

CHAPTER 11

Human Factors / Ergonomics

LEARNING OBJECTIVES

When you have completed this chapter you will be able to

- Explain the role of human factors in engineering design
- Describe and use the human-machine system model
- Apply sound design principles for visual and auditory displays
- Select appropriate control devices
- Specify human limitations for applying forces and torques
- Specify human size and range of motion limitations
- Describe and apply three strategies for design for fit

11.1 INTRODUCTION

Human factors is a term used to describe the abilities, limitations, and other physiological or cognitive characteristics of humans that affect the design and operation of tools, machines, systems, tasks, jobs, and environments. **Ergonomics** is a synonym frequently used by practitioners in Europe.

By careful consideration of human factors we strive to achieve user friendliness, convenience, effectiveness, efficiency, and increased productivity. Examples of poor human factors engineering include: handles that require too much torque to twist, parts that are too slippery to pick up, video equipment displays that are confusing, and shelves that are placed out of reach.

We also hope to enhance desirable human values such as improved safety, reduced fatigue or stress, increased comfort, greater user acceptance, increased job satisfaction, and improved quality of life (Sanders and McCormick, 1993).

The following three scenarios involve humans using a different product. Let's consider the physical interactions and the decisions made when performing the various tasks.

Making a pot of coffee with an electric coffeemaker. The consumer:

- grasps the pot, removes the pot top, and fills it with cold water,
- replaces the top, and pours the water into the coffeemaker water reservoir,
- removes the basket, inserts a new filter along with fresh coffee grounds,
- reinserts the basket into the coffeemaker, and
- pushes the power switch.

Changing the oil on a motorcycle. The repair person:

- starts and runs the engine for a few minutes to warm the oil and entrain particles that have settled to the bottom of the oil sump,
- places a suitable basin underneath the oil drain plug,
- removes ratchet wrench and socket from toolbox,
- loosens and removes the drain plug,
- inspects the plug and O-ring seal for dirt or wear,
- waits for oil to drain,
- replaces the plug finger-tight,
- tightens plug to a specified torque with torque wrench,
- removes the oil refill cap and pours in correct amount of fresh oil, and
- pours the waste oil into a suitable container for transport to recycle site.

Riding a bicycle. The rider:

- removes the bicycle from storage,
- climbs onto the bike and pedals down the street,
- pushes the handlebar to steer around a dog in the street,
- slows down by grasping hand brake lever and squeezing,
- steers to the side of the road to let car pass by,
- pushes the shift lever to a lower gear decreasing pedal force to climb hill,
- squeezes brake lever to stop at the top of the hill, dismounts, and
- walks the bike to roadside and enjoys the view.

First, we may notice that the user physically senses each product by seeing, hearing, and touching various components. Second, the user makes decisions, sometimes based on the sensory input, such as determining the amount of coffee grounds, how long to run the engine for warm up, and steering left or right around the dog. Finally, the user outputs or exerts forces and/or torques on parts of the machine. For example, the user grips the basket, pours water, pushes power switch, twists drain plug, pushes on handlebar to steer, pushes gearshift lever, and squeezes brake lever. The product, in turn, uses the human output to control its response.

We can model the interactions between the user and product as a **human-machine system**, as shown in Figure 11.1. The system includes the human operator,

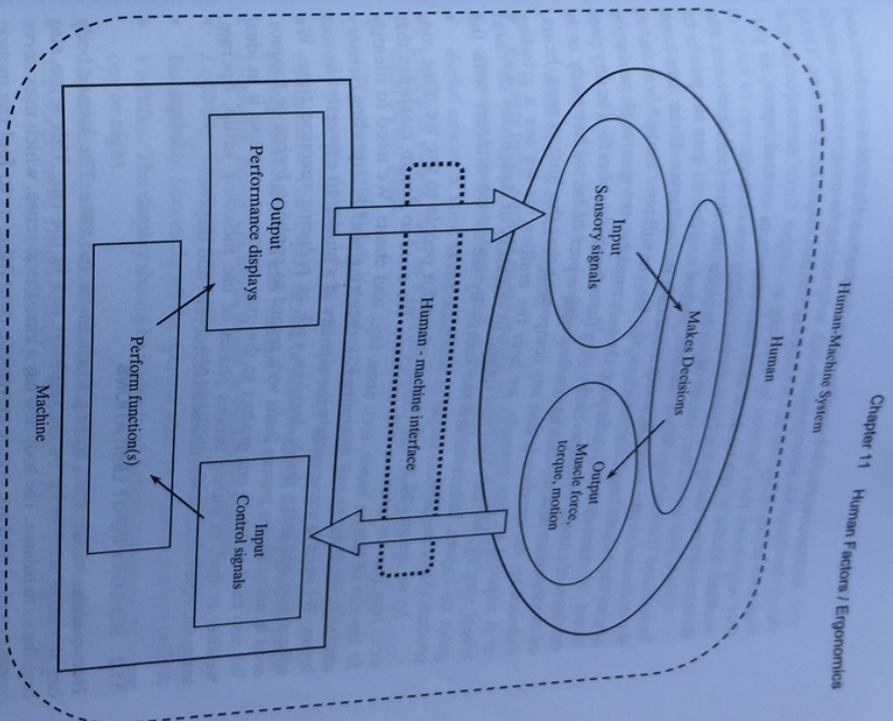


Figure 11.1 The human-machine system involves input and output interactions by means of interfaces

the machine, and the surrounding environment. The "machine" could be a consumer product such as a coffeemaker, motorcycle, or bicycle. The machine could also represent larger pieces of equipment, systems, and facilities such as a milling machine, a potato-chip-packaging system, or a nuclear-power plant.

Let's now use the model to understand why the study of human factors is so important in the design of a product or process.

Humans receive information about the current state of a machine and the environment via **sensory inputs** such as by seeing, hearing, touching, smelling, and tasting. They use this sensory information to make decisions. Then, they implement their decision by applying an output force or torque to the machine. Similarly, the machine uses these outputs as control inputs, to perform the desired changes in function, and displays new outputs.

Most important, the system depends upon the interfaces between the human and the machine. When the user pushes a switch to turn on power to the coffeemaker, the switch lights up to indicate its "on" state. If the user loses grip of the bicycle handlebar interface, the bicycle will not "know" how to respond. To reinstall the oil drain plug, the user must be strong enough to supply the correct amount of torque to the plug (interface). An interface is any part of the machine that the human touches with a part of his or her body or is exposed to. An interface is also any component that the human sees, hears, or is exposed to. For example, we hear the muffler, or we see a grinding wheel rotating. We may also be exposed to radiation or dangerous chemical gases or vapors. Interfaces are the means by which we interact with the product (Stanton, 1998).

As we design and manufacture products for people to use we must consider how humans interface with machines. We need to design machines that fit the size of human hands, feet, arms, legs, and chests. We need to identify and accommodate human limitations in detecting and interpreting sensory inputs. We need to accommodate the capacity of a human to correctly process information and make timely decisions such as reducing reaction time. We need to acknowledge human limits with regard to applying forces or torques. We also need to design our product so that our customer may use it in ideal weather or foul, or during various phases of use including setup, operate, maintain, repair, take-down, disassemble, recycle, and dispose.

11.2 SENSORY INPUT LIMITATIONS

Human senses include sight, hearing, touch, smell, and taste. The human body can also sense acceleration by the vestibular sacs in the ear. This sense also contributes to balance. The body also has a kinesthetic sense, which uses nerve receptors to feel joint and muscle movement, permitting us to feel the motion or position of our arms and legs. Each of these senses, however, is limited in its abilities. Let's examine our senses of sight, hearing, and touch in particular.

11.2.1 Sight

Humans differ in their ability to see. Some may not be able to focus on near (or far) objects. Some of us may not be able to distinguish certain colors. All of us, on the other hand, need a minimum of illumination to read or perform various tasks. In fact, as we age, even more illumination is needed. Some objects may move so fast that we cannot "see" them, as in the magician's "quicker than the eye" trick. Even when we can "see" an object, we may not

perceive it correctly. For example, objects may actually be nearer than they appear when looking into a rearview mirror. Or a poorly designed visual display could be confusing or difficult to interpret. Some displays may even cause "optical illusions."

In some cases we need to see and perceive a product's "visual displays" in order to operate it. For example, we frequently look at our car's instrument panel as we drive on the superhighway. If we see that the oil warning light is "on," we can stop the engine before permanent damage occurs. If we see that the water temperature gauge is within limits, we need not take action. A properly designed instrument panel displays abnormal operating conditions in a manner that can be quickly scanned and correctly interpreted (i.e., easily understood). Poorly designed machinery, however, may require the replacement of a part that is hidden or visually obscured during routine maintenance.

Visual display types include:

- **indicator lights**, such as an automobile oil pressure warning light,
- **continuous readout gauges**, such as the fuel gauge,
- **digital counters**, such as the odometer or digital radio tuner, and
- **graphical panels**, such as a railroad switchyard control center, or an electrical power plant.

Woodson (1981) lists a number of principles that enhance the effectiveness of warnings, signals, labels, and other displays:

- **Conspicuity**. The display should be conspicuous in that it should be prominently located, novel, and relevant.
- **Emphasis**. Important words should be visually emphasized.
- **Legibility**. Character fonts, size, and contrast should be exploited.
- **Intelligibility**. Succinctly tell the operator what the hazard is and how to fix it.
- **Visibility**. The display should be visible in all lighting conditions, including day or night.
- **Maintainability**. The display should resist aging, wear, and vandalism.
- **Standardization**. Display standard words and symbols whenever possible.

11.2.2 Hearing

Humans hear frequencies between 20 and 20,000 Hz. We are more sensitive to higher frequencies, however. We make use of our hearing to sense the operating condition of machinery. When operating a car brake, we can hear worn brake pads scraping on the rotor, indicating replacement. We may also hear the loud noise of a leaking muffler, or the repetitive thumping of a flat tire, or the hissing of an overheated radiator. A significant problem related to machinery in the workplace, however, is the **masking** of one sound by others. An audible alarm, for example, may go undetected if surrounding noise masks it.

A variety of auditory displays can be used in machine designs, including bells, buzzers, horns, sirens, tones, and electronic devices that speak single words or standard messages. Auditory displays should be avoided in noisy applications or when the operator is receiving too many other audio signals.

11.2.3 Touch/Kinesthetic/Vestibular

Humans are very sensitive to the tactile stimulation of skin tissues. We can feel sharp points, rough and smooth surfaces, as well as detect hot or cold temperatures or excessive electric voltages. As we operate a motorcycle we may feel excessive vibration through the handlebar, indicating a potential problem. We may detect a bearing failure in a machine by feeling how hot the surface is. We can feel the heat being radiated by a hot furnace. And we can inspect the surface of a part by feeling its roughness. Using our **kinesthetic sense**, we can "feel" how a golf club or baseball bat responds as we swing it, or the improved performance of a new pair of downhill skis or a new fishing rod. Similarly, using our **vestibular sense** we can feel the centrifugal acceleration of a roller coaster in our skin, muscles and joints, and our middle ear.

11.3 HUMAN DECISION-MAKING LIMITATIONS

Humans are limited in their ability to make decisions, especially when saturated with conflicting signals that are difficult to interpret. For example, let's consider the case when we are driving at night on a dark country road in a rainstorm with fog when a deer jumps in front of us. What do we do? Brake, steer, or pray? A well-trained driver will know where the brake pedal is and won't have to think about it first. And most likely, the driver will coordinate braking and steering to avoid the animal. Not all products are as user-friendly, however. As we make a decision, we receive sensory input information, interpret it, develop a set of choices, predict the outcomes associated with those choices, evaluate the pros and cons, and then select the "best" choice. In many cases we can take our time deciding. In other cases, such as in driving a car, a quick decision or short reaction time may be required.

Sanders and McCormick (1993) describe reaction time as a practical measure of performance. They define **simple reaction time** as the time to initiate a response when only one particular stimulus occurs and the same response is always required. Touching a hot surface, and jerking away, would be an example. Most decisions in real life, however, deal with multiple choices. **Choice reaction time** is the time when several stimuli are presented, each of which requires a different response. Choice reaction times are longer because of the decision making or thinking that we do.

Our role as product designers should be to make our machines display appropriate visual and auditory signals clearly and quickly. The user should be trained to react to these stimuli in a safe and predetermined manner, by activating "the" control that is clearly identified for the specific situation.

11.4 HUMAN MUSCLE OUTPUT

Humans execute their decisions by outputting a force (i.e., push or pull) or torque (i.e., twist) on a part of the machine. In some cases we apply a force or torque to a "control." For example, we step on a car brake to slow down, push on a bicycle handlebar to steer, twist the control on our radio to adjust its volume, twist the handle of a water faucet to control its flow, and squeeze the brake lever on our motorcycle to slow down. In other cases we hold and move the whole product to perform a task, as in trimming a hedge with an electric trimmer, or in shaving with an electric razor, or when cutting a ham with an electric carving knife.

Our ability to apply a force or torque depends on a number of **muscle strength** factors, including whether we are sitting, standing, or lying down, what part of the body is applying the force (i.e., the hand, foot, leg, or arm, etc.), and the direction and duration of the force. Hand, thumb-finger, and arm strength for 5th-percentile males adults is shown in Figure 11.2. Lifting leg strength for men is shown in Table 11.3. Intermittently applied

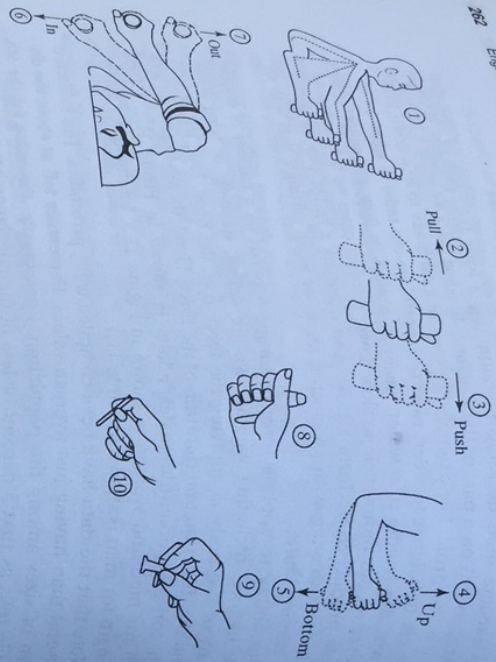
Note that the data have been compiled using percentiles. This method is more useful than having just average values. Percentiles tell us about the distribution of sizes among the population. For example, the value for the 5th percentile tells us that 5 percent or less of the population has a dimension of that value. Similarly, the 95th percentile tells us that 95 percent of the population has dimensions smaller than that listed. The average is a statistical measure, an arithmetic mean, which may or may not exist in reality. For example, where do we find an "average" family with 1.5 children?

As we apply a force through a displacement we perform translational work. As we apply a torque through an angular displacement we perform rotational work. Human motion depends on the **range of motion** (translations or rotations of body parts) at each of the joints, as shown in Figures 11.4–11.6.

We know from physics that work requires energy and energy expended per unit of time gives us power. When a human operator mentions "ease of use," we might question whether he or she is talking about the amount of physical effort, or energy expenditure needed to use the product, or the eventual muscle fatigue that can occur. **Energy expenditure** depends upon a number of factors, including the magnitude of the force or torque and the amount of displacement, its duration, number and length of rest periods, and whether the worker is standing, sitting, or lying, as well as environmental conditions, such as temperature and humidity. The mean value daily energy expenditures for a few occupations are given in Table 11.2.

Human muscle output is applied to the machine at a machine-input interface. Quite often, the interface is a control. Controls include levers, cranks, hand wheels, handles, pedals, push buttons, rotary knobs, rotary selector switches, toggle switches, rocker switches, slides, joysticks, and roll balls.

