an interface may look.

3.5.2. Detailed Design

Once design alternatives have been storyboarded, the best aspects of each design can be identified and integrated into a detailed design concept. The detailed design can be realized through the use of several techniques, including specification of nouns and verbs that represent interface objects and actions, as well as the use of metaphors (Hackos and Redish 1998). The metaphors can be further refined via use scenarios, use sequences, use flow diagrams, use workflows, and use hierarchies. Storyboards and rough interface sketches can support each stage in the evolution of the detailed design.

3.5.2.1. Objects and Actions Workplace artifacts, identified via the contextual task analysis, become the objects in the interface design (Hackos and Redish 1998). Nouns in the task flow also become interface objects, while verbs become interface actions. Continuing the use of paper prototyping, the artifacts, nouns, and verbs from the task flows and related models can each be specified on a sticky note and posted to the working storyboard. Desired attributes for each object or action can be delineated on the notes. The objects and actions should be categorized and any redundancies eliminated. The narratives and categories can generate ideas on how interface objects should look, how interface actions should feel, and how these might be structurally organized around specified categories.

3.5.2.2. Metaphors Designers often try to ease the complexity of system interaction by grounding interface actions and objects and related tasks and goals in a familiar framework known as a metaphor (Neale and Carroll 1997). A metaphor is a conceptual set of familiar terms and associations (Erickson 1990). If designed into a user interface, it can be used to incite users to relate what they already know about the metaphoric concept to the system interaction, thereby enhancing the learnability of the system (Carroll and Thomas 1982).

The purpose of developing interface metaphors is to provide users with a useful orienting framework to guide their system interaction. The metaphor provides insights into the spatial properties of the user interface and the manner in which they are derived and maintained by interaction objects and actions (Carroll and Mack 1985). It stimulates systematic system interaction that may lead to greater understanding of these spatial properties. Through this understanding, users should be able to tie together a configural representation (or mental model) of the system to guide their interactions (Kay 1990).

An effective metaphor will both orient and situate users within the system interaction. It will aid without attracting attention or energy away from the automated task process (Norman 1990). Providing a metaphor should help focus users to critical cues and away from irrelevant distractions. The metaphor should also help to differentiate the environment and enhance visual access (Kim and Hirtle 1995). Parunak (1989) accomplished this in a hypertext environment by providing between-path mechanisms (e.g., backtracking capability and guided tours), annotation capabilities that allow users to designate locations that can be accessed directly (e.g., bookmarks in hypertext), and links and filtering techniques that simplify a given topology.

It is important to note that a metaphor does not have to be a literal similarity (Ortony 1979) to be effective. In fact, Gentner (1983) and Gentner and Clement (1988) suggest that people seek to identify relational rather than object attribute comparisons in comprehending metaphors. Based on

Gentner's structure-mapping theory, the aptness of a metaphor should increase with the degree to which its interpretation is relational. Thus, when interpreting a metaphor, people should tend to extend relational rather than object attribute information from the base to the target. The learning efficacy of a metaphor, however, is based on more than the mapping of relational information between two objects (Carroll and Mack 1985). Indeed, it is imperative to consider the open-endedness of metaphors and leverage the utility of not only correspondence, but also noncorrespondence in generating appropriate mental models during learning. Nevertheless, the structure-mapping theory can assist in providing a framework for explaining and designing metaphors for enhancing the design of interactive systems.

Neale and Carroll (1997) have provided a five-stage process from which design metaphors can be conceived (see Table 7). Through the use of this process, developers can generate coherent, well-structured metaphoric designs.

3.5.2.3. Use Scenarios, Use Sequences, Use Flow Diagrams, Use Workflows, and Use Hierarchies Once a metaphoric design has been defined, its validity and applicability to task goals and subgoals can be identified via use scenarios, use sequences, use flow diagrams, use workflows, and use hierarchies (see Figure 5) (Hackos and Redish 1998). Use scenarios are narrative descriptions of how the goals and subgoals identified via the contextual task analysis will be realized via the interface design. Beyond the main flow of task activities, they should address task exceptions, individual differences, and anticipated user errors. In developing use scenarios, it can be helpful to reference task allocation schemes (see Section 3.3.5). These schemes can help to define what will be achieved by users via the interface, what will be automated, and what will be rendered to support resources in the use scenarios.

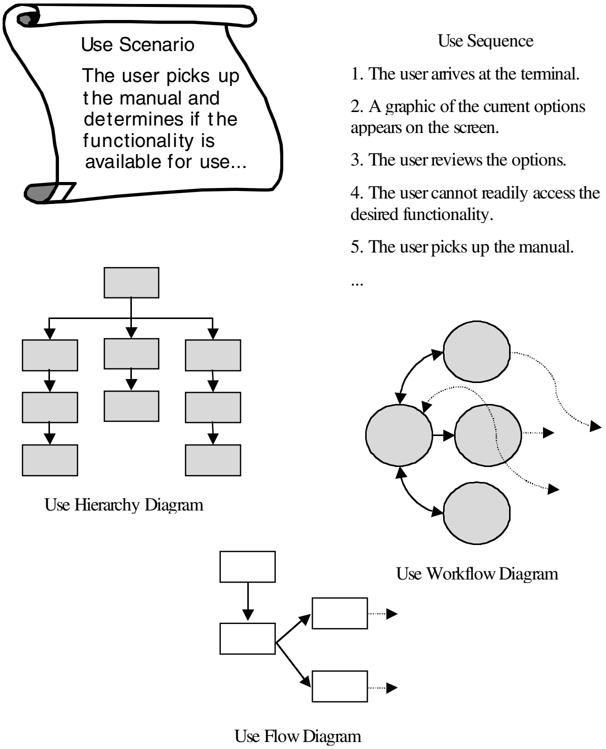
If metaphoric designs are robust, they should be able to withstand the interactions demanded by a variety of use scenarios with only modest modifications required. Design concepts to address required modifications should evolve from the types of interactions envisioned by the scenarios. Once the running of use scenarios fails to generate any required design modifications, their use can be terminated.

If parts of a use scenario are difficult for users to achieve or designers to conceptualize, use sequences can be used. Use sequences delineate the sequence of steps required for a scenario subsection being focused upon. They specify the actions and decisions required of the user and the interactive system, the objects needed to achieve task goals, and the required outputs of the system interaction. Task workarounds and exceptions can be addressed with use sequences to determine if the design should support these activities. Providing detailed sequence specifications highlights steps that are not appropriately supported by the design and thus require redesign.

When there are several use sequences supported by a design, it can be helpful to develop use flow diagrams for a defined subsection of the task activities. These diagrams delineate the alternative paths and related intersections (i.e., decision points) users encounter during system interaction. The representative entities that users encounter throughout the use flow diagram become the required objects and actions for the interface design.

TABLE 7 Stages of Metaphoric Design Generation

Stage	Design Outcome
Identify system functionality	Required functions, features, and system capabilities are identified (see Section 3.2)
Generate metaphoric concepts	Artifacts and other objects in the environment identified via the contextual task analysis (see Section 3.3) can assist in generating design concepts (see Table 6)
Identify metaphor–interface matches	Identify what users do (goals and subgoals), the methods they use to accomplish these objectives (actions and objects), and map to the physical elements available in the metaphor; use cases can be used for this stage
Identify metaphor–interface mismatches	Identify where the metaphor has no analogous function for desired goals and subgoals
Determine how to manage metaphor–interface mismatches	Determine where composite metaphors or support resources are needed (e.g., online help, agent assistance) so problems related to mismatches can be averted



Use Scenario

The user picks up the manual and determines if the functionality is available for use...

Use Sequence

1. The user arrives at the terminal.
2. A graphic of the current options appears on the screen.
3. The user reviews the options.
4. The user cannot readily access the desired functionality.
5. The user picks up the manual.

...

Figure 5 Design-Generation Techniques.

When interactive systems are intended to yield savings in the required level of information exchange, use workflows can be used. These flows provide a visualization of the movement of users or information objects throughout the work environment. They can clearly denote if a design concept will improve the information flow. Designers can first develop use workflows for the existing system interaction and then eliminate, combine, resequence, and simplify steps to streamline the flow of information.

Use hierarchies can be used to visualize the allocation of tasks among workers. By using sticky notes to represent each node in the hierarchy, these representations can be used to demonstrate the before- and after-task allocations. The benefits of the new task allocation engendered by the interactive system design should be readily perceived in hierarchical flow changes.

3.5.2.4. Design Support Developers can look to standards and guidelines to direct their design efforts. Standards focus on advising the look of an interface, while guidelines address the usability of the interface (Nielsen 1993). Following standards and guidelines can lead to systems that are easy to learn and use due to a standardized look and feel (Buie 1999). Developers must be careful, however, not to follow these sources of design support blindly. An interactive system can be designed strictly according to standards and guidelines yet fail to physically fit users, support their goals and tasks, and integrate effectively into their environment (Hackos and Redish 1998).

Guidelines aim at providing sets of practical guidance for developers (Brown 1988; Hackos and Redish 1998; Marcus 1997; Mayhew 1992). They evolve from the results of experiments, theory-based predictions of human performance, cognitive psychology and ergonomic design principles, and experience. Several different levels of guidelines are available to assist system development efforts, including general guidelines applicable to all interactive systems, as well as category-specific (i.e., voice vs. touch screen interfaces) and product-specific guidelines (Nielsen 1993).

Standards are statements (i.e., requirements or recommendations) about interface objects and actions (Buie 1999). They address the physical, cognitive, and affective nature of computer interaction. They are written in general and flexible terms because they must be applicable to a wide variety of applications and target user groups. International (e.g., ISO 9241), national (e.g., ANSI, BSI), military and government (e.g., MIL-STD 1472D), and commercial (e.g., Common User Access by IBM) entities write them. Standards are the preferred approach in Europe. The European Community promotes voluntary technical harmonization through the use of standards (Rada and Ketchell 2000).

Buie (1999) has provided recommendations on how to use standards that could also apply to guidelines. These include selecting relevant standards; tailoring these select standards to apply to a given development effort; referring to and applying the standards as closely as possible in the interactive system design; revising and refining the select standards to accommodate new information and considerations that arise during development; and inspecting the final design to ensure the system design complies with the standards where feasible. Developing with standards and guidelines does not preclude the need for evaluation of the system. Developers will still need to evaluate their systems to ensure they adequately meet users' needs and capabilities.

3.5.2.5. Storyboards and Rough Interface Sketches The efforts devoted to the selection of a metaphor or composite metaphor and the development of use scenarios, use sequences, use flow diagrams, use workflows, and use hierarchies result in a plethora of design ideas. Designers can brainstorm over design concepts, generating storyboards of potential ideas for the detailed design (Vertelney and Booker 1990). Storyboards should be at the level of detail provided by use scenarios and workflow diagrams (Hackos and Redish 1998). The brainstorming should continue until a set of satisfactory storyboard design ideas has been achieved. The favored set of ideas can then be refined into a design concept via interface sketches. Sketches of screen designs and layouts are generally at the level of detail provided by use sequences. Cardboard mockups and Wizard of Oz techniques (Newell et al. 1990), the latter of which enacts functionality that is not readily available, can be used at this stage to assist in characterizing designs.

3.5.3. Prototyping

Prototypes of favored storyboard designs are developed. These are working models of the preferred designs (Hackos and Redish 1998; Vertelney and Booker 1990). They are generally developed with easy-to-use toolkits (e.g., Macromedia Director, Toolbook, SmallTalk, or Visual Basic) or simpler tools (e.g., hypercard scenarios, drawing programs, even paper or plastic mockups) rather than high-level programming languages. The simpler prototyping tools are easy to generate and modify and cost effective; however, they demonstrate little if anything in the way of functionality, may present concepts that cannot be implemented, and may require a "Wizard" to enact functionality. The toolkits provide prototypes that look and feel more like the final product and demonstrate the feasibility of desired functionality; however, they are more costly and time consuming to generate. Whether high- or low-end techniques are used, prototypes provide means to provide cost-effective, concrete design concepts that can be evaluated with target users (usually three to six users per iteration) and readily modified. They prevent developers from exhausting extensive resources in formal development of products that will not be adopted by users. Prototyping should be iterated until usability goals are met.

3.6. Usability Evaluation of Human–Computer Interaction

Usability evaluation focuses on gathering information about the usability of an interactive system so that this information can be used to focus redesign efforts via iterative design. While the ideal approach is to consider usability from the inception of the system development process, often it is considered in later development stages. In either case, as long as developers are committed to implementing modifications to rectify the most significant issues identified via usability-evaluation techniques, the efforts devoted to usability are generally advantageous. The benefits of usability evaluation include, but are not limited to, reduced system redesign costs, increased system productivity, enhanced user satisfaction, decreased user training, and decreased technical support (Nielsen 1993; Mayhew 1999).

There are several different usability-evaluation techniques. In some of these techniques, the information may come from users of the system (through the use of surveys, questionnaires, or specific measures from the actual use of the system), while in others, information may come from usability experts (using design walk-throughs and inspection methods). In still others, there may be no observations or user testing involved at all because the technique involves a theory-based (e.g., GOMS modeling) representation of the user (Card et al. 1983). Developers need to be able to select a method that meets their needs or combine or tailor methods to meet their usability objectives and situation. Usability-evaluation techniques have generally been classified as follows (Karat 1997; Preece 1993):

- Analytic/theory based (e.g., cognitive task analysis; GOMS)
- Expert evaluation (e.g., design walk-throughs; heuristic evaluations)
- Observational evaluation (e.g., direct observation; video; verbal protocols)
- Survey evaluation (e.g., questionnaires; structured interviews)

- Psychophysiological measures of subjective perception (e.g., EEGs; heart rate; blood pressure)
- Experimental evaluation (e.g., quantitative data; compare design alternatives)

There are advantages and disadvantages to each of these evaluative techniques (see Table 8) (Preece 1993, Karat 1997). Thus, a combination of methods is often used in practice. Typically, one would first perform an expert evaluation (e.g., heuristic evaluation) of a system to identify the most obvious usability problems. Then user testing could be conducted to identify remaining problems that were missed in the first stages of evaluation. In general, a number of factors need to be considered when selecting a usability-evaluation technique or a combination thereof (see Table 9) (Dix et al. 1993; Nielsen 1993; Preece 1993).