Researchers have studied the adequacy of various controls with respect to the required input force or torque, operational characteristics, and assigned



Arm strength (N)												
(1)	(2)		(3)		(4)		(5)		(6)		(7)	
Degree of elbow flexion (deg)	Pull		Push		Up		Down		In		Out	
	L*	R*	L	R	L	R	L	R	L	R	L	R
180	222	231	187	222	40	62	58	76	58	89	36	62
150	187	249	133	187	67	80	80	89	67	89	36	67
120	151	187	116	160	76	107	93	116	89	98	45	67
90	142	165	98	160	76	89	93	116	71	80	45	71
60	116	107	98	151	67	89	80	89	76	89	53	76
Hand and thumb-finger strength (N)												
(8)			(9)			(10)						
Hand grip			Thumb-finger grip (Palmer)			Thumb-finger grip (Taps)						
L			R									
Momentary hold	250	260				60			60			
Sustained hold	145	155				35			35			

L = Left, R = Right

*L = Left; R = Right

FIGURE 11.2 Muscle strength of the arm, hand, and thumb for 5th-percentile males. (Adapted from MIL-STD-1472F, Courtesy of the U.S. Department of Defense.)



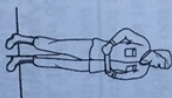
A. Standing two-handed pull: 38 cm (15.0) level. Standing with feet 45 cm (17.7 in) apart and knees bent, bending at the waist, grasping both sides of a 45 cm (17.7 in) handle located directly in front, 38 cm (15.0 in) above standing surface, and pulling, using primarily arms, shoulders, and legs

Strength measurements		5th percentile		95th percentile	
		Male	Female	Male	Female
Mean force (N)	737.5	330.9	1354.5	817.6	
Mean force (lbf)	(165.80)	(74.39)	(304.50)	(183.80)	
Peak force (N)	844.7	396.9	1437.2	888.3	
Peak force (lbf)	(189.90)	(89.23)	(323.10)	(199.70)	



B. Standing two-handed pull: 50 cm (19.7 in) level. Standing with feet 45 cm (17.7 in) apart and knees straight, bending at the waist, grasping both sides of a 45 cm (17.7 in) handle located directly in front, 50 cm (19.7 in) above standing surface, and pulling, using primarily arms and shoulders

Strength measurements		5th percentile		95th percentile	
		Male	Female	Male	Female
Mean force (N)	738.0	326.1	1341.6	840.7	
Mean force (lbf)	(170.41)	(73.31)	(301.60)	(189.00)	
Peak force (N)	830.9	374.1	1441.7	905.2	
Peak force (lbf)	(186.79)	(84.10)	(324.11)	(203.50)	



C. Standing two-handed pull: 100 cm (39.4 in) level. Standing erect with feet 45 cm (17.7 in) apart, grasping both sides of a 45 cm (17.7 in) handle located directly in front, 100 cm (39.4 in) above the standing surface, and pulling, using the arms

Strength measurements		5th percentile		95th percentile	
		Male	Female	Male	Female
Mean force (N)	444.4	185.0	931.0	443.0	
Mean force (lbf)	(99.91)	(41.59)	(209.50)	(99.59)	
Peak force (N)	504.0	218.0	988.4	493.3	
Peak force (lbf)	(113.30)	(49.01)	(222.20)	(110.90)	

FIGURE 11.3 Static muscle strength for vertical pull. (Reprinted from *Human Factors Design Guide* by Wagner, Snyder, and Duncanson, Courtesy of the Federal Aviation Administration, U.S. Department of Commerce.)

TABLE 11.1 Horizontal Push and Pull Forces That Can Be Exerted Intermittently by Males (adapted from MIL-STD-1472E)

Exertable horizontal force	Applied with	Coefficient of friction
110 N (24.7 lbf) push or pull	both hands or one shoulder or the back	with low traction $0.2 < \mu < 0.3$
200 N (45.0 lbf) push or pull	both hands or one shoulder or the back	with medium traction $\mu = 0.6$
240 N (54.0 lbf) push or pull	one hand	If braced against a vertical wall 510-1520 mm (20.08-59.84 in.) from and parallel to the push panel
310 N (70.0 lbf) push	both hands or one shoulder or the back	If braced against a vertical wall 510-1520 mm (20.08-59.84 in.) from and parallel to the push panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)
490 N (110.2 lbf) push or pull	both hands or one shoulder or the back	If braced against a vertical wall 510-1520 mm (20.08-59.84 in.) from and parallel to the push panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)
730 N (164.1 lbf) push	the back	If braced against a vertical wall 580-1090 mm (22.83-42.91 in.) from and parallel to the push panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)

control tasks, as shown in Figures 11.7-11.9 (Salvendy, 1987). The controls are separated into three categories: rotating, translating, and swiveling. The basic shape of the control, its approximate dimensions, and permissible actuating forces and torques are given along with ratings as to how well the control performs various functions. Note that the "●" symbol means recommended, the "○" means not suitable, and the half-filled circle means acceptable.

Example

Assume that we have been hired by Micro Robotics Industries, Inc. to design a custom machine tool to inspect raw materials as the factory receives them. A 300-hp motor drives the tool at one of four speeds. The control will electronically select one of the four speeds. It will be located on a control panel near the machine. Use Figures 11.7-11.9 to determine feasible controls for the application. Discuss some of the functional characteristics of each control.

The principal criterion for selection is that the control needs to energize one of four choices. Studying the figures and selecting only those recommended we find five possible controls:

Rotary selector switch (from figure 11.7) is recommended for having tactile feedback, a visible setting, and marginally recommended for a precise adjustment. It has an acceptable rating for accidental actuation and large force actuation. It is not recommended for continuous or quick adjustment.

Lever (from figure 11.8) is also recommended for large-force actuation. It is marginally recommended for precise adjustment. It is rated acceptable for quick adjustment, tactile feedback and setting visible. It is rated not suitable due to accidental actuation.

Joystick (from figure 11.8) is also recommended for precise adjustment. It is rated acceptable for quick adjustment, tactile feedback, and setting visible. It is marginally suitable for large-force application. It is rated not suitable due to accidental actuation.

Handle (slide) (from figure 11.9) is also recommended for large-force actuation, and marginally recommended for precise adjustment. It is acceptable for quick adjustment, tactile feedback, and setting visible. It is rated not suitable due to accidental actuation.

D-handle (from figure 11.9) is also recommended for large-force actuation. It is acceptable for precise adjustment and quick adjustment. It is rated not quite suitable for tactile feedback and setting visible. It is rated not suitable due to accidental actuation.

The rotary selector switch appears to be quite acceptable for the application. It is slightly better than the others because of its acceptable rating on accidental actuation.

11.5 PHYSICAL SIZE LIMITATIONS

Humans vary in size such as the length and width of body parts, including fingers, hands, arms, legs, and torsos. Some differences are due to sex and age. For example, men are generally taller than women, and children are smaller yet. Most humans grow taller as they grow to adulthood and then slightly shorten in their later years.

To fit the user, a product should not be too big or too small. A leaf rake that is too short might make the user stoop uncomfortably. A bicycle handlebar that is too large in diameter might not be graspable by a child. A sofa chair that is too narrow might squeeze the user. A coffee pot handle similarly has to fit the users. And the location of a motorcycle drain plug must be large enough to fit the user's hand.

Anthropometrics is a field of human factors that deals with the measurements of the human form such as height and/or reach (Kroemer et al., 2001). Researchers around the world routinely compile and categorize such information by age, sex, and/or country. The U.S. armed forces has compiled a significant amount of data and has prepared a number of documents to aid in the design of machines, equipment, systems, computers and facilities (MIL-STD-1472E, 1999; MIL-HDBK-759C, 1997; Wagner et al., 1996). Static human physical characteristics are given for adult males and females in Figures 11.10-11.17.

How should we design our product, machine, or system to fit our users? Should we design for the average person? Probably not, since the average person doesn't really exist. Anthropometric data appear to be normally distributed. Therefore, designing for an average person may eliminate many people slightly larger or smaller.

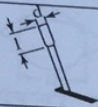
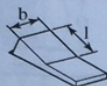
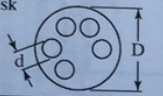
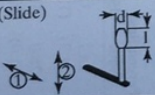
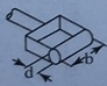
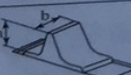
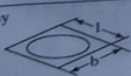
Path of C. motion	Control	Dimension [mm]	Force F [N] Moment M [Nm]	2 positions	>2 positions	Continuous adjustment	Precise adjustment	Quick adjustment	Large force application	Tactile feedback	Setting visible	Accidental actuation
Swiveling movement	Lever 	d : 30-40 l : 100-120	10-200 N	●	●	●	●	●	●	●	●	○
	Joystick 	s : 20-150 d : 10-20	5-50 N	●	●	●	●	●	●	●	●	○
	Toggle switch 	b : > 10 l : > 15	2-10 N	●	○	○	○	○	○	○	○	○
	Rocker switch 	b : > 10 l : > 15	2-8 N	●	○	○	○	○	○	○	○	○
	Rotary disk 	d : 12-15 D : 50-80	1-7 N	●	○	○	○	○	○	○	○	○
	Pedal 	b : 50-100 l : 200-300 l : 50-100 (Forefoot)	Sitting : 16-100 N Standing : 80-250 N	●	○	○	○	○	○	○	○	○

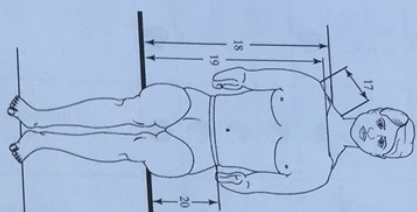
FIGURE 11.8

Hand and foot operated control devices and their operational characteristics and control functions; ● recommended; ○ not suitable. (Handbook of Human Factors, G. Salvendy (Ed.), Copyright © 1987. This material is used by permission of John Wiley & Sons, Inc.).

Path of C. motion	Control	Dimension (mm)	Force F [N] Moment M [Nm]	2 positions	>2 positions	Continuous adjustment	Precise adjustment	Quick adjustment	Large force application	Tactile feedback	Setting visible	Accidental actuation
Linear movement	Handle (Slide) 	d : 30-40 l : 100-120	F ₁ : 10-200 N F ₂ : 7-140 N	●	●	●	●	●	●	●	●	○
	D-Handle 	d : 30-40 b : 110-130	10-200 N	●	●	●	●	●	●	●	●	○
	Push button 	Finger : d > 15 Hand : d > 50 Foot : d > 50	Finger : F = 1-8 N Hand : F = 4-16 N Foot : F = 15-90 N	●	○	○	○	○	○	○	○	○
	Slide 	l : > 15 b : > 15	1-5 N (Touch grip)	●	○	○	○	○	○	○	○	○
	Slide 	b : > 10 h : > 15	1-10 N (Thumb-finger grip)	●	○	○	○	○	○	○	○	○
	Sensor key 	l : > 14 b : > 14		●	○	○	○	○	○	○	○	○

^b Recessed installation of the control

FIGURE 11.9 Hand and foot operated control devices and their operational characteristics and control functions; ● recommended; ○ not suitable. (Handbook of Human Factors, G. Salvendy (Ed.), Copyright © 1987. This material is used by permission of John Wiley & Sons, Inc.).



17 **Shoulder length.** The surface distance along the top of the shoulder from the junction of the neck and shoulder to the point of the shoulder (acromion).

		Percentiles				
Sample		1st	5th	50th	95th	99th
A Men	cm 12.4 (in) (4.9)	13.3 (5.3)	15.0 (5.9)	16.9 (6.7)	17.7 (7.0)	
B Women	cm 12.0 (in) (4.7)	12.7 (5.0)	14.5 (5.7)	16.2 (6.4)	17.1 (6.7)	

18 **Mid-shoulder height sitting.** The vertical distance from the sitting surface of the shoulder halfway between the neck and the point of the shoulder, measured with the subject sitting.

		Percentiles				
Sample		1st	5th	50th	95th	99th
A	Men	cm 56.3 (in) (22.2)	58.3 (23.0)	63.0 (24.9)	67.7 (26.7)	69.4 (27.3)
B	Women	cm 52.3 (in) (20.6)	53.9 (21.2)	58.4 (23.0)	63.1 (24.8)	64.7 (25.5)

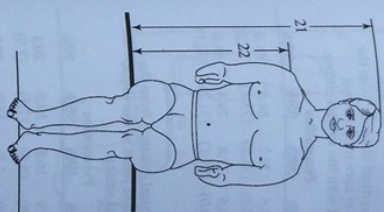
19 **Trunk (suprasternale) height sitting.** The vertical distance from the sitting surface to the lowest point of the notch in the upper edge of the breast bone (suprasternale), measured with the subject sitting.

		Percentiles				
Sample		1st	5th	50th	95th	99th
A Men	cm	53.1	55.2	59.6	64.2	65.9
	(in)	(20.9)	(21.7)	(23.5)	(25.3)	(25.9)
B Women	cm	49.8	51.1	55.3	59.6	61.2
	(in)	(19.6)	(20.1)	(21.8)	(23.5)	(24.1)

20 **Waist height sitting.** The vertical distance from the sitting surface to the level of the waist (natural indentation), measured with the subject sitting.

		Percentiles				
Sample	1st	5th	50th	95th	99th	
A Men	cm 24.8 (in) (9.8)	26.0 (10.2)	28.7 (11.3)	31.5 (12.4)	32.9 (13.0)	
B Women	cm 22.8 (in) (9.0)	24.4 (9.6)	28.0 (11.0)	31.5 (12.4)	32.7 (12.9)	

FIGURE 11.10 Static human physical characteristics. (Reprinted from *Human Factors Design Guide* by Wagner, Snyder, and Duncanson. Courtesy of the Federal Aviation Administration, U.S. Department of Commerce.)



21 **Sitting height.** The vertical distance from the sitting surface to the top of the head, measured with the subject sitting.

Sample		Percentiles				
		1st	5th	50th	95th	99th
A	Men	cm 82.8 (in) (32.6)	85.5 (33.7)	91.4 (36.0)	97.2 (38.3)	99.1 (39.0)
B	Women	cm 77.5 (in) (30.5)	79.5 (31.3)	85.1 (33.5)	91.0 (35.8)	93.3 (36.7)

22 **Shoulder (acromiale) height sitting.** The vertical distance from the sitting surface to the point of the shoulder (acromion), measured with the subject sitting.

		Percentiles				
Sample		1st	5th	50th	95th	99th
A Men	cm 129.9 (in) (51.1)	134.2 (52.8)	144.2 (56.8)	154.6 (60.1)	158.4 (62.4)	162.2 (63.9)
B Women	cm 120.4 (in) (47.4)	123.9 (48.8)	133.3 (52.5)	143.7 (56.6)	147.5 (58.1)	151.3 (59.5)

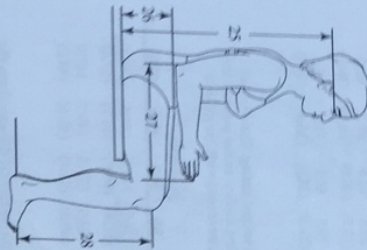
23 **Elbow grip length.** The horizontal distance from the back of the elbow to the center of the clenched fist.

		Percentiles				
Sample		1st	5th	50th	95th	99th
A Men	cm 32.3 (in) (12.7)	33.2 (13.1)	35.9 (14.1)	39.1 (15.4)	40.3 (15.9)	
B Women	cm 28.9 (in) (11.4)	30.0 (11.8)	32.8 (12.9)	35.8 (14.1)	37.2 (14.7)	

24 **Elbow rest height.** The vertical distance from the sitting surface to the bottom of the tip of the elbow, measured with the subject sitting and the forearm held horizontally.

		Percentiles				
Sample		1st	5th	50th	95th	99th
A Men	cm 16.8 (in) (6.6)	18.4 (7.2)	23.2 (9.1)	27.4 (10.8)	29.2 (11.5)	30.5 (12.0)
B Women	cm 15.8 (in) (6.2)	17.6 (6.9)	22.1 (8.7)	26.4 (10.4)	28.2 (11.1)	29.5 (11.6)

FIGURE 11.11 Static human physical characteristics. (Reprinted from *Human Factors Design Guide* by Wagner, Snyder, and Duncanson. Courtesy of the Federal Aviation Administration, U.S. Department of Commerce.)



25 **Eye height, sitting.** The vertical distance from the sitting surface to the outer corner of the eye (ecrotanthus), measured with the subject sitting.

Sample		1st	5th	50th	95th	99th
A	Men	cm 71.2	73.5	79.2	84.8	86.9
	(in)	(28.0)	(28.9)	(31.2)	(33.4)	(34.2)
B	Women	cm 66.4	68.5	73.8	79.4	81.6
	(in)	(26.1)	(30.0)	(29.1)	(31.2)	(32.1)

26 **Thigh clearance.** The vertical distance from the sitting surface to the highest point of the thigh, measured with the subject sitting.