As technology has evolved, there has been a shift in the technoeconomic paradigm, allowing for more universal access of computer technology (Stephanidis and Salvendy 1998). Thus, individuals with diverse abilities, requirements, and preferences are now regularly utilizing interactive products. When designing for universal access, participation of diverse user groups in usability evaluation is essential. Vanderheiden (1997) has suggested a set of principles for universal design that focuses on the following: simple and intuitive use; equitable use; perceptible information; tolerance for error; accommodation of preferences and abilities; low physical effort; and space for approach and use. Following these principles should ensure effective design of interactive products for all user groups.

While consideration of ergonomic and cognitive factors can generate effective interactive system designs, if the design has not taken into consideration the environment in which the system will be used, it may still fail to be adopted. This will be addressed in the next section.

4. SOCIAL, ORGANIZATIONAL, AND MANAGEMENT FACTORS

Social, organizational, and management factors related to human–computer interaction may influence a range of outcomes at both the individual and organizational levels: stress, physical and mental health, safety, job satisfaction, motivation, and performance. Campion and Thayer (1985) showed that some of these outcomes may be conflicting. In a study of 121 blue-collar jobs, they found that enriched jobs led to higher job satisfaction but lower efficiency and reliability. The correlations between efficiency on one hand and job satisfaction and comfort on the other hand were negative. Another way of looking at all the outcomes has been proposed by Smith and Sainfort (1989). The objective of the proposed balance theory is to achieve an optimal balance among positive and negative aspects of the work system, including the person, task and organizational factors, technology, and physical environment. See Figure 1 for a model of the work system. The focus is not on a limited range of variables or aspects of the work system but on a holistic approach to the study and design of work systems. In this section we will focus on how social, organizational and management factors related to human–computer interaction influence both individual and organizational outcomes.

4.1. Social Environment

The introduction of computer technology into workplaces may change the social environment and social relationships. Interactive systems become a new element of the social environment, a new communication medium, and a new source of information. With new computer technologies there may be a shift from face-to-face interaction toward computer-mediated communication, or at least a change in how people communicate and interact. This shift may be most obvious with electronic mail and teleconferencing systems. A study of Eveland and Bikson (1988) on electronic mail shows that people connected to a network of microcomputers with electronic mail relied more on scheduled meetings than people with conventional office support, who relied more on unscheduled meetings. The impact on face-to-face interaction was not studied. A study of electronic mail by Rice and Case (1983) did not find any reduction in face-to-face interaction, but increased communications as a result of using electronic mail. Computers seem to be just another way of communicating with coworkers, subordinates, and supervisors (Rice and Case 1983). However, other studies have found that there was not only a change in quantity of communications (more or new information to and from more or new recipients), but also a change in quality of communications (Kiesler et al. (1984).

Aydin (1989) showed that the use of medical information systems for communicating physicians' medication orders from the nursing department to the pharmacy led to increased interdependence between the two departments. The change in work organization (increased interdependence) was accompanied by changes in the social environment: communication and cooperation between the two departments improved, leading to better working relationships.

Computer technologies also allow work to be performed at remote distances. Recently there has been an increase in home-based work due to technological advances in computer and network technologies. Telework or working at home is most common for clerical workers performing routine transactions and for autonomous professionals (e.g., writers, designers) (Sproull and Kiesler 1991). In general, home-based work increases social isolation from coworkers and supervisors. This not only reduces opportunities to socialize and make friends but also reduces chances for advancement

TABLE 8 Advantages and Disadvantages of Existing Usability Evaluation Techniques

Evaluation Method	Example Tools/Techniques	General Use	Advantages	Disadvantages
Analytic/theory-based	• Cognitive Task Analysis • GOMS	Used early in usability design life cycle for prediction of expert user performance.	Useful in making accurate design decisions early in the usability life cycle without the need for a prototype or costly user testing.	Narrow in focus; lack of specific diagnostic output to guide design; broad assumption on users' experience (expert) and cognitive processes; results may differ based on the evaluators' interpretation of the task.
Expert Evaluation	• Design walk-throughs • Heuristic evaluations • Process/system Checklists • Free play • Group evaluations	Used early in the design life cycle to identify *theoretical* problems that may pose actual *practical* usability problems.	Strongly diagnostic; can focus on entire system; high potential return in terms of number of usability issues identified; can assist in focusing observational evaluations.	Even the best evaluators can miss significant usability issues; results are subject to evaluator bias; does not capture real user behavior.
Observational evaluation	• Direct observation • Video • Verbal protocols • Computer logging • Think aloud techniques • Field evaluations • Ethnographic studies • Facilitated free play	Used in iterative design stage for problem identification.	Quickly highlights usability issues; verbal protocols provide significant insights; provides rich qualitative data.	Observation can affect user performance with the system; analysis of data can be time and resource consuming.

Survey evaluation	• questionnaires • Structured interviews • Ergonomics checklists • Focus groups	Used any time in the design life cycle to obtain information on users' preferences and perception of a system.	Provides insights into users' opinions and understanding of the system; can be diagnostic; rating scales can provide quantitative data; can gather data from large subject pools.	User experience important; possible user response bias (e.g., only dissatisfied users respond); response rates can be low; possible interviewer bias; analysis of data can be time and resource consuming; evaluator may not be using appropriate checklist to suit the situation.
Psychophysiological measures of satisfaction or workload	• EEGs • Heart rate • Blood pressure • Pupil dilation • Skin conductivity • Level of adrenaline in blood	Used any time in the design life cycle to obtain information on user satisfaction or workload.	Eliminate user bias by employing objective measures of user satisfaction and workload.	Invasive techniques are involved that are often intimidating and expensive for usability practitioners.
Experimental evaluation	• Quantitative measures • Alternative design comparisons • Free play • Facilitated free play	Used for competitive analysis in final testing of the system.	Powerful and prescriptive method; provides quantitative data; can provide a comparison of alternatives; reliability and validity generally good.	Experiment is generally time and resource consuming; focus can be narrow; tasks and evaluative environment can be contrived; results difficult to generalize.

TABLE 9 Factors to Consider in Selecting Usability-Evaluation Techniques

Purpose of the evaluation
Stage in the development life cycle in which the evaluation technique will be carried out
Required level of subjectivity or objectivity
Necessity or availability of test participants
Type of data that need to be collected
Information that will be provided
Required immediacy of the response
Level of interference implied
Resources that may be required or available

and promotion (OTA 1985). On the other hand, home-based work allows workers to spend more time with their family and friends, thus increasing social support from family and friends. Telework allows for increased control over work pace and variability of workload. It has been found, however, that electronic communication and telework have led to feelings of not being able to get away from work and to the augmentation (rather than substitution) of regular office hours (Sproull and Kiesler 1991; Phizacklea and Wolkowitz 1995). In addition, increased distractions and interruptions may disrupt work rhythm (OTA 1985). From a social point of view, home-based work has both negative and positive effects.