Sample		1st	5th	50th	95th	99th
A	Men	cm 14.1	14.9	16.8	19.0	20.1
	(in)	(5.6)	(5.9)	(6.6)	(7.5)	(7.9)
B	Women	cm 13.4	14.0	1.8	18.0	19.0
	(in)	(5.3)	(5.5)	(6.2)	(7.1)	(7.5)

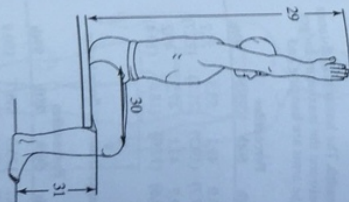
27 **Elbow-finger length.** The horizontal distance from the back of the elbow to the tip of the middle finger, with the hand extended.

Sample		1st	5th	50th	95th	99th
A	Men	cm 43.4	44.8	48.3	52.4	54.2
	(in)	(17.1)	(17.6)	(19.2)	(20.6)	(21.3)
B	Women	cm 39.1	40.6	44.2	48.3	49.8
	(in)	(15.4)	(16.0)	(17.4)	(19.0)	(19.6)

28 **Knee height, sitting.** The vertical distance from the footrest surface to the top of the knee, measured with the subject sitting.

Sample		1st	5th	50th	95th	99th
A	Men	cm 49.7	51.4	55.8	60.6	62.3
	(in)	(19.6)	(20.2)	(22.0)	(23.9)	(24.5)
B	Women	cm 45.4	47.4	49.8	56.0	57.8
	(in)	(17.9)	(18.7)	(20.2)	(22.0)	(22.8)

FIGURE 11.12 Static human physical characteristics. (Reprinted from *Human Factors Design Guide* by Wagner, Snyder, and Duncanson. Courtesy of the Federal Aviation Administration, U.S. Department of Commerce.)



29 **Vertical reach, sitting.** The vertical distance from the sitting surface to the tip of the middle finger, measured with the subject sitting and the arm, hand, and fingers extended vertically.

Sample		1st	5th	50th	95th	99th
A	Men	cm 129.3	133.8	143.3	153.2	156.7
	(in)	(50.1)	(52.7)	(56.4)	(60.3)	(61.7)
B	Women	cm 119.7	123.3	132.7	141.8	145.4
	(in)	(47.1)	(48.5)	(52.2)	(55.8)	(57.2)

30 **Abdominal depth, sitting.** The depth of the abdomen, measured with the subject sitting.

Sample		1st	5th	50th	95th	99th
A	Men	cm 18.6	19.9	23.6	29.1	31.4
	(in)	(7.3)	(7.8)	(9.3)	(11.5)	(12.4)
B	Women	cm 17.3	18.5	21.9	27.1	29.5
	(in)	(6.1)	(7.3)	(8.6)	(10.7)	(11.6)

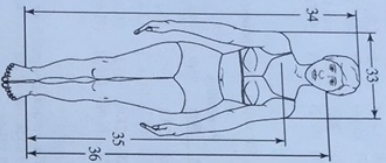
31 **Popliteal height, sitting.** The vertical distance from the footrest surface to the underside of the lower leg, measured with the subject sitting.

Sample		1st	5th	50th	95th	99th
A	Men	cm 37.8	39.5	43.3	47.6	49.5
	(in)	(14.9)	(15.6)	(17.1)	(18.7)	(19.5)
B	Women	cm 33.7	35.1	38.9	42.9	44.6
	(in)	(13.3)	(13.8)	(15.3)	(16.9)	(17.6)

32 **Forearm-forearm breadth, sitting.** The horizontal distance across the body between the outer surfaces of the forearms, measured with the forearms flexed and held against the body.

Sample		1st	5th	50th	95th	99th
A	Men	cm 45.1	47.79	54.5	62.1	65.3
	(in)	(17.8)	(18.8)	(21.5)	(24.5)	(25.7)
B	Women	cm 39.4	41.5	46.7	52.8	56.0
	(in)	(15.5)	(16.3)	(18.4)	(20.8)	(22.1)

FIGURE 11.13 Static human physical characteristics. (Reprinted from *Human Factors Design Guide* by Wagner, Snyder, and Duncanson. Courtesy of the Federal Aviation Administration, U.S. Department of Commerce.)



33 **Shoulder (bideleoid) breadth.** The horizontal distance across the upper arms between the maximum bulges of the deltoid muscles; the arms are hanging and relaxed.

Percentiles					
Sample	1st	5th	50th	95th	99th
A Men	cm 43.4	45.0	49.1	53.5	55.2
	(in) (17.1)	(17.7)	(19.3)	(21.1)	(21.7)
B Women	cm 38.0	39.7	43.1	47.2	49.2
	(in) (15.0)	(15.6)	(17.0)	(18.6)	(19.4)

34 **Stature.** The vertical distance from the floor to the top of the head.

Percentiles					
Sample	1st	5th	50th	95th	99th
A Men	cm 160.3	164.7	175.5	186.7	190.9
	(in) (63.1)	(64.8)	(69.1)	(73.5)	(75.2)
B Women	cm 148.3	152.8	162.7	173.7	178.0
	(in) (58.4)	(60.2)	(64.1)	(68.4)	(70.1)

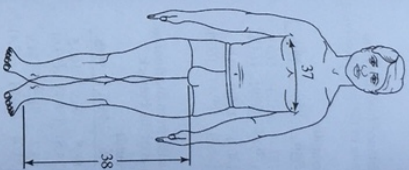
35 **Suprasternal height.** The vertical distance from the floor to the lowest point of the notch in the upper edge of the breast bone (suprasternal).

Percentiles					
Sample	1st	5th	50th	95th	99th
A Men	cm 130.2	134.3	143.7	153.7	157.5
	(in) (51.3)	(52.9)	(56.6)	(60.5)	(62.0)
B Women	cm 120.7	124.1	132.9	142.5	146.4
	(in) (47.5)	(48.9)	(52.3)	(56.1)	(57.6)

36 **Tragion height, standing.** The vertical distance from the floor to the tragon, the cartilaginous notch at the front of the ear.

Percentiles					
Sample	1st	5th	50th	95th	99th
A Men	cm 147.4	151.9	162.4	173.4	177.5
	(in) (58.0)	(59.8)	(63.9)	(68.3)	(69.9)
B Women	cm 136.3	140.7	150.4	161.2	165.4
	(in) (53.7)	(55.4)	(59.2)	(63.5)	(65.1)

FIGURE 11.14 Static human physical characteristics. (Reprinted from *Human Factors Design Guide* by Wagner, Snyder, and Duncanson, Courtesy of the Federal Aviation Administration, U.S. Department of Commerce.)



37 **Chest (bust) circumference.** The circumference of the torso measured at the level of the nipples.

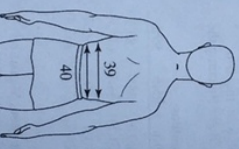
Percentiles					
Sample	1st	5th	50th	95th	99th
A Men	cm 84.5	88.6	98.7	111.3	116.8
	(in) (33.3)	(34.9)	(38.9)	(43.8)	(46.0)
B Women	cm 78.1	81.4	90.1	102.2	107.7
	(in) (30.8)	(32.1)	(35.5)	(40.2)	(42.4)

38 **Crook height.** The vertical distance from the floor to the midpoint of the crook.

Percentiles					
Sample	1st	5th	50th	95th	99th
A Men	cm 73.2	76.4	83.5	91.6	94.6
	(in) (28.8)	(30.1)	(32.9)	(36.1)	(37.2)
B Women	cm 67.0	70.0	77.0	84.6	88.1
	(in) (26.4)	(27.6)	(30.3)	(33.3)	(34.7)

39 **Waist circumference (natural indentation).** The horizontal circumference of the torso at the level of the natural indentation of the waist.

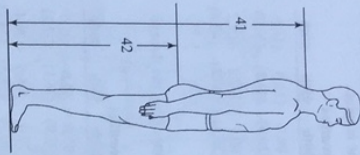
Percentiles					
Sample	1st	5th	50th	95th	99th
A Men	cm 69.9	73.0	83.4	97.1	102.9
	(in) (27.5)	(28.7)	(32.8)	(38.2)	(40.5)
B Women	cm 60.7	63.7	71.7	84.3	91.0
	(in) (23.9)	(25.1)	(28.2)	(33.2)	(35.8)



40 **Waist circumference (omphalion).** The horizontal circumference of the torso at the level of the navel (omphalion).

Percentiles					
Sample	1st	5th	50th	95th	99th
A Men	cm 70.0	73.3	85.6	101.6	107.7
	(in) (27.6)	(28.9)	(33.7)	(40.0)	(42.4)
B Women	cm 64.4	67.6	78.1	94.6	102.6
	(in) (25.4)	(26.6)	(30.8)	(37.2)	(40.4)

FIGURE 11.15 Static human physical characteristics. (Reprinted from *Human Factors Design Guide* by Wagner, Snyder, and Duncanson, Courtesy of the Federal Aviation Administration, U.S. Department of Commerce.)

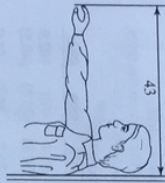


41 Cervical height. The vertical distance from the floor to the cervical, the tip of the spine of the seventh cervical vertebra at the base of the neck.

Sample		1st	5th	50th	95th	99th
Percentiles						
A	Men	cm 137.4	141.8	151.8	162.4	166.1
	(in)	(54.1)	(55.8)	(59.8)	(63.9)	(65.4)
B	Women	cm 127.3	131.4	140.6	150.8	154.8
	(in)	(50.1)	(51.7)	(55.4)	(59.4)	(60.9)

42 Buttock height. The vertical distance from the floor to the maximum posterior protrusion of the buttock.

Sample		1st	5th	50th	95th	99th
Percentiles						
A	Men	cm 78.4	81.5	88.5	96.9	100.5
	(in)	(30.9)	(32.1)	(34.8)	(38.1)	(39.6)
B	Women	cm 73.9	76.7	83.7	91.5	94.9
	(in)	(29.1)	(30.2)	(33.0)	(36.0)	(37.4)



43 Functional (thumb-tip) reach. The horizontal distance from the wall to the tip of the thumb, measured with the subject's shoulders against the wall, the arm extended forward, and the index finger touching the tip of the thumb.

Sample		1st	5th	50th	95th	99th
Percentiles						
A	Men	cm 72.0	73.9	80.0	86.7	89.7
	(in)	(28.4)	(29.1)	(31.5)	(34.1)	(35.3)
B	Women	cm 65.8	67.7	73.4	79.7	82.4
	(in)	(25.9)	(26.7)	(28.9)	(31.4)	(32.4)

44 Functional (thumb-tip) reach, extended. Measured similarly to functional (thumb-tip) reach, except that the right shoulder is extended forward as far as possible, while the left shoulder is kept pressed firmly against the wall.

Sample		1st	5th	50th	95th	99th
Percentiles						
A	Men	cm 77.9	80.5	87.3	94.2	97.7
	(in)	(30.0)	(31.7)	(34.4)	(37.1)	(38.5)
B	Women	cm 71.2	73.5	79.6	86.2	89.0
	(in)	(28.0)	(28.9)	(31.3)	(33.9)	(35.0)

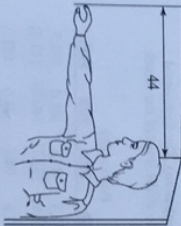
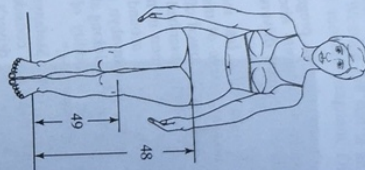


FIGURE 11.16 Static human physical characteristics. (Reprinted from *Human Factors Design Guide* by Wagner, Snyder, and Duncanson. Courtesy of the Federal Aviation Administration, U.S. Department of Commerce.)



48 Hip (trochanteric) height. The vertical distance from the floor to the level of the maximum posterior protrusion of the greater trochanter of the femur (trochanterion).

Sample		1st	5th	50th	95th	99th
Percentiles						
A	Men	cm 82.1	85.3	92.7	100.9	104.0
	(in)	(32.3)	(33.6)	(36.5)	(39.7)	(40.9)
B	Women	cm 76.1	78.9	86.0	93.8	97.5
	(in)	(30.0)	(31.1)	(33.9)	(36.9)	(38.4)

49 Knee height, midpatella. The vertical distance from the footrest surface to the top of the knee, measured with the subject sitting.

Sample		1st	5th	50th	95th	99th
Percentiles						
A	Men	cm 44.3	46.1	50.4	55.2	56.8
	(in)	(17.4)	(18.2)	(19.8)	(21.7)	(22.4)
B	Women	cm 39.9	41.7	45.8	50.3	52.3
	(in)	(15.7)	(16.4)	(18.0)	(19.8)	(20.6)

FIGURE 11.17 Static human physical characteristics. (Reprinted from *Human Factors Design Guide* by Wagner, Snyder, and Duncanson. Courtesy of the Federal Aviation Administration, U.S. Department of Commerce.)

One strategy is to design for the **extreme case**, that is, design to fit the smallest or largest person. For example, if we want an access doorway to be wide enough to handle the "largest" person, we would consider the shoulder width of the 95th-percentile male. That size would accommodate 95 percent of all adult males, a higher percentage of most females, and almost 100 percent of all children. Or, in a different case, we need to determine the arm reach distance for a control, we would want the "smallest" arm length and therefore consider the 5th-percentile female.

A **close fit** strategy is used when we try to match all our differently sized customers. Clothing manufacturers accommodate a close fit by producing a collection of sizes to obtain more or less "close fits" for all of their customers. It is somewhat expensive, however, considering the costs of producing and maintaining differently sized inventories.

Finally, we may need to design for **adjustability**. How would we design an automobile seat, for example? If we used the 95th-percentile male it would not fit most women or adolescent drivers. In this case the driver needs to be in contact with the steering wheel and foot controls. Therefore, for cases such as these we design for adjustability. Other examples of design for adjustability include office chairs, microphone stands, stereo headphones, and bicycle seat posts.

Sunday, May 11, 2003 By Anita Lienert, *Special to The Detroit News*
Designers Have Moons on the Mind.

DEARBORN—Early in the development of the 2004 Mercury Monterey minivan, Jared Glaspell's supervisor at Ford Motor Co. suggested that he strap on an "Empathy Belly" and don a frumpy denim smock designed to make him look and feel like a pregnant woman.

The request came as the 26-year-old Glaspell and 15 other, mostly male, engineers were standing around a clay model of the minivan, searching for ways to improve the vehicle for female consumers.

The \$900 patented pregnancy simulator—one of two owned by Ford—includes breasts, a large water-filled "belly," a tight corset that restricts breathing and two 7-pound metal balls that emulate fetal movement.

"There were 'aha' moments," Glaspell said of wearing the suit. "I became more aware of where the instrument panel controls were placed. I wanted more grab handles to get in and out of the vehicle. Other guys wore it and said they began to appreciate how much your body can change when you are pregnant. But after about an hour in the pregnancy suit, we'd all be begging for mercy."

The contraption highlights a growing trend in the auto industry of creating cars and trucks not only aimed at women, but targeted specifically at making pregnant women—a once-overlooked segment of the market—more comfortable behind the wheel.

Birthways Inc. of Vashon Island, Wash., created the Empathy Belly. The company claims that after about 10 minutes, wearers feel a weight gain of about 30 pounds, their breathing grows more shallow and they're tired.

The suit originally was designed as a tool for expectant fathers and adolescents in sex-education programs. At Ford, it's a critical tool used in many new product programs. The 2004 Monterey, which goes on sale in September, is the first minivan Ford has developed using lessons learned from the Empathy Belly.

Still, some industry observers question the value of taking such extreme measures to get into the minds—and bodies—of the consumer.

"Anything that connects the people engineering the cars to the people who buy the cars is good," said auto consultant James N. Hall of Auto Pacific Inc. in Troy. "But to think this device is simulating pregnancy is a male fanta-

sy."

Even if they aren't strapping on pregnancy suits, engineers at other automakers also are focusing on the needs of pregnant drivers and passengers.

At the New York auto show last month, Gene Stefansky, who's in charge of midsize cars for General Motors Corp., showed off the 2004 Malibu Maxx hatchback and described how it was designed with pregnant women in mind. "Historically, we've designed cars around the 50th percentile male figure," Stefansky said. "With the Malibu Maxx, we were thinking about pregnant women. The whole flexibility of the vehicle's interior speaks to that effort."

Opening the driver's door, Stefansky pointed out features that engineers considered necessary for making a pregnant driver's life easier.

The vehicle, which goes on sale in January, boasts standard adjustable pedals, standard vertical height adjustment on the driver's seat and a standard adjustable steering wheel—fairly unusual on a vehicle expected to start at under \$20,000. But they help give a pregnant woman an almost custom-fit cockpit.

Back at Ford, Julie Dilis, a 39-year-old mother of two and a prototype planning supervisor, stands in front of an early version of the Monterey pointing out the pregnancy-friendly features. The Monterey's second-row seats easily fold and tumble forward—a first for a Mercury minivan. The third-row seat folds flat—another first. An articulating arm adds length to the strap used to pull the third-row seat into the floor. Dilis said that will make it easier for a woman in the final three months of pregnancy to pull the heavy seat into a deep well in the floor.

Like the Malibu Maxx, the Monterey has standard adjustable pedals, which make it easier for a pregnant woman to find a comfortable spot behind the wheel.

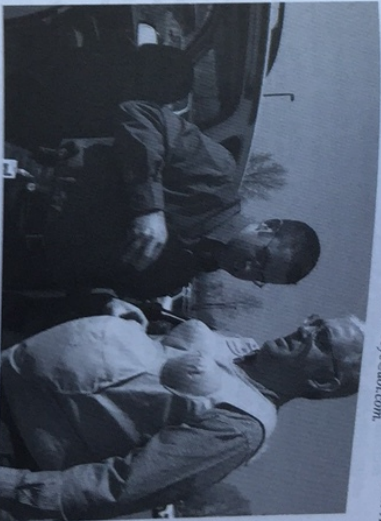
The Monterey will be available with a game lift gate, too. Dilis said management was planning to drop the option until the mothers on the Monterey team lobbied hard for its inclusion. They argued that a power lift gate is crucial for a mother loaded down with groceries and the who is trying to access the rear of the minivan. Dilis is a believer in the pregnancy suit, but she said the 40 working mothers on the Monterey

team—mainly engineers—probably did more to ensure that the minivan would be friendly to pregnant women.

"Wearing the suit is an enlightenment," the eight-months pregnant Dilis said, holding her

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6-year-old daughter, Madison. "The men noticed so many things a normal male engineer wouldn't notice. But to make it absolutely realistic, they need to sleep in it." You can reach Anita Lienert at anl@ednet.com.



Historically design engineers have used anthropometric data of the 50 percentile male to design the interior of an automobile. To satisfy the needs of the adult female market, however, male design engineers are now using an "Empathy Belly" to simulate the human factors associated with pregnancy. (By permission of The Detroit News.)

11.6 WORKSPACE CONSIDERATIONS

When we design larger machines and systems such as processing or manufacturing facilities, we should consider the effects of climate, illumination, noise, and motion on worker performance, safety, and job satisfaction.

Climate. The design of a workspace should take into consideration the physical exertion levels of its occupants in relation to acceptable temperature and humidity ranges. In addition, thought should be given to airborne particulate filtration, odor control, and ventilation of harmful vapors.

Illumination. Being able to see equipment displays and activate machine controls is directly linked to how well the workspace is illuminated. Important factors include the intensity of the light, the color content, glare, and reflection.

Noise. Excessive noise levels can lead to hearing loss as well as impact job performance. Important factors include sound level, frequency, duration, and the fluctuations in level or frequency.

Motion. The ability to operate machinery may depend on whether the operator is subjected to vibration or acceleration. Depending on the frequency

and intensity, workers subjected to whole-body vibration may feel discomfort. In addition, humans are affected by excessive accelerations with respect to head motion in the "footward," forward, backward, and lateral directions (Sanders and McCormick, 1993). Symptoms include discomfort, disorientation, and motion sickness.

11.7 SUMMARY

- Human factors affect the design and operation of tools, machines, systems, tasks, jobs, and environments.
- The human-machine system model provides a handy tool to consider interface interactions when designing a product.
- Visual and auditory displays require considerations of conspicuity, emphasis, legibility, intelligibility, visibility, maintainability, and standardization.
- Human output is limited with respect to force, torque, work, and power.
- Design for human-fit strategies include extreme fit, close fit, and adjustable fit.
- Human workspace design considers climate, illumination, noise and motion.

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KEY TERMS

Adjustability	Extreme case	Muscle strength
Anthropometrics	Human factors	Range of motion
Choice reaction time	Human-machine system	Sensory inputs
Close fit	Human senses	Simple reaction time
Energy expenditure	Kinesthetic sense	Vestibular sense
Ergonomics	Masking	

EXERCISES

Self-Test Write the letter of the choice that best answers the question.

1. B Touching a hot stove and jerking away is an example of:
a. choice reaction time b. simple reaction time c. real reaction time
d. stimulus reaction time
2. B A subfield of human factors that deals with the measurement of the human form such as height and reach is called: a. biomatrics
b. anthropometrics c. biomechanics d. animalronics
3. C We sense joint and muscle movement by our: a. tactile sense
b. sense of touch c. kinesthetic sense d. biorhythms
4. E Display and warning signals can be enhanced by: a. legibility
b. visibility c. conspicuity d. intelligibility e. all of these
5. D Examples of design for adjustability include all of the following except:
a. microphone stands b. driver car seats c. stereo head phones
d. computer printers
6. B A term used to describe the abilities, limitations, and other physiological or cognitive characteristics of humans that affect design and operation of tools, machines, systems, tasks, jobs, and environments is:
a. ergonomics b. human factors c. biofeedback d. both a and b
7. D All of the following parts are an example of a human-machine interface except: a. car steering wheel b. motorcycle handlebar
c. TV remote d. PC-cpu
8. D If your main screening criterion was to prevent accidental actuation, which of the following control devices would you not consider:
a. rollball b. thumbwheel c. slide d. crank
9. A If you were designing an elastic tool belt for both men and women, what waste circumference range would you consider: a. 60.7-102.9 cm
b. 69.9-102.9 cm c. 69.9-91 cm d. 60.7-91 cm
10. D All of the following are examples of a close fit strategy except:
a. shoes b. gloves c. roller skates d. wallet
11. D The workspace of our employees should be designed with considerations of: a. noise b. illumination c. climate d. all of these
12. B When a sound is concealed by noise is termed: a. muffled b. masked
c. covered d. obscured
13. B A synonym for human factors is: a. anthropometrics b. ergonomics
c. kineshetics d. psycho-physiologicals
14. D The rate of human energy expenditure depends on: a. worker position
b. rest periods c. environmental conditions d. all of these
15. D The rotation of a body part at a joint is called its: a. translation
b. work c. dynamics d. range of motion

CHAPTER 12

Introduction to Engineering Economics

LEARNING OBJECTIVES

When you have completed this chapter you will be able to

- Understand and apply simple- and compound-interest formulas
- Apply present-worth, future-worth, uniform-series, and gradient formulas
- Evaluate engineering alternatives using a variety of methods
- Describe and apply fundamental breakeven equations
- Determine the breakeven point

12.1 INTRODUCTION

Evaluating the economic merits of different alternatives may be as simple as comparing annual costs. For example, candidate A will cost \$45 per year versus candidate B at \$55 per year. Usually, however, alternatives include other aspects, such as a complex stream of cash flows over time. For example, assume that we wish to purchase one of two machine tools. Machine tool A will last three years and cost \$45,000 to replace. Machine B initially costs \$30,000, performs as well as the other machine, but needs to be replaced every two years. Given that the interest rate is 6 percent per year, how would we evaluate the economic merits of each machine?

This problem includes time as an important factor. Intuitively we know that a dollar today can be worth more than a dollar three years from now. We call that the **time value of money** because we can put the money to work and earn more money over the coming years. So, we might be inclined to choose Machine B, which has the lower initial cost, saving us the most initial cost. We also find that the machines have different lives. Is there a way that we can evaluate these alternatives on a common basis? The short answer is yes. We can and we will solve this problem later in the chapter.

First, however, we need to develop a few evaluation tools. In the next sections, we define the basic concepts of interest, principal, simple interest, compound interest, present value, future value, and uniform-series payments. Then, we will describe and apply five methods for evaluating engineering alternatives.

including present worth, future worth, equivalent uniform annual worth, rate of return, and discounted payback period. Finally, we will model the revenues and costs associated with producing a product to determine the breakeven point of production.

12.2 FUNDAMENTAL CONCEPTS

Interest is the amount we pay for the use of money. For example, if we borrow an amount called the **principal**, interest is the difference between the total amount owed and the principal as

$$\text{interest} = \text{total amount owed} - \text{principal} \quad (12.1)$$

The **interest rate** is a relative measure of the interest with respect to the principal as

$$\text{interest rate (\%)} = \frac{\text{interest (\$)}}{\text{principal (\$)}} \times 100 \quad (12.2)$$

The length of time between interest payments is called the interest period. We often find that the interest period is on a yearly basis, such as 8 percent per year. For car loans and home mortgage loans, we usually find interest periods to be monthly or even daily, such as 0.5 percent per month.

Simple Interest. Simple interest is the fee on the original principal. Interest is not accrued on interest. We calculate simple interest I (dollars), on the principal P (dollars), at an interest rate i (percent per period), for n periods as

$$I = Pni \quad (12.3)$$

Example

Assume that our company borrowed \$50,000 for one year. At the end of the year, the company paid back a total of \$51,500 in interest and principal. Determine the interest charged and the interest rate.

Using equation (12.1), we obtain

$$\text{interest} = \text{total amount} - \text{principal}$$

$$\text{interest} = \$51,000 - 50,000 = \$1,500$$

$$\text{interest rate (\%)} = \frac{\text{interest}}{\text{principal}} \times 100 = \frac{1,500}{50,000} (100) = 3.0\%$$

Example

ARW, Inc. borrows \$1,500,000 for a period of two years at a simple interest rate of 5 percent per year. Determine the interest and the total amount to be paid.

$$I = Pni = (\$1,500,000) (2 \text{ year}) (5\% / \text{year}) / 100$$

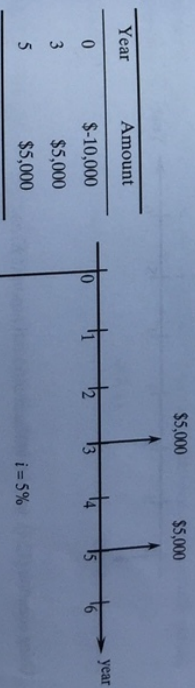
$$I = 1,500,000 (2) (5/100) = \$150,000$$

$$\text{Total amount} = \text{principal} + \text{interest} = \$1,500,000 + \$150,000 = \$1,650,000.$$

We illustrate a stream of cash receipts and disbursements using a cash flow diagram. We use upward-pointing arrows to represent cash inflows or receipts and downward-pointing arrows for cash outflows, or disbursements. The length of each arrow is roughly proportional to the amount. Along the abscissa, we show the number of interest periods and the interest rate per period. The diagram is a simplified but, complete, snapshot of cash flows, time periods, and interest rate. Cash flow diagrams are particularly useful in complex problems.

Example

Illustrate the cash flows shown in the table at the left using a cash flow diagram. The interest rate is 5 percent per year.



Compound Interest. Compound interest occurs when interest is accrued on the principal and the interest from prior periods. In other words, interest is allowed to accumulate from one interest period to another.

Let's define the total amount received F_1 in the first interest period as

$$F_1 = P + I_1$$

and the total amount due in the second interest period as

$$F_2 = F_1 + I_2$$

Since $I_1 = iP$ and $I_2 = i(F_1)$

We obtain $F_2 = P + iP + i(P + iP) = P(1 + i)(1 + i) = P(1 + i)^2$

In general, for n interest periods, the compounded amount is

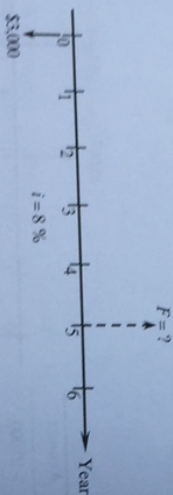
$$F = P(1 + i)^n \quad (12.4)$$

This is the *law of compound interest*. The total amount F is the future value, that increases exponentially with the number of interest periods.

Example

What is the total amount due at the end of the fifth year of a \$3,000 deposit given that it earns 8 percent per year compounded annually? Find the compounded interest.

We summarize the problem details in a cash flow diagram shown below. Note that the known deposit payment of \$3,000 is drawn as a solid-line arrow. The unknown future value F is shown as a dashed-line arrow.



Using equation (12.4), we obtain the compound amount F , as

$$F = P(1 + i)^n = \$3,000(1 + .08)^5 = \$3,000(1.469328) = \$4,407.98$$

To find the amount of compounded interest, we subtract the principal from F to obtain

$$\text{Interest} = F - \text{principal} = \$4,407.98 - \$3,000 = \$1,407.98$$

12.3 TIME VALUE OF MONEY FACTORS

In this section we define a number of useful equations and factors that will help us solve typical problems in engineering economics.

12.3.1 Single-Payment Compound-Amount Factor

Dividing both sides of equation (12.4) by P , we obtain the single-payment compound-amount factor F/P , shown in equation (12.5).

$$F/P = (1 + i)^n \quad (12.5)$$

The F/P factor has been computed for different values of interest rate and number of periods in Appendix B.

We use the expression, $(F/P, i\%, n)$, to denote the type of factor, interest rate and number of periods. For example, we write $(F/P, 5\%, 10)$ as a substitute for the F/P factor having a 5% interest rate and 10 periods.

Example

Solve the previous example by using the $(F/P, i\%, n)$ factor from the appendix.

$$F = P(F/P)$$

$$F = P(F/P, 8\%, 5)$$

Using the appendix we find the factor $(F/P, 8\%, 5)$ as 1.4693, and therefore

$$F = \$3,000(1.4693) = \$4,407.90$$

The eight-cent difference is due to rounding. Quite frequently, engineering economics calculations are carried out to 4 significant figures. In that case, both answers are the same (e.g., \$4,408).

12.3.2 Single-Payment Present-Worth Factor

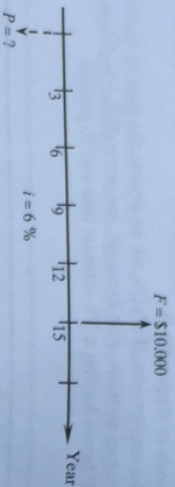
The **present worth** of an amount received in the future is the reciprocal of the single-payment compound-amount factor and is designated as P/F , and similarly as $(P/F, i\%, n)$. It is called the single-payment present-worth factor, and is shown in equation (12.6). Values for the factor have been tabulated in Appendix B.

$$P/F = (F/P)^{-1} = (1 + i)^{-n} \quad (12.6)$$

Example

Determine the present worth of a machine that will be sold 15 years from now for \$10,000. Assume the interest rate is 6 percent per year. First, solve the problem using the formula. Then check it by using the table value.

We summarize the problem details in a cash flow diagram. Note that the known receipt of \$10,000 is drawn as a solid-line arrow. The unknown present value P is shown as a dashed-line arrow.



Using equation (12.6) we obtain

$$P = F(P/F) = \$10,000(1 + 0.06)^{-15}$$

$$P = \$10,000(0.41727) = \$4,173$$

Or, using the appendix, we find the factor $(P/F, 6\%, 15)$ is 0.4173, and by substituting

$$P = \$10,000(0.4173) = \$4,173$$

Note how the appendix value simplifies the arithmetic.