Another important social factor is intragroup relationships and relationships with coworkers. The role of computer technologies in influencing intragroup functioning is multidimensional. If workers spend a lot of time working in isolation at a computer workstation, they may have less opportunity for socialization. This may affect the group performance, especially if tasks are interdependent. On the other hand, intragroup relationships may be improved if workers gain access to better information and have adequate resources to use computers. The positive or negative effects may also vary across jobs and organizations. And they may depend on the characteristics of the interactive system (e.g., single- vs. multiple-user computer workstation).

Aronsson (1989) found that work group cohesion and possibilities for contacts with coworkers and supervisors had become worse among low-level jobs (e.g., secretary, data-entry operator, planner, office service) but had not been affected among medium- to high-level jobs. Changes in job design were related to changes in social relationships. The higher the change in intensity demands, the lower the work group cohesion and the possibilities for contacts with coworkers and supervisors. That is, increase in workload demands came along with worsening of the social environment. The negative effect was more pronounced among low-level jobs, presumably because higher-level job holders have more resources, such as knowledge, power, and access to information and can have a say in the implementation/design process as well as more control over their job.

Access to organizational resources and expertise is another important facet of the social environment for computer users. Technology can break down or malfunction, and users may need help to perform certain tasks or to learn new software. In these situations, access to organizational resources and expertise is critical for the end users, especially when they are highly dependent on the computer technology to perform their job or when they use the technology in their contact with customers. Danziger et al. (1993) have studied the factors that determine the quality of end-user computing services in a survey of 1869 employees in local governments. Three categories of factors were identified that might influence the quality of computing services: (1) the structure of service provision (e.g., centralization vs. decentralization), (2) the level of technological problems, and (3) the service orientation of computing service specialists. The results do not provide support for the argument that structural factors are most important; whether computing services are centralized or decentralized within an organization does not explain the perceived quality of computing services.

On the other hand, the results demonstrate the importance of the attitudes of the service providers. Computer specialists who are clearly user oriented, that is, who are communicative and responsive to user needs and are committed to improving existing applications and proposing appropriate new ones, seem best able to satisfy end users' criteria for higher quality computing services. Researchers emphasize the importance of a positive sociotechnical interface between end users and computing specialists, in addition to good operational performance (e.g., low incidence of technical problems).

The introduction of computers in workplaces can also change how workers interact with their supervisor and management. That change in social interaction may result in changes in social support. Sproull and Kiesler (1988) showed that electronic mail affected social relationships within organizations. Status equalization was observed in that messages from subordinates were no different than messages from supervisors. Thus, computer technologies can have positive effects on worker–management relationships because workers have easier access to their supervisors and/or feel less restrained from communicating with their supervisors. However, expectations of rapid service and faster work completion may impose more supervisory pressure on workers (Johansson and Aronsson 1984). This is a negative effect of computer technologies on worker–supervisor relationships. A study by Yang and Carayon (1995) showed that supervisor support was an important buffer against worker stress in both low and high job demands conditions. Two hundred sixty-two computer users of three organizations participated in the study. Supervisor social support was an important buffer against worker stress; however, coworker social support did not affect worker stress.

The social environment can be influenced by computer technologies in various ways: quality, quantity, and means of communications, social isolation, extended network of colleagues, work group cohesion, quality of social interaction among workers, coworkers and supervisors, and social support. Table 10 summarizes the potential effects of computer technologies on the social environment. There are several strategies or interventions that can be applied to counteract the negative influences of computer technology on the social environment and foster positive effects.

Computerized monitoring systems have an important impact on how supervisors interact with their employees. It is natural that when supervisors are suddenly provided with instantaneous, detailed information about individual employee performance, they feels a commitment, in fact an obligation, to use this information to improve the performance of the employees. This use of hard facts in interacting with employees often changes the style of supervision. It puts inordinate emphasis on hourly performance and creates a coercive interaction. This is a critical mistake in a high-technology environment where employee cooperation is essential.

Supervision has to be helpful and supportive if employee motivation is to be maintained and stress is to be avoided. This means that supervisors should not use individual performance data as a basis for interaction. The supervisor should be knowledgeable about the technology and serve as a resource when employees are having problems. If management wants employees to ask for help, the relationship with the supervisor has to be positive (not coercive) so that the employee feels confident enough to ask for help. If employees are constantly criticized, they will shun the supervisor and problem situations that can harm productivity will go unheeded.

Employees are a good source of information about productive ways to work. Their daily contact with the job gives them insight into methods, procedures, bottlenecks, and problems. Many times they modify their individual work methods or behavior to improve their products and rate of output. Often these are unique to the individual job or employee and could not be adopted as a standardized approach or method. If work systems are set up in a rigid way, this compensatory behavior cannot occur. Further, if adverse relationships exist between supervisors and employees, the employees are unlikely to offer their innovative ideas when developers are conducting a contextual task analysis (see Section 3.3). It is in the interest of the employer to allow employees to exercise at least a nominal level of control and decision making over their own task activity. Here again, the computer hardware and software have to be flexible so that individual approaches and input can be accommodated as long as set standards of productivity are met.

One approach for providing employee control is through employee involvement and participation in making decisions about interactive system design—for instance, by helping management select ergonomic furniture through comparative testing of various products and providing preference data, or being involved in the determination of task allocations for a new job, or voicing opinions about ways to improve the efficiency of their work unit. Participation is a strong motivator to action and a good way to gain employee commitment to a work standard or new technology. Thus, participation can be used as a means of improving the social environment and foster the efficient use of interactive

TABLE 10 Potential Effects of Computer Technologies on the Social Environment

Less face-to-face interaction
More computer-mediated communication
Change in the quality of communications (status equalization, pressure)
Increased or decreased interdependence between departments/work units
Increased or decreased cooperation between departments/work units
Increased or decreased opportunities for contacts with coworkers and supervisor
Increased quantity/quality of information
Increased or decreased work group cohesion
Home-based work:
Isolation
Reduced chances for advancement and promotion
Increased/decreased social support

systems. But participation will only be effective as long as employees see tangible evidence that their input is being considered and used in a way that benefits them.

Employees who make positive contributions to the success of the organization should be rewarded for their efforts. Rewards can be administrative, social, or monetary. Administrative rewards can be such things as extra rest breaks, extended lunch periods, and special parking spaces. They identify the person as someone special and deserving. Another type of reward is social in that it provides special status to the individual. This is best exemplified by the receipt of praise from the supervisor for a job well done. This enhances personal self-esteem. If the praise is given in a group setting, it can enhance peer group esteem toward the individual. Monetary rewards can also be used, but these can be a double-edged sword because they may have to be removed during low-profit periods, and this can lead to employee resentment, thus negating the entire purpose of the reward system. Some organizations use incentive pay systems based on performance data provided by the computers. Computers can be used to keep track of worker performance continuously (Carayon 1993). That quantitative performance data can then be used to set up incentive pay systems that reward good performers. In general, incentive pay systems can lead to increase in output but at the expense of worker health (Levi 1972). Schleifer and Amick (1989) have shown how the use of a computer-based incentive system can lead to an increase in worker stress.

Different ways of improving the social environment in computerized workplaces thus include helpful and supportive managers and supervisors, increased control over one's job, employee involvement and participation, and rewards.