12.3.3 Uniform-Series Present-Worth Factor

The present worth P of a uniform series of amounts A is illustrated on the cash flow diagram shown in Figure 12.1. The present value is calculated using equation (12.7), the uniform-series present-worth factor P/A (Blank and Tarquin, 1998). Values for the uniform-series present-worth factor $(P/A, i\%, n)$ have been tabulated in Appendix B.

$$P/A = \frac{(1+i)^n - 1}{i(1+i)^n} \quad (12.7)$$

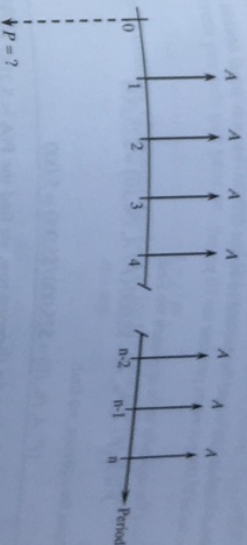
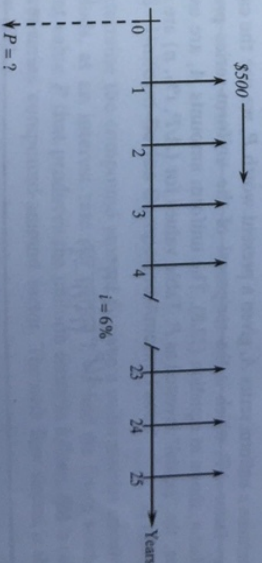


FIGURE 12.1 Uniform series present worth.

Example

Determine the present value of a machine tool that saves \$500 a year for 25 years, assuming that the interest rate is 6 percent per year over the life of the tool.

We summarize the problem details in a cash flow diagram. Note that the known savings of \$500 / year are drawn as solid-line arrows. The unknown present value P is shown as a dashed-line arrow.



$$P = A(P/A) = A \left[\frac{(1+i)^n - 1}{i(1+i)^n} \right] = \$500 \left[\frac{(1+0.06)^{25} - 1}{0.06(1+0.06)^{25}} \right] = \$500(12.7834) = \$6,391.70$$

or, we can use the tables to conveniently obtain:

$$P = A(P/A, 6\%, 25) = \$500(12.7834) = \$6,391.70$$

Example

What interest rate would be needed to invest \$25,000 in year 0, to obtain a uniform series of \$5,000 payments per year for 10 years?

Using the appendix table approach we find:

$$P = A(P/A, i\%, n) = \$5,000(P/A, i\%, 10) = \$25,000$$

Rearranging the equation, we find:

$$(P/A, i\%, 10) = \$25,000 / \$5,000 = 5.000$$

Looking in Appendix B along the 10-period row, we find the $P/A = 5.2161$ for 14 percent and 4.8332 for 16 percent. Interpolating, we can estimate the interest rate as:

$$\frac{5.2161 - 5.000}{5.2161 - 4.8332} = \frac{14 - i}{16 - 14}$$

$$i = 15.13\%$$

Using equation (12.7) and GOALSEEK in an Excel spreadsheet we find a more accurate rate value of 15.10 %.

12.3.4 Capital-Recovery Factor

To determine a uniform series A , given a present worth P , we use the capital-recovery factor A/P , which is the reciprocal of the uniform-series present-worth factor, shown as equation (12.8). The uniform amounts A , are used to "recover" the "capital" invested as P . Table values for $(A/P, i\%, n)$ are given in Appendix B.

$$A/P = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (12.8)$$

Example

What uniform series amount per year needs to be saved by investing in a new machine that costs \$6,391.70 and will last for 25 years? Assume that the interest rate is 6 percent. Use the appendix table values for the capital-recovery factor.

$$A = P(A/P) = P(A/P, 6\%, 25) = \$6391.70(0.0782) = \$499.83$$

The amount is almost the same as used in the prior example, except for rounding. Also note the simplicity of using the table value.

Nominal and Effective Rate of Interest. The **nominal interest rate** r , is the interest rate *per year*, typically quoted in interest-related loan agreements. The **effective interest rate** i , is the interest rate *per interest period*. The effective interest rate i is equal to the ratio of the nominal rate r , divided by the number of interest periods per year m .

$$i = r/m$$

The total number of interest periods n , for the total number of years y , is

$$n = my$$

(12.10)

Example

DCE Banks of America, Inc. has offered to finance the construction of our new \$550,000 warehouse. The loan will have a term of 15 years with a nominal interest rate of 6 percent compounded monthly. Determine the effective interest rate, number of interest periods, and monthly loan payment.

Since the interest is compounded monthly $m = 12$ periods per year, the effective rate is $i = 8\% / 12 = 0.5\%$ per month and $n = 12(15) = 180$ periods

$$A = P(A/P) = P(A/P, 0.5\%, 180) = P \frac{i(1+i)^n}{(1+i)^n - 1} = \$550,000 \frac{0.005(1+0.005)^{180}}{(1+0.005)^{180} - 1}$$

$$A = \$550,000 \frac{0.005(1+0.005)^{180}}{(1+0.005)^{180} - 1} = \$550,000(0.008438531) = \$4641.19/\text{month}$$

12.3.5 Uniform-Series Compound-Amount Factor

To determine the compound amount F , given a uniform-series amount A , for n periods, at an interest rate per period i , we find the future worth of the present value P that produces the uniform series as follows. F/A is called the uniform-series compound-amount factor. The cash flow stream is shown in Figure 12.2.

$$F/A = (F/P)(P/A) = (1+i)^n \frac{(1+i)^n - 1}{i(1+i)^n} \quad (12.11)$$

$$F/A = \frac{(1+i)^n - 1}{i} \quad (12.12)$$

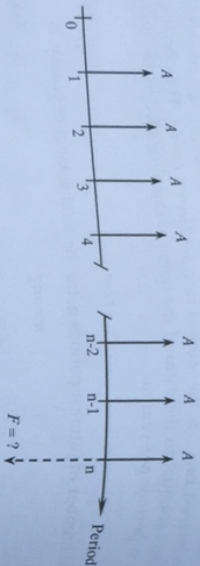


FIGURE 12.2 Uniform-series compound-amount cash flow diagram.

12.3.6 Uniform-Series Sinking-Fund Factor

The reciprocal of the equation produces the uniform-series sinking-fund factor A/F shown in equation (12.13). Table values for the uniform-series compound amount and the uniform-series sinking-fund factors are given in Appendix B.

$$A/F = \frac{i}{(1+i)^n - 1} \quad (12.13)$$

Example

ARW, Inc. would like to set aside a uniform series of cash payments in a sinking-fund account to replace a machine tool 15 years from now. The future cost of the machine is estimated to be \$45,000. Assume that the interest rate per period is 8 percent. Use Appendix B to estimate the annual deposits required.

$$A = F(A/F) = F(A/F, 8\%, 15) = \$45,000(0.0368) = \$1,656/\text{year}$$

12.3.7 Gradient-Series Factors

In some cases we find cash flows that increase or decrease in a regular fashion, as shown in Figure 12.3. Note that after year one, the annual amounts increase in a linear fashion. The present worth P , future worth F , and uniform series A factors for gradient-series cash flows are given in equations (12.14–12.16) (Thuesen and Fabrycky, 1993).

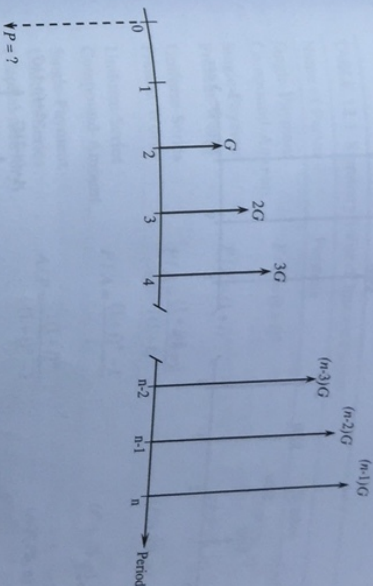


FIGURE 12.3 Gradient series cash flow diagram.

$$P/G = \frac{(1+i)^n - 1}{i^2(1+i)^n} - \frac{n}{i(1+i)^n} \quad (12.14)$$

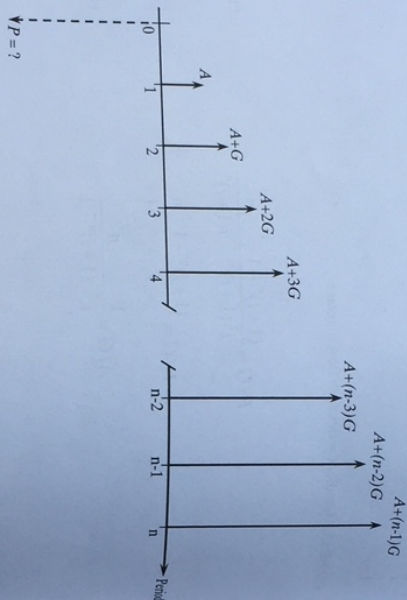
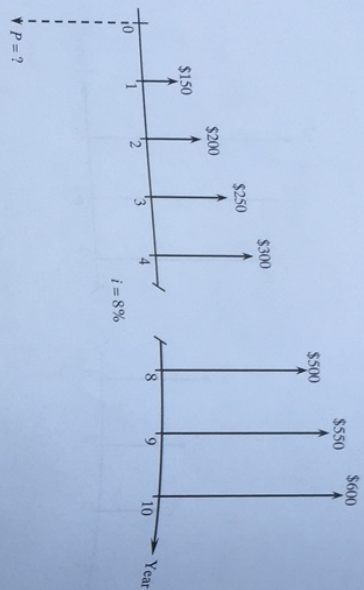
$$F/G = \frac{(1+i)^n - 1}{i^2} - \frac{n}{i} \quad (12.15)$$

$$A/G = \frac{1}{i} - \frac{n}{(1+i)^n - 1} \quad (12.16)$$

Example

A new piece of equipment will require \$150 worth of maintenance at the end of the first year. The costs will increase \$50 per year for the second year and so on through year 10, at which time the equipment will be retired. Sketch a cash flow diagram and use the table values to determine the amount of money the company should put away now to cover these expenses. Assume the interest rate per period is 8 percent.

Examining the cash flows carefully, we note that the gradient series has a uniform series superposed on top of the gradient series as shown below.



To find the present value for the combined cash flows, we need to superpose a P/A component to the G/A component.

$$P = A(P/A) + G(P/G)$$

$$P = A(P/A, 8\%, 10) + G(P/G, 8\%, 10)$$

$$P = \$150(6.7107) + \$50(25.977)$$

$$P = \$2,305.46$$

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Interest factor formulas are summarized in Table 12.1. Values for various interest rates and periods are given in Appendix B.

TABLE 12.1 Summary Table of Interest Factors

Name of Factor	Formula	Symbol
Single-Payment	$F/P = (1+i)^n$	$(F/P, i\%, n)$
Compound-Amount	$P/F = (1+i)^{-n}$	$(P/F, i\%, n)$
Single-Payment Present-Worth	$P/A = \frac{(1+i)^n - 1}{i(1+i)^n}$	$(P/A, i\%, n)$
Uniform-Series Present-Worth	$F/A = \frac{(1+i)^n - 1}{i}$	$(F/A, i\%, n)$
Compound-Amount Single-Payment	$A/P = \frac{i(1+i)^n}{(1+i)^n - 1}$	$(A/P, i\%, n)$
Uniform-Series (Capital-recovery)	$A/F = \frac{i}{(1+i)^n - 1}$	$(A/F, i\%, n)$
Compound-Amount Uniform-Series (Sinking-fund)	$P/G = \frac{(1+i)^n - 1}{i^2(1+i)^n} \cdot \frac{n}{i(1+i)^n}$	$(P/G, i\%, n)$
Uniform-Gradient Present-Worth	$F/G = \frac{(1+i)^n - 1}{i^2} \cdot \frac{n}{i}$	$(F/G, i\%, n)$
Uniform-Gradient Future-Worth	$A/G = \frac{1}{i} \cdot \frac{n}{(1+i)^n - 1}$	$(A/G, i\%, n)$

12.4 EVALUATING ECONOMIC ALTERNATIVES

The previous sections provide us with the tools to evaluate economic alternatives having different cash flows over time. We will use one of five methods to determine whether alternatives have equivalent economic value: present-worth, future-worth, equivalent-uniform annual-worth, rate-of-return, and payback period.

12.4.1 Present-Worth Method

The present worth PW of each alternative is calculated. The alternative with the most positive PW is the best alternative. Assuming that we have a stream of cash flows CF_j at the end of year j for n years, at interest rate i , we obtain

$$PW = CF_0 + CF_1(P/F, i\%, 1) + CF_2(P/F, i\%, 2) + \dots + CF_n(P/F, i\%, n) \quad (12.17)$$

$$PW = \sum_j CF_j(P/F, i\%, j) \quad (12.18)$$

Many companies will make an initial investment outlay in year 0, expecting to receive inflows over time. In such cases the present worth is usually called the **net present worth** or **net present value**. Also note that this method assumes equal length lives for each alternative. For unequal length lives, the least common multiple is calculated.

Example

Our company has received a vendor quote stipulating that it will supply 5,000 parts per year for the next three years at \$25,000 per year. Our manufacturing engineering department, however, estimates that if the company invests in a new machine tool for \$10,000, we can produce the same 5,000 parts per year for an annual cost of \$18,000 per year. Assume that the interest rate is 8 percent per year. Which alternative is more economical, make or buy?

The present worth of the "buy" alternative is

$$PW_{\text{buy}} = \$-25,000(P/F, 8\%, 1) - \$25,000(P/F, 8\%, 2) - 25,000(P/F, 8\%, 3)$$

$$PW_{\text{buy}} = \$-25,000(0.9259) - 25,000(0.8573) - 25,000(0.7938) = \$-64,425$$

The present worth of the "make" alternative is

$$PW_{\text{make}} = \$-10,000 - \$18,000(P/F, 8\%, 3)$$

$$PW_{\text{make}} = \$-10,000 - \$18,000(2.5771) = \$-56,388$$

The "make" alternative would be the best choice based upon estimated present worth.

Example

Machine tool A will last three years and cost \$45,000 to replace. Machine B costs \$30,000, performs as well as the other machine, but needs to be replaced every two years. Which machine is better assuming the interest rate is 6 percent per year?

This problem is a case of unequal lives. The PW method assumes that each alternative will last the same number of years. For cases such as these, we find the least common multiple of years that would produce equivalent life spans. Often, this will be the product of the two lives. For this problem the **least common multiple** is 2(3) or 6 years. The equivalence of the common multiple is shown in Figure 12.4.

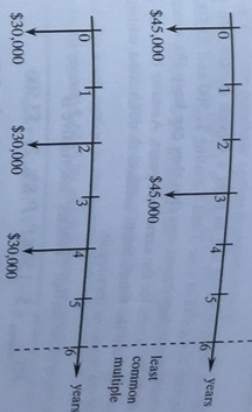


FIGURE 12.4 Least common multiple is used for alternatives with unequal lives.

Machine A

$$PW_A = \$-45,000 + \$-45,000(P/F, 6\%, 3)$$

$$PW_A = \$-45,000 + \$-45,000(0.8396) = \$-82,782$$

Machine B

$$PW_B = \$-30,000 + \$-30,000(P/F, 6\%, 2) + \$-30,000(P/F, 6\%, 4)$$

$$PW_B = \$-30,000 + \$-30,000(0.8900) + \$-30,000(0.7921) = \$-80,463$$

Since the present worth of machine B is less than the present worth of machine A, machine B is the more economical choice.

12.4.2 Future-Worth Method

The **future worth (FW)** of each alternative is calculated. The alternative with the most positive FW is the best alternative. Assuming that we have a stream of cash flows CF_j at the end of year j for n years, assuming interest rate i , we find

$$FW = CF_0(F/P, i\%, n) + CF_1(F/P, i\%, n-1) + \dots + CF_n \quad (12.19)$$

$$FW = \sum_j CF_j(F/P, i\%, n-j) = PW(F/P, i\%, n) \quad (12.20)$$

We can also compute the FW by compounding the PW forward in time as

$$FW = PW(F/P, i\%, n) \quad (12.21)$$

This method assumes equal length lives for each alternative. For unequal length lives, the least common multiple is calculated.

Example

An equipment supplier would like to offer a service contract to perform overhauls on our machine at the end of year 2 and 4 costing \$1,500 and \$3,500, respectively. However, our maintenance department says that they can keep the machine in perfect working order for \$1,500 a year for the same four years. Assume that the interest rate is 8 percent per year and use the future-worth method to determine which alternative is more economical: we repair, or they repair.

The future worth of the service "contract" alternative is

$$\begin{aligned} FW_{\text{contract}} &= \$-1,500(F/P, 8\%, 2) - \$3,500 \\ &= \$-1,500(1.1664) - \$3,500 = \$-5,250 \end{aligned}$$

The future worth of the "we" repair and maintain alternative is

$$\begin{aligned} FW_{\text{we}} &= \$-1,500(F/A, 8\%, 4) \\ &= \$-1,500(4.5061) = \$-6,759 \end{aligned}$$

The service contract alternative is the most economical.