4.2. Organizational Factors

The way work is organized changes with the introduction of computer technologies, such as changes in workflow. Computer technologies obviously provide opportunities for reorganizing how work flows and have the potential of increasing efficiency. However, increased worker dependence on the computer is a potential problem, especially when the computer breaks down or slows down. It may affect not only performance but also stress. Organizational redesign may be one way of alleviating problems linked to dependence on the computer. Aronsson and Johansson (1987) showed that organizational rearrangement was necessary to decrease workers' dependence on the computer system by expanding their jobs with new tasks and allowing them to rotate between various tasks.

Given their technical capabilities, computers can be used to bring people closer and make them work in groups. The concept of computer-supported cooperative work is based on the expectation that the computer favors group work. Researchers in this area focus on all aspects of how large and small groups can work together in using computer technology (Greif 1988). They develop interactive systems that facilitate group work and study the social, organizational, and management impacts of computer-supported work groups. For instance, Grief and Sarin (1988) identified data-management requirements of computer group work.

New computer technologies allow work to be performed at a distance. This new work organization has some potential negative and positive effects for workers and management. Benefits for workers include increased control over work schedule and eliminating the commute to work (OTA 1985; Bailyn 1989). Constraints for workers include social isolation, increased direct and indirect costs (e.g., increased heating bill, no health insurance), lack of control over physical environment, and fewer opportunities for promotion (OTA 1985; Bailyn 1989). Benefits for employers include lowered costs (e.g., floor space, direct labor costs, and workers' benefits), more intensive use of computers (e.g., outside peak hours), increased flexibility (workers can be used when needed), and increased productivity; while problems include change in traditional management and supervision techniques and loss of control (OTA 1985).

Within organizations, the use of computer technologies has been linked to various positive and negative effects on job design (see, e.g., the case study of Buchanan and Boddy 1982). Increased workload, work pressure and demand for concentration, decreased job control, and variety are some of the negative effects (Smith et al. 1981; Buchanan and Boddy 1982; Johansson and Aronsson 1984). Increased feedback, control over one's job, and career opportunities are some of the positive effects (Buchanan and Boddy 1982). For some, such as professionals, the job-design effects of the use of computer technology may be all positive, while for others, such as clerical workers or data-entry operators, the effects may all be negative (Smith et al. 1981; Sauter et al. 1983; Johansson and Aronsson 1984).

The computer technology itself may have characteristics that can affect worker stress by inducing negative characteristics. For instance, technology characteristics such as breakdown and slowdown may increase perceived workload and work pressure and reduce the amount of control one has over work (Carayon-Sainfort 1992; Asakura and Fujigaki 1993). Carayon-Sainfort (1992) found that computer system performance was indirectly related to stress through its effect on perceived workload, work pressure and job control. Specifically, greater frequencies of computer problems were related to increases in perceived workload and work pressure as well as decreases in job control. These can have negative effects on an organization. Asakura and Fujigaki (1993) examined the direct and indirect effects of computerization on worker well being and health in a sample of 4400 office workers. The results of their study paralleled Carayon-Sainfort (1992).

A major complaint of office employees who have undergone computerization is that their workload has increased substantially. This is most true for clerical employees, who typically have an increased number of transactions to process when computers are introduced into the work routine. This increase in transactions means more keystrokes and more time at the workstation. These can lead to greater physical effort than before and possibly more visual and muscular discomfort. This discomfort reinforces the feeling of increased workload and adds to employee dissatisfaction with the workload.

Quite often the workload of computer users is established by the data-processing department in concert with other staff departments such as human resources and line managers. An important consideration is the cost of the computer equipment and related upkeep such as software and maintenance. The processing capability of the computer(s) is a second critical element in establishing the total capacity that can be achieved. The technology cost, the capability to process work, and the desired time frame to pay for the technology are factored together to establish a staffing pattern and the required workload for each employee. This approach is based on the capacity of the computer(s) coupled with investment recovery needs and does not necessarily meet the objective of good human resource utilization. Workload should not be based solely on technological capabilities or investment recovery needs but must include important considerations of human capabilities and needs. Factors such as attentional requirements, fatigue, and stress should be taken into account in establishing the workload. A workload that is too great will cause fatigue and stress that can diminish work quality without achieving desired quantity. A workload that is too low will produce boredom and stress and also reduce quality and economic benefits of computerization.

Workload problems are not concerned solely with the immediate level of effort necessary but also deal with the issue of work pressure. This is defined as an unrelenting backlog of work or workload that will never be completed. This situation is much more stressing than a temporary increase in workload to meet a specific crisis. It produces the feeling that things will never get better, only worse. Supervisors have an important role in dealing with work pressure by acting as a buffer between the demands of the employer and the daily activities of the employees. Work pressure is a perceptual problem. If the supervisor deals with daily workload in an orderly way and does not put pressure on the employee about a pile-up of work, then the employee's perception of pressure will be reduced and the employee will not suffer from work pressure stress.

Work pressure is also related to the rate of work, or work pace. A very fast work pace that requires all of the employee's resources and skills to keep up will produce work pressure and stress. This is exacerbated when this condition occurs often. An important job-design consideration is to allow the employee to control the pace of the work rather than having this controlled automatically by the computer. This will provide a pressure valve to deal with perceived work pressure.

A primary reason for acquiring new technology is to increase individual employee productivity and provide a competitive edge. Getting more work out of employees means that fewer are needed to do the same amount of work. Often employees feel that this increased output means that they are working harder even though the technology may actually make their work easier. Using scientific methods helps establish the fairness of new work standards.

Once work standards have been established, they can serve as one element in an employee-performance-evaluation scheme. An advantage of computer technology is the ability to have instantaneous information on individual employee performance in terms of the rate of output. This serves as *one* objective measure of how hard employees are working. But managers have to understand that this is just one element of employee performance and emphasis on quantity can have an adverse effect on the quality of work. Therefore, a balanced performance-evaluation system will include quality considerations as well. These are not as easy to obtain and are not as instantaneously available as are quantity measures. However, managers must resist the temptation to emphasize quantity measures just because they are readily available. A key consideration in any employee evaluation program is the issue of fairness, just as in workload determination.

Jobs in which people use computer technology may require high mental effort. Some types of computer-mediated tasks may increase information-processing requirements and place great demands on attention, decision making, and memory. Increased levels of cognitive demands due to computer technology have been shown to influence employee stress and health (Lindstrom and Leino 1989; Czaja and Sharit 1993; Yang 1994). Several types of cognitive demands can be generated from the use of computer technology: (1) a great amount of information given in a certain unit of time, (2) abstract information being presented on the screen, and (3) difficult and concurrent tasks being performed at the same time.

Cognitive demands can be increased when the system response time is poor and the nature of workflow is not transparent to the workers. In other words, unpredictable demands and interruptions of workflow caused by system breakdowns may be difficult to deal with because of the disruptive effect on the cognitive control process. Overall, cognitive demands are associated with job characteristics such as intensity of computer work, the type of communication, and high speed/functions of computers. The implementation of computer technology in work organizations can lead to greater demands on cognitive resources in terms of memory, attention, and decision making that may have a negative impact on worker health and work performance. If, however, computer systems have been designed with the cognitive capabilities and limitations of the user in mind (see Section 3), these issues should not occur.

There has been interest in the role of occupational psychosocial stress in the causation and aggravation of musculoskeletal disorders for computer users (Smith et al. 1981; Smith 1984; Bammer and Blignault 1988; Smith and Carayon 1995; Hagberg et al. 1995). It has been proposed that work organization factors define ergonomic risks to upper-extremity musculoskeletal problems by specifying the nature of the work activities (variety or repetition), the extent of loads, the exposure to loads, the number and duration of actions, ergonomic considerations such as workstation design, tool and equipment design, and environmental features (Smith and Carayon 1995; Carayon et al. 1999). These factors interact as a system to produce an overall load on the person (Smith and Sainfort 1989; Smith and Carayon 1995; Carayon et al. 1999), and this load may lead to an increased risk for upper extremity musculoskeletal problems (Smith and Carayon 1995; Carayon et al. 1999). There are psychobiological mechanisms that make a connection between psychological stress and musculoskeletal disorders plausible and likely (Smith and Carayon 1995; Carayon et al. 1999). At the organizational level, the policies and procedures of a company can affect the risk of musculoskeletal disorders through the design of jobs, the length of exposures to stressors, establishing work–rest cycles, defining the extent of work pressures and establishing the psychological climate regarding socialization, career, and job security (Smith et al. 1992; NIOSH 1992, 1993).

Smith et al. (1992), Theorell et al. (1991) and Faucett and Rempel (1994) have demonstrated that some of these organizational features can influence the level of self-reported upper-extremity musculoskeletal health complaints. In addition, the organization defines the nature of the task activities (work methods), employee training, availability of assistance, supervisory relations, and workstation design. All of these factors have been shown to influence the risk of upper-extremity musculoskeletal symptoms, in particular among computer users and office workers (Linton and Kamwendo 1989; Smith et al. 1992; Lim et al. 1989; Lim and Carayon. 1995; NIOSH 1990, 1992, 1993; Smith and Carayon 1995).

The amount of esteem and satisfaction an employee gets from work are tied directly to the content of the job. For many jobs, computerization brings about fragmentation and simplification that act to reduce the content of the job. Jobs need to provide an opportunity for skill use, mental stimulation, and adequate physical activity to keep muscles in tone. In addition, work has to be meaningful for the individual. It has to provide for identification with the product and the company. This provides the basis for pride in the job that is accomplished.

Computerization can provide an opportunity for employees to individualize their work. This lets them use their unique skills and abilities to achieve the required standards of output. It provides cognitive stimulation because each employee can develop a strategy to meet his or her goals. This requires that software be flexible enough to accept different types and order of input. Then it is the job of the software to transform the diverse input into the desired product. Usually computer programmers will resist such an approach because it is easier for them to program using standardized input strategies. However, such strategies build repetition and inflexibility into jobs that reduce job content and meaning.

Being able to carry out a complete work activity that has an identifiable end product is an important way to add meaningfulness to a job. When employees understand the fruits of their labor, it provides an element of identification and pride in achievement. This is in contrast to simplifying jobs into elemental tasks that are repeated over and over again. Such simplification removes meaning and job content and creates boredom, job stress, and product-quality problems. New computer systems should emphasize software that allows employees to use existing skills and knowledge to start out. These then can serve as the base for acquiring new skills and knowledge. Job activities should exercise employee mental skills and should also require a sufficient level of physical activity to keep the employee alert and in good muscle tone.

Table 11 summarizes the potential impacts of computer technologies on organizational factors. Overall, the decision about the use or design of interactive systems should include considerations for work load, work pressure, determination of work standards, job content (variety and skill use), and skill development. Computerization holds the promise of providing significant improvements in the quality of jobs, but it also can bring about organizational changes that reduce employee satisfaction and performance and increase stress. Designing interactive systems that meet both the aims of the organization and the needs of employees can be difficult. It requires attention to important aspects of work that contribute to employee self-esteem, satisfaction, motivation, and health and safety.

TABLE 11 Potential Effects of Computer Technologies on Organizational Factors

- Job design:
  - Increased/decreased workload and work pressure
  - Increased demand for concentration
  - Increased/decreased job control and autonomy
  - Increased/decreased variety
  - Increased feedback
- Increased work efficiency
- Computer malfunctions and breakdowns
- Computer-supported work group
- Home-based work
- Electronic monitoring of worker performance
- Incentive pay systems

4.3. Management Factors

Consideration of management factors in human–computer interaction is highly relevant in understanding the global effects of interactive systems (Clement and Gotlieb 1988). The introduction of computer technology is often accompanied by or responsible for changes in management structure. For instance, computer technologies can be used to increase workers' access to information. That move toward decentralization can lead to more decisions being made at lower levels. There has been a long debate about whether computer technology leads to centralization or decentralization of decision making (Attewell and Rule 1984; Blackler 1988). There is no clear answer to this debate: Variables such as organizational size, past experiences, management style, and work force skill level play a role in these structural effects (Attewell and Rule 1984). Furthermore, power may not be a simple zero-sum relationship. Various organizational actors may experience increased power and control opportunities after the implementation of computer technology. Information systems specialists increase their power because they have valuable expertise and knowledge, and workers may depend on them when a technical problem occurs or when they need additional training. Worker control may also increase when workers are given efficient technologies and are taught new computer skills.

The amount of information and the ease of access to information are important management factors affected by computer technologies. Electronic mail systems tend to change how information flows in organizations. Sproull and Kiesler (1988) found that electronic mail added new recipients to information being circulated and also added new information. However, one could ask about the usefulness and relevancy of the new information for organizational functioning. Information has been identified as a potent source of power (Crozier 1964). Computer technology that changes the type and amount of information available is likely to change the power distribution between various organizational actors, such as workers, supervisors, managers, computer experts, and unions. In addition, the introduction of computer technologies may create new sources of power and increase status differences between computer experts and nonexperts, between heavy computer users and light users.

Computer technologies can be used for increasing management control over production/service processes. Electronic monitoring of worker performance is an example of this effect. Computers are used to get detailed online data on worker performance to, for instance, improve work schedule and planning and increase control over worker performance. This may greatly enhance management capabilities and improve overall organizational effectiveness, but may induce stressful working conditions (Carayon 1993).

Smith et al. (1992) conducted a questionnaire survey study examining the differences in stress responses between employees who were electronically monitored while doing computer work and those who were not. Both groups performed the same jobs. The results of the surveys completed by 745 telecommunication employees showed that employees who had their performance electronically monitored perceived more stressful working conditions and more job boredom, psychological tension, anxiety, depression, anger, health complaints, and fatigue. Smith et al. (1992) suggest that the results might have been due to job-design changes associated with the monitoring.

In fact, when Carayon (1994) reanalyzed data from two job categories (255 service representatives and 266 clerks) from Smith et al. (1992), the results supported the proposition that electronic performance monitoring had an indirect effect on worker stress through its effects on job design. Carayon (1994) also reported on a second study to specifically examine whether or not electronic performance monitoring had a direct or indirect effect on worker stress. The results revealed that monitored employees reported more supervisor feedback and control over work pace and less job content than nonmonitored employees. There were no differences between the monitored and nonmonitored groups with regard to stress or health.