12.4.3 Equivalent-Uniform Annual-Worth Method

The **equivalent-uniform annual worth** $EUAW$, of each alternative is calculated. The alternative with the most positive $EUAW$ is the best alternative. Assuming that we have cash flows CF_j at the end of year j for n years, and interest rate i , we find the $EUAW$ as

$$EUAW = PW(A/P, i\%, n) = \sum_j CF_j (P/F, i\%, j)(A/P, i\%, n) \quad (12.22)$$

If there is a salvage value SV the end of the n th year, it is converted to a uniform series and subtracted as follows

$$EUAW = PW(A/P, i\%, n) - SV(A/F, i\%, n) \quad (12.23)$$

A major advantage of the $EUAW$ method is that alternatives that have different lives do not have to be compared using the least common multiple of the lives.

Example

A new machine initially costs \$40,000 and \$10,000 per year to operate. The machine has a 10-year life and \$1,000 salvage value. Assume that the interest rate is 10 percent per year. As an alternative, the company can lease the machine for \$7,500 per

year for 10 years. Use the $EUAW$ method to determine which alternative is most economical.

The $EUAW$ of the purchase option is obtained from

$$\begin{aligned} EUAW &= PW(A/P, 10\%, 10) - SV(A/F, 10\%, 10) \\ &= \$-40,000(0.1627) - (\$-1,000)(0.0627) \\ &= \$-6,508.00 - \$62.70 = \$-6445.30 \end{aligned}$$

The $EUAW$ of the lease option is the annual lease payment of \$7,500. The purchase option results in an annual \$6445.30, which is more economical.

12.4.4 Rate-of-Return Method

The **rate of return** (ROR) of each alternative is calculated. The alternative with the greatest rate of return is the best alternative. Assuming that we have a stream of cash flows CF_j at the end of year j for n years, we find the ROR as that specific interest rate i^* such that the present worth of the cash flows is zero.

$$PW = CF_0 + CF_1(P/F, i^*, 1) + \dots + CF_n(P/F, i^*, n) = 0 \quad (12.24)$$

Example

The redesign of an existing product will require a \$50,000 investment but will return \$16,719 each year for years 1 through 5. The company has a minimum attractive rate of return of 25 percent. Use the ROR method to determine whether to complete the redesign.

To determine the ROR we need to find the i^* such that the $PW = 0$.

$$\begin{aligned} PW &= \$-50,000 + \$16,719(P/A, i^*, 5) = 0 \\ (P/A, i^*, 5) &= \$50,000/\$16,719 = 2.991 \end{aligned}$$

Using the tables we find the ROR = $i^* = 20\%$ for $P/A = 2.991$. Since the ROR is less than the minimum required, it is not economical to complete the redesign. Note that if the P/A factor had been a value between two tables, we would have interpolated.

12.4.5 Payback Period

The payback period is the amount of time that it takes for the cash flows to recover the initial investment. The **simple payback period** is equal to the investment divided by the annual savings as shown in equation (12.25).

$$SPP = \frac{\text{investment}}{\text{annual savings}} \quad (12.25)$$

While the SPP is a convenient method, it ignores the time value of money. The more preferred measure is the **discounted payback period** (DPP), which is the number of years for the discounted cash flow to equal zero. It is the same as the number of years for the net present value to break even.

$$0 = -P_0 + \sum_{t=1}^n CF_t(P/F, i\%, t) \quad (12.26)$$

Example

Calculate the simple payback period for a new machine tool that costs \$245,000 and will save the company \$95,000 per year.

$$SPP = \frac{\text{investment}}{\text{annual savings}} = \frac{\$245,000}{\$95,000/\text{year}} = 2.58 \text{ years}$$

Example

Use a spreadsheet to determine the discounted payback period DPP, for a new product that will result in the following disbursements and receipts shown in the first two columns of the table below.

Year	Cash Flow (\$)	CF_t (\$)	$(P/F, 8\%, n)$	$CF_t(P/F, 8\%, n)$ (\$)	Sum (\$)
0	-750,000	-750,000	1.00000	-750,000	-750,000
1	125,000	125,000	0.92593	115,741	-634,259
2	190,000	190,000	0.85734	162,894	-471,365
3	350,000	350,000	0.79383	277,841	-193,524
4	565,000	565,000	0.73503	415,292	221,768
5	345,000	345,000	0.68058	234,801	456,569
6	255,000	255,000	0.63017	160,693	617,263
7	125,000	125,000	0.58349	72,936	690,199
8	100,000	100,000	0.54027	54,027	744,226

We find that the cumulative discounted cash flows zero out between the end of the third year and the end of the fourth year. Interpolating we find the DPP = 3.46 years.

12.5 BREAK-EVEN ECONOMICS

We can develop a simplified mathematical model to show the relationships between the costs and revenues of manufacturing and selling a product. If we designate the revenue per unit as r , and the quantity of product produced and sold as q , then the total revenues R is obtained from

$$R = rq \quad (12.27)$$

The costs of manufacturing can be broken down into **variable costs** VC and **fixed costs** FC . Variable costs refer to items that depend upon the amount of product manufactured, such as raw materials and production labor. Fixed costs refer to cost elements that do not vary with production, such as administrative labor, advertising, legal, and building depreciation. If we designate v as the variable costs per unit of production, and q as the number of units produced, we can obtain the total cost of production TC as

$$TC = FC + VC \quad (12.28)$$

$$TC = FC + vq \quad (12.29)$$

Profit is the difference between total revenues and total costs. When total costs exceed revenues, a **loss** occurs. Profit/loss can be obtained from

$$\text{profit} = TR - TC = (rq) - (FC + vq) \quad (12.30)$$

The **break-even point** q^* is that specific volume of production such that the profit is zero; that is, the revenues equal the total costs.

$$\text{break-even profit} = rq - FC - vq = 0 \quad (12.31)$$

$$q^* = \frac{FC}{r - v} \quad (12.32)$$

Total revenues and total costs are linearly related to production quantity as shown in Figure 12.5. Note that for production quantities less than q^* , the company suffers a loss, and that for $q > q^*$ the company earns a profit. The figure also illustrates the sensitivity of profits to fixed costs.

Example

The company receives \$5 per unit sold and the variable cost to make each unit are \$3.50 per unit. Determine the fixed costs such that the company will break even when making 20,000 units.

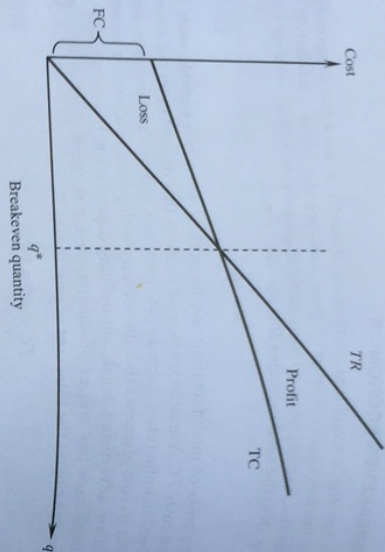


FIGURE 12.5 Break-even point analysis for linearly related variable costs and revenues.

Using equation (12.32) we obtain

$$q^* = \frac{FC}{r - v}$$

$$20,000 = \frac{FC}{5 - 3.5}$$

$$FC = (\$1.5/\text{unit})(20,000 \text{ units}) = \$30,000$$

12.6 SUMMARY

- Engineering economic analyses need to consider the time value of money.
- Interest factor formulas and tables are useful in evaluating alternatives.
- A cash flow diagram can be used to summarize cash flow data.
- The PW and FW methods can be used to evaluate alternatives having different lives by using the least common multiple of years.
- The EUAW method is preferred because it has the advantage of not requiring the use of the least common multiple.
- The ROR, SPP and DPP methods are also useful.
- The breakeven point is that level of production that results in a zero profit.

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- Thuesen, G. J., and W. J. Fabrycky, 1993. *Engineering Economy*, 8th ed. Englewood Cliffs, NJ: Prentice Hall.

KEY TERMS

Break-even point	Interest	Principal
Compound interest	Interest rate	Profit
Discounted payback period	Least common multiple	Rate of return
Effective interest rate	Loss	Simple interest
Equivalent-uniform annual worth	Net present value	Simple payback period
Fixed costs	Nominal interest rate	Time value of money
Future worth	Present worth	Variable costs

EXERCISES

Self-Test. Write the letter of the choice that best answers the question.

1. C
The time between interest payments or receipts is the: a. loan period
b. contract term c. interest period d. collection period
2. B
The original amount borrowed or invested is the: a. loan value b. principal
c. payment schedule d. interest rate
3. B
When interest is earned at the end of each interest period and allowed to accumulate from one period to the next, it is called: a. nominal interest b. compound interest c. simple interest d. effective interest
4. A
The amount of time it takes for the cash flow to recover the initial investment is called: a. simple payback period b. recovery period c. investment period d. compound period
5. C
The amount paid for the use of money is called: a. investment b. cost factor c. interest d. revenue
6. D
The interest rate per interest period is called: a. nominal rate
b. the rate of return c. compound rate d. effective rate
7. A
All of the following methods can be used to determine whether alternatives have equivalent economic value except: a. Pugh's b. present worth c. rate of return d. payback period
8. B
The least common multiple does not have to be used when finding the: a. present worth b. equivalent uniform annual worth c. future worth d. none of these
9. D
Costs that depend upon the amount of product manufactured, such as raw materials and production labor, are called: a. production costs b. fixed costs c. future costs d. variable costs

10. A The specific quantity of production such that the revenues are just enough to cover the total costs is called: a. breakeven point b. crossover point c. payback point d. profit point
11. A The interest that is earned on principal and interest is called: a. simple interest b. compound interest c. usury interest d. effective interest
12. D Costs that do not depend upon the amount of product manufactured such as legal and depreciation, are called: a. production costs b. variable costs c. future costs d. fixed costs
13. A The interest rate per year is called: a. nominal rate b. the rate of return c. compound rate d. effective rate
14. C Number of years for the discounted cash flow to equal zero is the: a. break-even period b. simple payback period c. discounted payback period d. foreclosure
15. B The time value of money refers to: a. profit b. dollar is worth more today than tomorrow c. dollar is worth more tomorrow than today d. principal
16. Determine the interest due on a \$5,000 loan after three years. Assume that the loan accrues simple interest at 6 percent per year. Determine the total amount to be paid.
17. Uncle George received a \$1,500 interest payment after five years for a loan to his niece. Given that the interest rate was 10 percent per year, what was the principal?
18. After 10 years, what is the compound amount for a single payment amount of \$300 given that the amount earned 5 percent interest per year, compounded annually.
19. An IOU is purchased for \$895. It will pay \$1,000 three years from the date of purchase. Determine the interest rate per period.
20. Redesign of an existing product will produce an additional \$1,500,000 and \$2,500,000 at the end of the next two years. What is the present value of the cash flows given that the interest rate per period is 10 percent.
21. The company is considering purchasing a new CAD system for the engineering department that will cost \$150,000 to install. Given that the cost of money is 7 percent, what uniform-series amount will be required each year, for the next five years, to pay for the new system?
22. A new machine tool is expected to cost \$450,000 to acquire and install. The manufacturing engineering department estimates that the machine will save \$65,000 each year for the next 10 years. Determine the interest rate per period. Is the machine a good investment if the company's borrowing rate is 15 percent?
23. ARW, Inc. would like to buy a new materials-handling system for its factory. Overhauls, costing \$50,000 and \$75,000, will be required at the end of the fifth and tenth year of operation, respectively. The new system will save \$5,000 per year for its 15-year life. What is the present value of the cash flows, given that the interest rate per period is 6 percent?
24. In 15 years a machine tool will need to be replaced at a future cost of \$95,000. What annual amount should the company deposit to a sinking fund that can earn 10 percent?
25. The company would like to finance the \$250,000 construction of a new assembly line. The bank is willing to provide a five-year loan at 6 percent per year, compounded monthly. What is the monthly payment amount?

26. An engineering student would like to buy a used car. He has \$2,000 available to use as a down payment and he will finance the balance over four years at 12 percent per year compounded monthly. Determine the most expensive car he can buy.
27. Use the present-worth method to determine whether receiving \$4,000 annually for ten years is equivalent to receiving \$5,000 annually for eight years, assuming the interest rate is 8 percent per year.
28. In nine years a machine tool will have a \$12,488 salvage value. If \$1,000 can be saved each year until then, what interest rate would it have to earn?
29. Use the present-worth method to determine which machine the company should choose, assuming the interest rate is 10 percent per year.

	Machine G	Machine H
Initial cost	\$35,000	\$30,000
Annual operating expenses	500	1,500
Salvage value	1000	0
Life	10	10

30. Use the future-worth method to determine which machine the company should choose, assuming the interest rate is 15 percent per year.

	Machine K	Machine L
Initial cost	\$55,000	\$45,000
Annual operating expenses	500	1,500
Salvage value	4,500	3,000
Life	15	15

31. Use the equivalent-uniform annual-worth method to determine the best machine in problem 30, assuming the interest rate is 12 percent per year.
32. Use the equivalent-uniform annual-worth method to determine which alternative is more economical, assuming the interest rate is 14 percent per year.

	I	J
Initial cost	\$8,500,000	\$50,000,000
Annual operating expenses	8,000	7,000
Salvage value	5,000	2,000
Life	5	500

33. Determine the rate of return on a machine that will cost \$575,000 to purchase and install and will produce \$45,000 of annual savings for the next 15 years.
34. Determine the rate of return for problem 28, but assume that the machine has a \$100,000 salvage value at the end of the fifteenth year.
35. Determine the rate of return for the purchase of a \$5,000 security that will return \$6,500 at the end of 8 years.

CHAPTER 13

Detail Design

LEARNING OBJECTIVES

When you have completed this chapter you will be able to

- Describe the essential inputs and outputs of the detail design process
- Describe detail design responsibilities
- Employ different drawing types
- Utilize various types of graphic illustrations
- Employ different kinds of written documentation
- List the topics in a design-project report
- Prepare a project progress report
- Prepare and give an effective oral presentation
- Explain electronic product documentation and management

13.1 INTRODUCTION

During the parametric design phase we will have determined most of the form of our product. We will have found optimal values for the design variables such as dimensions and tolerances, and selected materials and primary manufacturing processes. Also, we will have prepared a collection of analyses predicting the expected performance of the product and have an estimate of the customer's satisfaction. In some cases, we will also have prototype test results supporting our "final" design. These are essential inputs to the detail design phase as shown in Figure 13.1.

During detail design we use these data to make the remaining decisions on specific details that can no longer be deferred. For example, we might find that during parametric design of a transmission a shaft diameter between 0.5 and 0.65 inch would be "optimal." Knowing that stock shaft materials are available in 1/2-inch and 5/8-inch sizes, we need to determine which to specify for manufacture and assembly. Assuming that our development team is concurrently engineering, it has a purchasing representative that would investigate the cost and availability of both sizes. The team would make its final decision using that information. Using the final shaft size, the engineering design team

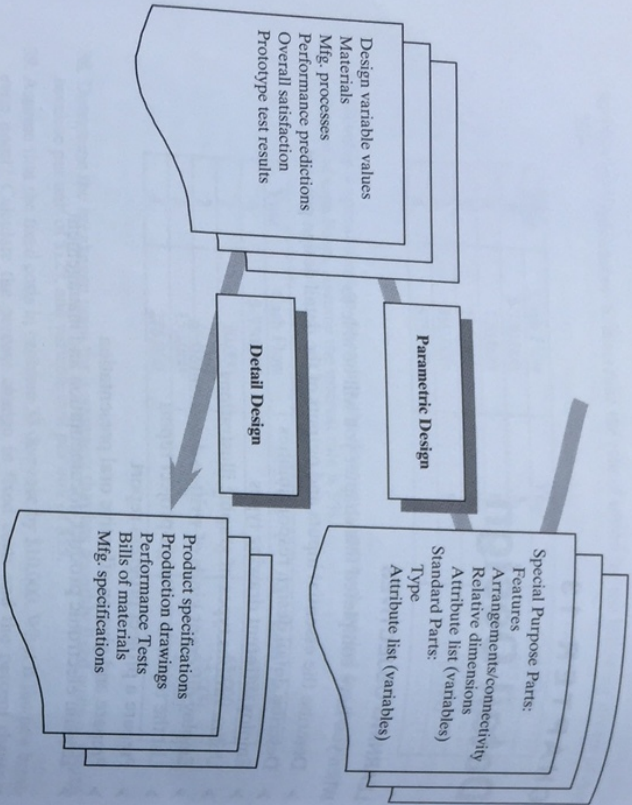


FIGURE 13.1 Detail-design phase includes the generation of product specifications, production drawings, performance-test summaries, bills of materials, and manufacturing process specifications.

member would reanalyze the expected performance. A subsequent beta prototype might also be built and tested, if needed.