The process by which computer technologies are implemented is only one of the management factors that affect the effectiveness and acceptance of computer use. Management attitudes toward the implementation of computer technologies are very important insofar as they can affect overall job and organizational design and worker perceptions, attitudes, and beliefs regarding the new technologies (Crozier 1964; Smith 1984; Blackler 1988; Kahn and Cooper 1986). Several models that link the organizational effects of computer systems to the process used to implement those systems have been proposed (Blackler and Brown 1987; Robey 1987; Flynn 1989). They all emphasize the need to identify potential technical and social impacts, advocate general planning, and emphasize the support of workers and managers for successful implementation of new computer technology.

Carayon and Karsh (2000) examined the implementation of one type of computer technology, that is, imaging technology into two organizations in the Midwest. Results showed that imaging users in the organization that utilized end-user participation in the implementation of their imaging system rated their imaging systems better and reported higher job satisfaction than imaging users in the organization that did not incorporate end-user participation in the implementation of the system. Studies by Korunka and his colleagues (Korunka et al. 1993, 1995, 1996) have also demonstrated the benefits of end-user participation in technological change on quality of working life, stress, and health.

Management needs to also consider retraining issues when introducing new computer technology. Kearsley (1989) defined three general effects of computer technology: skill twist (change in required skills), deskilling (reduction in the level of skills required to do a job), and upskilling (increase in the level of required skills). Each of these effects has different implications for retraining. For instance, skill twist requires that workers be able and willing to learn new skills. Training or retraining are critical issues for the successful implementation and use of new computer technology. Even more critical is the need for continuous retraining because of rapid changes in hardware and software capabilities of computer technologies (Smith et al. 1981; Smith 1984; Kearsley 1989). Training can serve to enhance employee performance and add new skills. Such growth in skills and knowledge is an important aspect of good job design. No one can remain satisfied with the same job activities over years and years. Training is a way to assist employees in using new technology to its fullest extent and reduce the boredom of the same old job tasks. New technology by its nature will require changes in jobs, and training is an important approach not only for keeping employees current but also in building meaning and content into their jobs.

Computer technologies have the potential to affect both positively and negatively the following management factors: organizational structure (e.g., decentralization vs. centralization), power distribution, information flow, and management control over the production process. Management's strategies for implementing new computer technologies are another important management factor to take into account to achieve optimal use of these technologies. Table 12 summarizes the potential impacts of computer technologies on management factors. Some of the negative effects of computers on management factors can be counteracted. The rest of this section proposes various means of ensuring that computerization leads to higher performance and satisfaction and lower stress.

Monitoring employee performance is a vital concern of labor unions and employees. Computers provide greatly enhanced capability to track employee performance, and this will follow from such close monitoring. Monitoring of employee performance is an important process for management. It helps to know how productive your workforce is and where bottlenecks are occurring. It is vital management information that can be used by top management to realign resources and to make important management decisions. However, it is not a good practice to provide individual employee performance information to first-line supervisors; it can lead to a coercive supervision style. To

TABLE 12 Potential Effects of Computer Technologies on Management Factors

Decentralization vs. centralization of decision making
Flow and amount of information
Management control over work process
Implementation of technological change
Training
Electronic monitoring of worker performance
Job security
Career development

enhance individual performance, it is helpful to give periodic feedback directly to employees about their own performance. This can be done in a noncoercive way directly by the computer on a daily basis. This will help employees judge their performance and also assist in establishing a supervisory climate that is conducive to satisfied and productive employees.

While computerized monitoring systems can be particularly effective in providing employees with feedback, the misuse of such systems can be particularly counterproductive and cause stress. The following principles contribute to the effective use of computerized monitoring for performance enhancement and reduced stress:

- Supervisors should not be involved directly in the performance feedback system. Information on the performance that is given by the computerized monitoring system should be directly fed back to the operator.
- Computerized monitoring systems should give a comprehensive picture of the operator's performance (quantity *and* quality).
- Performance information should not be used for disciplinary purposes.
- Electronic monitoring should not be used for payment purposes such as payment by keystrokes (piece rate) or bonuses for exceeding goals.

Any kind of change in the workplace produces fears in employees. New technology brings with it changes in staff and the way work is done. The fear of the unknown, in this case the new technology, can be a potent stressor. This suggests that a good strategy in introducing new technology is to keep employees well informed of expected changes and how they will affect the workplace. There are many ways to achieve this. One is to provide informational memorandums and bulletins to employees at various stages of the process of decision making about the selection of technology and, during its implementation, on how things are going. These informational outputs have to be at frequent intervals (at least monthly) and need to be straightforward and forthright about the technology and its expected effects. A popular approach being proposed by many organizational design experts is to involve employees in the selection, design, and implementation of the new technology. The benefit of this participation is that employees are kept abreast of current information, employees may have some good ideas that can be beneficial to the design process, and participation in the process builds employee commitment to the use of the technology.

A large employee fear and potent stressor is concern over job loss due to improved efficiency produced by new technology. Many research studies have demonstrated that the anticipation of job loss and not really knowing if you will be one of the losers is much more stressful and more detrimental to employee health than knowing right away about future job loss. Telling those employees who will lose their jobs early provides them with an opportunity to search for a new job while they still have a job. This gives them a better chance to get a new job and more bargaining power regarding salary and other issues. Some employers do not want to let employees know too soon for fear of losing them at an inopportune time. By not being fair and honest to employees who are laid off, employers can adversely influence the attitudes and behavior of those employees who remain.

For those employees who are retained when new technology is acquired, there is the concern that the new technology will deskill their jobs and provide less opportunity to be promoted to a better job. Often the technology flattens the organizational structure, producing similar jobs with equivalent levels of skill use. Thus, there is little chance to be promoted except into a limited number of supervisory positions, which will be less plentiful with the new technology. If this scenario comes true, then employees will suffer from the ''blue-collar blues'' that have been prevalent in factory jobs. This impacts negatively on performance and stress.

Averting this situation requires a commitment from management to enhancing job design that builds skill use into jobs as well as developing career paths so that employees have something to look forward to besides 30 years at the same job. Career opportunities have to be tailored to the needs of the organization to meet production requirements. Personnel specialists, production managers, and employees have to work together to design work systems that give advancement opportunity while utilizing technology effectively and meeting production goals. One effective technique is to develop a number of specialist jobs that require unique skills and training. Workers in these jobs can be paid a premium wage reflecting their unique skills and training. Employees can be promoted from general jobs into specialty jobs. Those already in specialty jobs can be promoted to other, more difficult specialty jobs. Finally, those with enough specialty experience can be promoted into troubleshooting jobs that allow them to rotate among specialties as needed to help make the work process operate smoothly and more productively.

Organizations should take an active role in managing new computer technologies. Knowing more about the positive and negative potential effects or influences of computerization on management factors is an important first step in improving the management of computer technologies.

4.4. An International Perspective

In order to increase the market for their products and services and thus gain increasing profitability and, where appropriate, shareholder value, corporations are penetrating the international market. This requires a number of adjustments and considerations by corporations, including consideration of standard of living, prevailing economies, government incentives and public policies, and practices in the country where products and services will be marketed. In addition, it is important to consider the characteristics of the individuals in the country where products and services will be utilized, such as differences in anthropometric (body size), social, and psychological considerations. Table 13 illustrates with regard to computer products designed in the United States and the changes that need to be made for Chinese in Mainland China (Choong and Salvendy 1998, 1999; Dong and Salvendy 1999a,b). If both versions of the product were produced, both U.S. and Chinese users would be expected to achieve the fastest possible performance time with the lowest error rates. Identifying a local expert and following international standards (Cakir and Dzida 1997) can assist in identifying the modifications required to ensure a product is well suited to each international target market.

5. ITERATIVE DESIGN

Interactive systems are meant to make work more effective and efficient so that employees can be productive, satisfied, and healthy. Good design improves the motivation of employees to work toward the betterment of the employer. The consideration of ergonomic, cognitive, social, organizational, and management factors of interactive system design must be recognized as an iterative design process. By considering these factors in an iterative manner, system designs can evolve until the desired level of performance and safety are achieved. Additional modifications and resources expenditure will then be unnecessary. This allows valuable resources to be saved or applied to other endeavors. Table 14 provides a list of general guidelines as to how these factors can be designed to create an effective, productive, healthy, and satisfying work environment.

The concept of balance is very important in managing the design, introduction, and use of computer technologies (Smith and Sainfort 1989). Negative effects or influences can be counteracted by positive aspects. For instance, if the physical design of the technology cannot be changed and is known to be flawed, decision makers and users could counteract the negative influences of such design by, for instance, providing more control over the work–rest schedule. By having control over their work–rest schedule, workers could relieve some of the physical stresses imposed by the technology by moving around. If management expects layoffs due to the introduction of computers, actions should be taken to ensure that workers are aware of these changes. Sharing information and getting valuable training or skills could be positive ways to counteract the negative effects linked to layoff. Carayon (1994) has shown that office and computer jobs can be characterized by positive and negative aspects and that different combinations of positive and negative aspects are related to different strain outcomes. A job with high job demands, but positive aspects such as skill utilization, task clarity, job control and social support, led to low boredom and a medium level of daily life stress. A job with many negative aspects of work led to high boredom, workload dissatisfaction, and daily life stress.

Another important aspect of the iterative design process is time. Changes in the workplace occur at an increasing pace, in particular with regard to computer technology. The term *continuous change* has been used to characterize the fast and frequent changes in computer technology and its impact on people and organizations (Korunka et al. 1997; Korunka and Carayon 1999). The idea behind this is that technological change is rarely, if ever, a one-time shot. Typically, technology changes are closer to continuous rather than discrete events. This is because rapid upgrades and reconfigurations to make the systems work more effectively are usually ongoing. In addition to technological changes, time has other important effects on the entire work system (Carayon 1997). In particular, the aspects of the computerized work system that affect people may change over time. In a longitudinal study

TABLE 13 Differences in Design Requirements between Chinese and American Users

Attribute	Chinese	American
Knowledge regeneration	Abstract	Concrete
Base menu layout	Thematic	Functional
Menu layout	Vertical	Horizontal
Cognitive style	Relational–conceptual	Inferential–categorical
Thinking	Relational	Analytical
Field	Dependent	Independent
Translation from English to Chinese	Dynamics	N/A

TABLE 14 Guidelines for Designing Effective Interactive Systems

Helpful and supportive supervision
Allow job task characteristics to define ergonomic interventions
Appropriate consideration of ergonomic factors, including the technology, sensory environment, thermal environment, workstation design, and work practices
Consider light-related environmental factors, device use and posture factors, environmental factors, job design factors, individual user factors
Flexibility of hardware and software design
Focusing on target user groups in design
Employee involvement and participation in decision making (design, purchasing, and implementation of hardware and software)
Implementation of sound design practices, including the use of requirements definition, user profile development, tasks analysis, and task allocation
Setting usability objectives that focus around effectiveness, intuitiveness, and subjective perception
Iterative usability evaluation
Identification of users' mental models
Identification of appropriate metaphors
Effective integration of tasks into design via use scenarios, use sequences, use flow diagrams, use workflows, and use hierarchies
Design of reward systems (administrative, social, and monetary rewards)
Setup of workload standards (scientific basis, fairness, employee involvement, and acceptance)
Job enlargement and enrichment
Electronic monitoring of worker performance (fairness, feedback to employees, supervisory style, privacy)
Continuous communication between employees and management
Implementation of change
Development of career paths
Systemic approach (organizational culture, past experiences, long-term vs. short-term approach)
Balanced approach
Monitoring of changes (continuous data collection and monitoring of employee attitudes and performance)

of computer users, Carayon and her colleagues have shown that the job characteristics related to worker strain change over time (Carayon et al. 1995). Therefore, any iterative design strategy for improving the design of interactive systems should take into account temporal factors.

The idea of balancing the negative aspects of the work system by the positive aspects implies an active role from the part of all actors involved in the process. An active role characterized by information gathering, planning, and looking for alternatives can be much more effective than a passive role in achieving efficient use of computer technologies (Haims and Carayon 1998; Wilson and Haines 1997).

This chapter has presented information and data on how to design human–computer interfaces effectively from the physical, cognitive, and social points of view. Each of these has been presented separately, but there is a definite interaction among these three aspects. For example, Eberts et al. (1990) concluded that in group computer work, when the job design was enriched, the individuals in the group better understood the other group members' cognitive style than when the job was simplified. The better understanding resulted in more effective group performance than when the cognitive styles of other group members were less understood. This illustrates an interaction effect between social and cognitive factors in human–computer interaction.

The effects of physical and cognitive interaction in human–computer interaction have been documented by Karwowski et al. (1994). They demonstrated, as a result of a highly controlled study in computer-based mail sorting, that the mode of information presentation on a computer screen and the cognitive response requirement of the user affected and changed their physical posture. Thus, if designers consider both factors in interactive system design they can optimize their interaction.

Cook and Salvendy (1999) have documented, in computer-based work, the interrelationship between social and cognitive factors. They found that increased job enrichment and increased mental workload are some of the most important variables affecting job satisfaction. This raises an interesting dilemma for designers since the cognitive scientist would argue to minimize or optimize mental workload in order to minimize training time and maximize performance. The industrial engineer would argue for minimizing mental workload because that simplifies the work and thus decreases the rate of pay that a company needs to pay for the job. And the social scientist would argue that increasing the mental workload on the job would result in increased job satisfaction. The increased job satisfaction would, in turn, be expected to yield decreased labor turn over and decreased absenteeism, frequently resulting in increased productivity.

These interactions illustrate the type of dilemmas system developers can encounter during interactive system design. Involving a multidisciplinary team in the development process allows such opposing requirements to be addressed better. The team must be supported by ergonomists who understand physical requirements, human factors engineers who understand cognitive requirements, and management that believes in the competitive edge that can be gained by developing user-centered interactive systems. Close collaboration among these team members can lead to the development of remarkably effective and highly usable systems that are readily adopted by users.

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