13.1.1 Product Realization

When we consider the overall product realization process we recognize that a number of related activities are needed before a product is finally manufactured, including: production design, manufacturing, distribution, sales, service, and disposal. Departments responsible for these activities will also be making decisions as they prepare for full production. Assuming that we have been communicating with these “downstream” departments, we should not expect any surprises that would affect the product design or manufacture.

At the completion of the detail-design phase most, if not all, of the design decisions have been made, thereby “freezing” the design of the product.

The resulting detail-design documents provide the required information necessary to manufacture the product (Hales, 1993). These include production drawings (e.g., layout, detail, and assembly), bill(s) of materials, owner's manual(s), and product performance specification sheet(s).

13.1.2 Design Is Iterative and Nonlinear

The design phases have been presented as a linear sequence of decision-making activities. This was done to keep the explanations simple and concise. Engineering practice, on the other hand, is rarely linear. Owing to differences in product, industry, or management style, some design activities will be completed “out of sequence.”

A large equipment manufacturer, for example, may freeze the design of a large casting because of long-lead-time requirements, even though other sub-assembly designs are not finished. Or, we may select another manufacturing process because beta testing shows that the intended process is not capable of maintaining satisfactory tolerances.

Companies often specialize their product development processes to take advantage of unique circumstances and consequently involve nonlinear by-passes or iterations of redesign, and possibly respecification. In general, however, product development activities usually involve aspects of formulation, concept design, configuration design, parametric design, and detail design.

In the next sections, we will examine the types of decisions that remain to be made during the detail-design phase and how they are appropriately documented so that the entire manufacturing organization will know who will be doing what, when and why.

13.2 MAKING DETAIL-DESIGN DECISIONS

We might ask “When is the detail design finally completed?” Is the design frozen when the fabrication and assembly lines are up and running, and finished goods are being shipped to our warehouses? Before that? After that? Another question that we might also ask is “Who is responsible for making these final decisions?” Is it design engineering, or manufacturing engineering, or production?

Let's examine some of the “details” needed by various departments to gain a better understanding of what the words “detail design” mean. Table 13.1 is an example of a concurrent engineering team with seven members representing the critical departments in its company.

For companies that concurrently engineer, the answer to these questions is that the “team” is responsible for the timing and quality of these decisions. Perhaps this answer is somewhat oversimplified. But, when the team manager is a high-level officer in the company, the team will have the authority and responsibility to make things happen.

Recall that the team is composed of representatives from all the critical functional departments of the organization. Therefore, we find that in practice,

the entire organization is involved in getting the product designed, manufactured, and delivered to the customer. The idea that "a detail-design package" is prepared and forwarded to some other department is somewhat meaningless.

TABLE 13.1 Example Concurrent Engineering, Team Membership and Typical Responsibilities Related to the Detail Design, Manufacture, and Distribution of a Finished Product.

Department Representative	Team Responsibilities
Sales/marketing	Product Warranty Shipping Warehousing Advertising campaign Product literature Owner's manual Product launch
Industrial Design	Product trim details Finish details Ergonomic refinements Product packaging
Design Engineering	Detail design performance analyses Preproduction prototype performance tests Manufacturing process specifications Owner manual(s) Layout drawing Detail drawings Assembly drawings Bills of materials Engineering change notices Patents, trademarks, copyrights
Industrial Engineering	Facility layout/remodeling Material handling equipment Inventory warehousing Product flow Assembly planning
Manufacturing Engineering	Fixture design / fabrication Tool design / fabrication Process equipment refurbishment/adaptation Process equipment acquisition / installation Process planning
Purchasing	Make or buy, Vendor qualification, selection, negotiation Out sourcing parts/subassemblies Materials planning Raw materials Quality control
Production	Tooling changeover Worker training Acceptance testing

For simple products, such as a single-part product, the detail-design package is sometimes frozen before the product is launched. The product works as it was tested, manufactured and delivered to the customer. For more complex products, such as a home vacuum cleaner, we might discover design or manufacturing defects during initial production runs. We would change the design or manufacturing specifications to fix the problem using an engineering-change notice (ECN) form to advise company personnel. Finally, for highly complex products, such as a gas turbine electric generation facility, some of the detail design is completed in the field, as the facility is constructed, shut-down, acceptance-tested, and commissioned.

Therefore, a collection of documents emerges from multiple departments throughout the company in the final weeks or months before launch. It is this final collection of documents that we might loosely call the "detail design." The design of a product does not freeze at once, but rather progressively, heterogeneously, in different departments throughout the organization. Since the design is not "thrown over the wall" a distinct transition of responsibility does not really occur. Ideally, the detail-design phase ends and the manufacturing phase begins in a seamless fashion.

In the next section we will examine how employees communicate with each other as the product design freezes.

13.3 COMMUNICATING DESIGN AND MANUFACTURING INFORMATION

As we have seen in the preceding chapters, a team will make many decisions about the product's form and how it will satisfy the customer's desired function(s). Also, we recognize that the whole organization is involved in those decisions. How, then, do we keep everyone "in the loop"?

The answer is quite simple, but rather difficult to accomplish in practice. We must communicate to all the stakeholders often, thoroughly, and clearly. Frequent communications by e-mail, letter, phone calls, and written reports are instrumental in informing stakeholders. Keeping everyone informed helps to maintain coordination among the various departments. By communicating thoroughly and clearly we save ourselves work in the long run, by not having to spend time answering a multitude of follow-up questions or correct a lot of misunderstandings.

We next examine three principal modes of communication: (1) graphic documents, (2) written documents, and (3) oral presentations.

13.3.1 Graphic Documents

Production drawings are used to communicate a product design in sufficient detail to enable its manufacture. Production drawings are also called working drawings and include: detail drawings and assembly drawings with bill of materials or parts list.

Detail Drawings Detail drawings are orthographic projection views (front, side, and/or top) of a part showing its geometric features drawn to scale along with full dimensions, tolerances, manufacturing-process notes, and title block (Bertoline et al., 1997). Detail drawings sometimes include section views and oblique-plane views. Sometimes a pictorial view (isometric or oblique) is shown. Detail drawings do not have a bill of materials. An example of a detail drawing is shown in Figure 13.2.

Assembly Drawings Assembly drawings show the components that make up a product or subassembly. They illustrate the location of each part in relation to the other parts and, in some cases, illustrate the operation of the product. The parts are shown to scale in orthographic and/or pictorial views. Balloon notes are used to identify each part and cross-reference it to the bill of materials also placed on the drawing. **Sectioned assembly drawings** cut away a portion of the assembly to expose or illustrate the details of an interior portion of the assembly. A completed title block is added along with manufacturing and assembly notes. No dimensions are shown on assembly drawings. The **bill of materials (BOM)** is a table of part information organized with column headings for: part number, part name, material, quantity used in assembly, and other special notes as required. In some companies, the bill of materials is placed on a separate drawing sheet with its own drawing number. An example assembly drawing is shown in Figure 13.3.

Illustrations Graphics are also used in business reports, owner's manuals, and oral reports to illustrate parts, assemblies, information flow, decision making, and numerical data. **Charts** are used to portray relationships among numerical data, for example, sales versus time. **Schematics** are diagrams of electrical, mechanical or other systems using abstract symbols, for example, a piping schematic or electronics schematic. **Figures** can be defined as illustrations that show textual material (e.g., see Figure 13.1). **Sketches** are hand-drawn rough "drawings" done without the use of drawing instruments. **Diagrams** are illustrations intended to explain how something works or to show the relationship between the parts. For example, we use free-body diagrams to analyze static equilibrium forces and moments. Figure 8.6, in particular, shows a complete free-body diagram of the pulley, free of its surroundings, with a set of axes, relevant geometry, orientation, forces, and moments, and motions.

13.3.2 Written Documents

Written documents can be as brief as a one-page letter or as long as a 500-page technical report. They can be written using the personal first-person "We" or "I," or the impersonal third person, such as "it has been determined ..." Let's examine the content and format of typical written documents including: letters, memoranda, test reports, project progress reports, research reports, and owner's manuals (Beer and McMurtry, 1997).

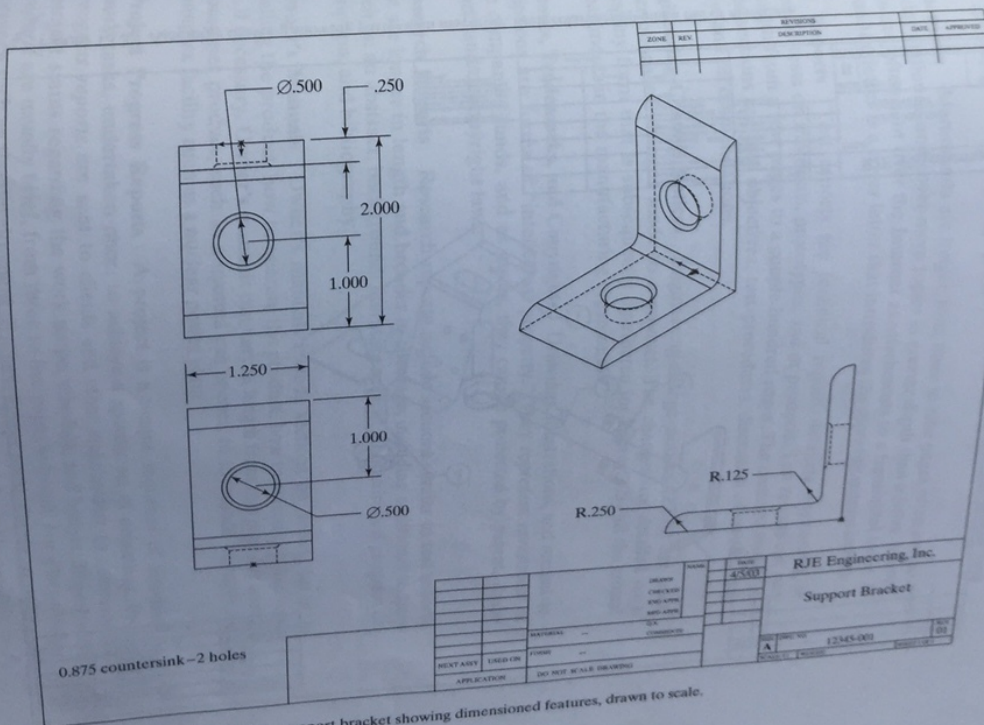


Figure 13.2 Detail drawing of a support bracket showing dimensioned features, drawn to scale.

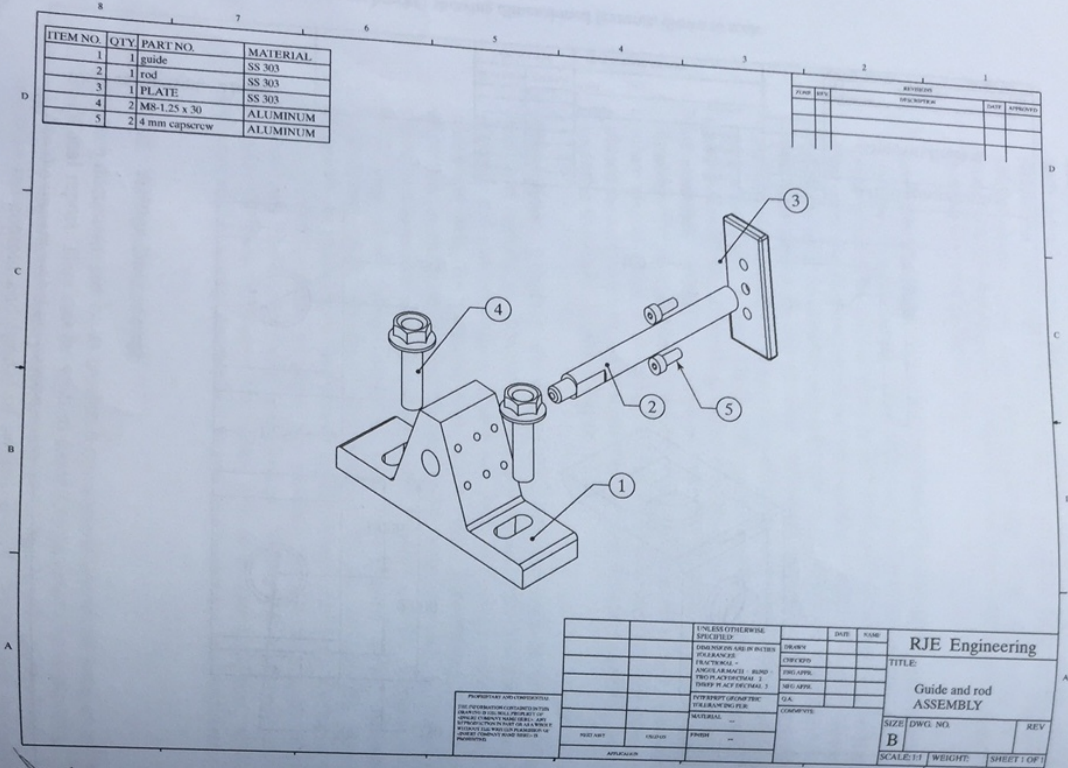


Figure 13.3 Assembly drawing showing parts of an assembly, their relationship and a bill of materials.

Letters Letters are brief communications, usually less than a page in length, sent to a few selected individuals on a specific topic with which the readers are somewhat familiar. E-mail "letters" are informal in format and usually very brief (perhaps one or two paragraphs).

Memoranda Memoranda are longer, from three to nine pages, often sent to a broader audience, and cover more topics in greater depth than a letter. Memoranda are often sent over the Internet as attachments to a transmittal letter. A transmittal letter is a cover letter that introduces the report or memorandum.

Test Reports Test reports are technical reports detailing engineering or scientific tests on materials, prototypes, and/or products. Test reports can vary in length from a few pages to a couple hundred pages. The contents usually include sections on: test objectives, test procedures, discussion of results, summary, and recommendations.

Engineering-Change Notices Engineering-change notices (ECN) are brief descriptions of changes made to a product. The changes are detailed on a company form that is subsequently distributed for approval by all the critical departments in the manufacturing organization.

Patents, Trademarks, and Copyrights Drawings, illustrations, and textual descriptions are forms of "intellectual property." They represent investment of the company's funds, and as assets, they can be protected by patent, trademark, and/or copyright laws.

Research Reports Research reports include sections similar to test reports, but are longer in length and broader in coverage, including additional sections such as: an abstract, background, literature review, laboratory/test program description, and bibliography.

Owner's Manuals Owner's manuals include sections on: setting up or installing the product, how to operate the product, how to maintain it and repair it, if necessary. Owner's manuals can vary in length from one page for a simple consumer product, such as a manual can opener, to thousands of pages for a complex facility such as a nuclear power plant.

Project Progress Reports A project is a unique sequence of activities or work tasks, undertaken once, to achieve a specific set of objectives. Project progress reports are sent to clients and other stakeholders to communicate project status regarding the work scope, schedule, and budget. Project status reports are usually brief, from three to five pages in length. For a large-budget project, such as the development of a new fighter plane, the status reports can be a couple hundred pages. Status reports are prepared weekly, monthly, quarterly, and annually depending upon the budget, schedule, and stakeholders' desires. An example project progress report template is shown in Figure 13.4.

To:	Mr. Adam Smith, Client contact title
cc:	All the other stakeholders
From:	Mr. John Doe, Project Manager
Re:	Design Project Progress Report #XXX-Y
Current Project Status for period __/__/__ through __/__/__	brief discussion of work completed since last report (scope)
Future Work	technical issues resolved, and those unresolved
Project Budget and Schedule	work to be performed until next report
Action Items	technical issues to be resolved
recommendations	reminders of deadlines, requested information
response(s) needed from client, customers, others,	changes in scope (i.e., Engineering Change Notices)
e.g., "Please review and approve within two weeks"	impacts on schedule, milestone dates, deliverables
	brief discussion of progress with respect to schedule
	cost variances, schedule variances, earned-value analysis

FIGURE 13.4 Project-progress-report template indicating updates on the project's scope of work, schedule, and budget.

Design Project Report A formal report is most often prepared at the conclusion of a design project. The report summarizes the work tasks undertaken and discusses the recommended design in detail. The report usually includes content on: the nature of the design problem, design formulation, concept design, configuration design, parametric design, prototype testing, and detail design description and performance. A sample design project report outline is shown in Figure 13.5.

13.3.3 Oral Presentations

When we have the opportunity to make an oral presentation before our management, customers, or colleagues, we should honor and respect their willing participation and, consequently, put forth our best efforts. In so doing, we will increase our chances of achieving our objectives and, in most cases, also make good first impressions. In this section we will examine three characteristics of presentations (Martin, 1993). Then we will consider how to prepare a presentation. Finally, we discuss some guidelines for giving a presentation.

1. Introduction	
1.1 Background	
1.2 Problem statement	
1.3 Mission statement	
2. Design Problem Formulation	
2.1 Initial site visit	
2.2 House of quality	
2.3 Design objectives	
2.4 Engineering design specifications	
2.5 Solution evaluation parameters	
2.6 Satisfaction curves	
3. Project Engineering	
3.1 Work breakdown structure	
3.2 Workscope	
3.3 Schedule	
3.4 Budget	
3.5 Earned-value analysis	
3.6 Work task responsibility table	
3.7 Project team organization chart	
4. Concept Design	
4.1 Generation of alternatives	
4.2 Analyses	
4.3 Evaluation and recommendations	
5. Configuration Design	
5.1 Generation of alternatives	
5.2 Analyses	
5.3 Design for assembly	
5.4 Design for manufacture	
5.5 Evaluation and recommendations	
6. Parametric Design	
6.1 Analytical/experimental methods used	
6.2 Calculations summary	
6.3 Product safety/failure modes and effects analysis	
6.4 Design refinement/optimization	
6.5 Results and recommendations	
7. Prototype Tests	
7.1 Prototype fabrication	
7.2 Test results	
8. Final Design	
8.1 Product specifications	
8.2 Product cost estimates	
8.3 Drawings (layout, detail, assembly)	
8.4 Bill of materials	
9. Recommendations and conclusions	
Appendices	

FIGURE 13.5 Example design-project report summarizing the major work tasks undertaken to develop a new product.

Presentation Characteristics We will likely make many oral presentations during our engineering careers, both formal and informal. As we prepare, we need to consider the time available, the topic to be presented and the temperament or mood.

Time. On one occasion, we may be given a few minutes to make an ad-hoc mini-presentation. On another occasion, we may have 30 minutes devoted to a single topic. And lastly, we may have hours available.

Topic. Given the wide scope of engineering responsibilities and activities in the product-realization process, we can expect presentations on various topics, including: sales, marketing, product development, industrial design, concept design, configuration design, parametric design, detail design, prototype testing, production planning, manufacturing engineering, purchasing, and service.

Temperament. An informal presentation can often be accomplished with a few well-constructed sentences. In other cases, an accompanying visual aid such as a drawing, diagram, chart, or schematic is used to refer to specific details. In contrast, we give comprehensive formal presentations to thoroughly address topics that are important to customers, upper management, and fellow employees. Therefore, formal presentations usually involve detailed information and require the utmost in preparation and execution.

Preparing a Presentation When we give a presentation, it is our responsibility to be understood. They may have heard what we said, but did they understand us? To make sure our message is correctly communicated we need to prepare and deliver a clear and engaging presentation.

The following steps are recommended for preparing an oral presentation. Excellent presentations are the result of thoughtful hard work. We begin with a plan to consider who, what and why. We then draft an outline for discussion and approval. We draft and rewrite notes covering key topics. We rehearse orally, recognizing that the spoken word takes longer to say than the written word does by reading. Then we revise and refine, until we are satisfied that what we need to communicate will be understood. These steps are further detailed in Table 13.2.

An excellent presentation requires excellent preparation.

TABLE 13.2 Recommended Steps for Preparing an Oral Presentation Chapter 13 Detail Design 321

Step 1. Plan	Consider who our audience will be, what we wish to communicate, why we are giving the presentation, and how long it should be.
Step 2. Outline	Prepare a draft outline of the topics. If we are giving a group presentation, we need to agree upon responsibilities. Estimate the time to be devoted to each topic. Break up longer topics into smaller chunks. Combine or eliminate incidental topics. Discuss the draft outline with your immediate supervisor. Confirm the draft outline with your co-workers.
Step 3. Compose	Use the outline to compose 3x5 (or 5x7) note cards. Write clear and concise statements for major ideas and facts. Number each card in succession. Compose clear overhead slides or PowerPoint slides, use font > 20 pt. Prepare videos using CAD animations or camcorder movies.
Step 4. Rehearse	Practice saying the note card phrases. Give the draft presentation to some friendly co-workers. Rehearse using the intended room and audiovisual aids. Videotape and critically evaluate our delivery and use of visual aids.
Step 5. Refine	Revise or rewrite the note cards. Eliminate confusing visual aids. Refine the visual aids. Revise presentation room layout or equipment.

Preparing a Formal Design-Project Presentation We will often have the opportunity to give a formal presentation at the conclusion of each design phase. These occur at various milestones in the product-development schedule. In some cases, we might give a presentation on the work that was completed during the whole project. An example outline is presented in Table 13.3.

Questions, Answers, and Follow-up At the conclusion of a presentation we have the opportunity to learn whether our listeners understood the presentation. Typically an engaged audience asks questions and makes comments. We can be ready by anticipating some likely questions and preparing a few concise answers. A slide that was eliminated from a lengthy draft presentation could be held in reserve, then shown. We can even ask the audience questions. For example, "Do you agree that our design is economical?" "Did we demonstrate that the fabrication and assembly concerns have been resolved?" "Can we have your approval to go ahead and schedule production as soon as possible?" Finally, if we don't have an answer for a listener, we should get one and personally contact the listener at a later date. Follow-up is a natural, usual, and necessary part of business presentations.

TABLE 13.3 Sample Outline for a Formal Presentation of a Design Project

1. Project title, participants
2. Design-problem background
3. Design objectives
4. Alternative designs
5. Analyses and evaluations
6. Design for assembly
7. Design for manufacture
8. Prototype-test results
9. Recommended design
10. Expected performance
11. Summary
12. Acknowledgments

Guidelines for Giving a Presentation The following guidelines are recommended for oral presentations:

1. Make the listeners physically comfortable. Provide adequate seating and lighting. Ensure that the room temperature, noise level, and ventilation are agreeable.
2. Expect that we will be somewhat nervous. Accept it. Convert nervousness to enthusiasm.
3. Take a deep breath and relax for a moment before beginning.
4. Start on time, stick to the presentation schedule, and finish on time. Do not go over the time allotted.
5. Pronounce words clearly, with sufficient volume and at a relaxed pace.
6. Vary the pitch or tone of voice occasionally.
7. Add enthusiasm to the delivery.
8. Use visual aids judiciously.
9. Use appropriate gestures and avoid annoying mannerisms.
10. Make frequent eye contact with the audience.
11. Use a pointer when appropriate.
12. Relax and "enjoy the ride."

13.4 PRODUCT DATA MANAGEMENT

Graphic and written documents are instrumental to a company's success. Product-related documents and e-files include items such as: CAD drawings, CAD numerical-control programs, design specifications, design data, manufacturing-process plans, and finished-goods-inventory data.

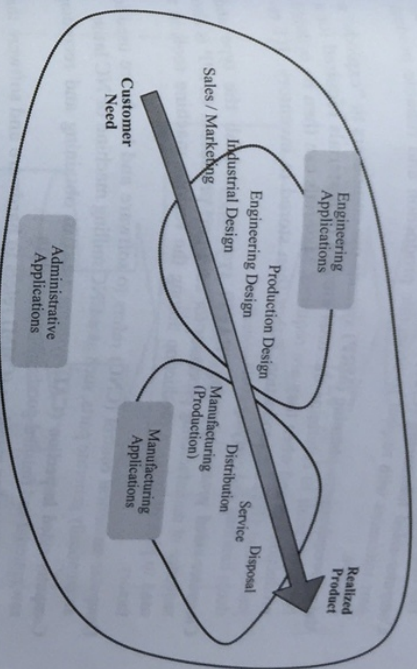


Figure 13.6 Computer applications used in the product realization process for engineering, manufacturing and administrative.

Computer applications used in the product-realization process, generally relate to engineering, manufacturing, and administration, as shown in Figure 13.6, and can be categorized into the following groups:

Engineering

Computer-aided design (CAD) software is used to prepare two-dimensional and three-dimensional drawings of product parts and assemblies. Full-featured solid-modeling packages can also render parts as if artistically painted or photographed. In addition, assembly components can be animated, thus illustrating various motions.

Computer-aided engineering (CAE) refers to any computer package that aids the engineering of a product. This includes analysis software typically relating to loads, stresses, vibrations, motions, heat transfer, fluid mechanics, and thermodynamics.

Bill(s) of materials (BOM) are documents that list the components, quantity, and part numbers used in a product. Often a BOM is an official drawing that is automatically generated by the company's computer-aided-design software.

Manufacturing

Automatic storage and retrieval system (AS/RS)'s are integrated materials handling hardware and software used to automatically store and retrieve

raw materials or finished goods from inventory locations in the factory.

Computer-aided tolerancing (CAT) software is used to analyze and specify part tolerances with respect to economic production and reliable product function.

Material-requirements planning (MRP) systems use computers to "explode" a bill of materials to determine the total amount of materials required for a production run and when they are required. Materials can then be ordered just-in-time (JIT) for production, rather than stored in inventory. JIT reduces handling and carrying costs.

Computer-aided process planning (CAPP) systems establish the type and sequence of manufacturing processes for each part produced. CAPP is also used to plan or balance production among the various machine tools in a factory.

Computer numerical control (CNC) refers to software and hardware used to automatically generate parts, such as a CNC milling machine or NC lathe.

Computer-aided inspection (CAI) systems assist in obtaining and recording raw material and finished-goods-inspection data.

Coordinate measuring machines (CMM) refers to hardware and software that obtains and records measurements of parts.

Statistical process control (SPC) software obtains and analyzes process characteristic statistics. The data are used to alert machine operators and management when a manufacturing machine or process is producing out-of-tolerance parts.

Administrative

Administrative computer applications include accounting, payroll, sales, marketing, finance, and human resources.

The use of computers has facilitated electronic-document preparation, storage, retrieval, and revision. It has also automated the distribution process. Copies of a drawing or textual document can be sent instantly to many recipients, compared to the mailing of hard-copy reproductions of whiteprints (the modern equivalent of blueprints).

To help manage product-development information some companies are using **product-data management (PDM)** systems, which are special computer software packages written just for that purpose (Rehg, 1994). A generalized version of a product-data-management system is shown in Figure 13.7.

Management of product information includes the initial approval and filing, or archiving and subsequent revisions, of original "master" documents. Revision control refers to authorizing engineering-change notices, which then require revisions to the master documents.

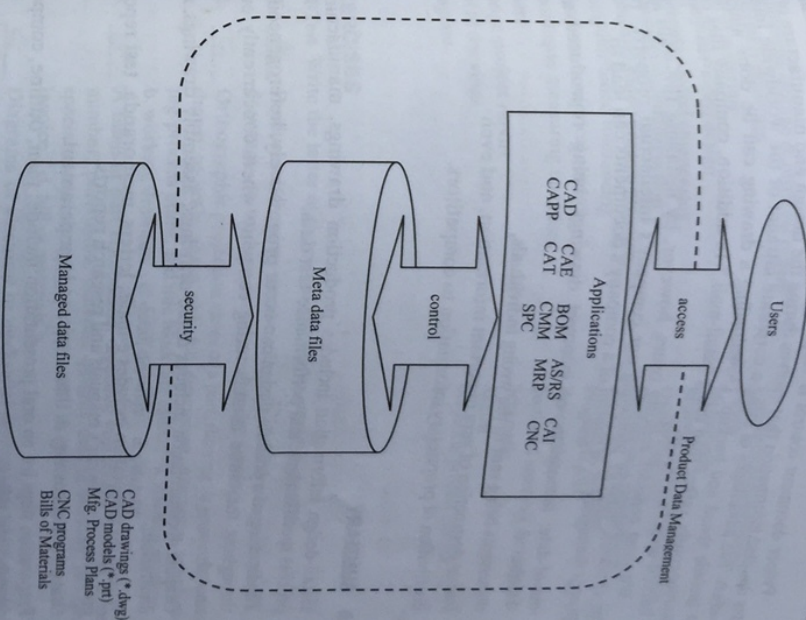


FIGURE 13.7 Product-data-management systems provide access to the users in the company while securely isolating the master data files.

When using a product-data-management system, an authorized engineer or technician "checks out" a virtual master drawing from the database. At this point anyone attempting to retrieve the drawing will be advised that the master is currently being revised, and that only unofficial copies will be permitted. After the approved revisions have been made, the master is "returned" to the database with a new revision number. Then, individuals in the approval chain are automatically electronically notified that a revised document is ready for their approval. After each individual has electronically approved the revised drawing, it is made accessible to authorized employees or customers.

Proper document control is very important. Each document communicates detailed information that evolves during the design and manufacture of a product. The advantages of using a corporate intranet or the worldwide Internet include speed and backup. Downloading a drawing can be done almost instantaneously, rather than using "snail-mail." In addition, company files can be backed-up at "mirror-sites."

We must consider security issues, however, by installing fire-walls and virus checkers, thereby protecting our company's intellectual property. The improper management or control of a company's documents can lead to:

- out-of-date, incomplete, or incorrect drawings being reproduced and distributed,
- documents being sent to the wrong individuals,
- loss or destruction of very important information, and even
- distribution of proprietary information to competitors.

13.5 SUMMARY

- Detail-design information includes production drawings, manufacturing process specifications, and performance-test data.
- The freezing of a product design can occur progressively, heterogeneously, throughout the entire manufacturing company when concurrently engineered.
- Graphic documentation includes detail drawings, assembly drawings, and illustrations.
- Written documentation includes e-mails, letters, memoranda, test reports, project reports, owner's manuals and research reports.
- Oral presentations vary in time, topic, and temperament.
- Preparation steps for an oral presentation include: plan, outline, compose, rehearse, and refine.
- Product data management systems can effectively automate and secure important product information.

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KEY TERMS

Automatic storage & retrieval system	Engineering-change notice
Assembly drawings	Figure
Bill of materials	Memoranda
Computer-aided design	Material-requirements planning
Computer-aided engineering	Owner's manual
Computer-aided inspection	Product-data management
Computer-aided process planning	Production drawings
Computer-aided tolerancing	Progress report
Computer numerical control	Research report
Coordinate measuring machines	Sectioned assembly drawing
Chart	Schematic
Design-project report	Sketch
Detail drawings	Statistical process control
Diagram	Test report

EXERCISES

Self-Test. Write the letter of the choice that best answers the question.

1. A Production drawings are also called: a. detail drawings b. graphic drawings c. working drawings d. design drawings
2. C Orthographic projection views of a part, showing its geometric features drawn to scale along with full dimensions, tolerances, manufacturing-process notes, and title block, are called: a. assembly drawings b. working drawings c. detail drawings d. diagrams
3. D A table of part information, organized with column headings for part number, part name, material, quantity used in assembly, and other special notes, is called: a. parts bill b. piece invoice c. resource invoice d. bill of materials
4. C Diagrams of electrical or mechanical systems using abstract symbols are called: a. charts b. figures c. schematics d. sketches
5. A Illustrations that portray relationships among numerical data, for example, sales versus time, are called: a. charts b. figures c. schematics d. sketches
6. B Hand-drawn rough drawings, drawn without the use of drawing instruments are called: a. schematics b. sketches c. figures d. charts
7. C Communications, three to nine pages long, sent to a broad audience, and covering many topics are called: a. test reports b. progress reports c. memoranda d. letters
8. B Technical reports detailing engineering or scientific tests on materials, prototypes, and/or products are called: a. memoranda b. test reports c. letters d. progress reports