Joint ventures differ from proprietorships, partnerships, and corporations in that they exist for a fixed period of time defined by the duration of the project being undertaken. Therefore, as a legal entity they exist to perform a given objective and are then dissolved.

The partners in a joint venture must each bring important contributions or capabilities to the undertaking. Each firm in the consortium brings special abilities which may include technical expertise, financial resources, or special knowledge—all of which are key to successful completion of the project being pursued. In the Design Build contract format discussed in Chapter 4, some of the partners are involved with the design aspects of the project while others are focused purely on the construction phase of the work. The legal aspects of joint venture formation and operation are typically unique to each project and will vary based on special aspects of the team partners (e.g., is the consortium multinational or not, etc.) and the location and nature of the project being constructed.

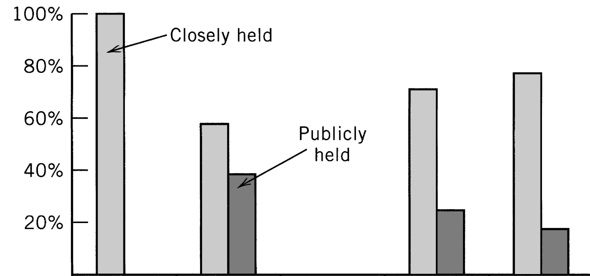
5.1 TYPES OF ORGANIZATION

One of the first problems confronting an entrepreneur who has decided to become a construction contractor is that of deciding how best to organize the firm to achieve the goals of profitability and control of business as well as technical functions. When organizing a company, two organizational questions are of interest. One relates to *the legal organization* of the company, and the second focuses on the *management organization*. The legal structure of a firm in any commercial undertaking, be it construction or dairy farming, is extremely important since it influences or even dictates how the firm will be taxed, the distribution of liability in the event the firm fails, the state, city, and federal laws that govern the firm's operation, and the firm's ability to raise capital. Management structure establishes areas and levels of responsibility in accomplishing the goals of the company and is the road map that determines how members of the firm communicate with one another on questions of common interest. The types of company legal organization will be considered in this chapter.

5.2 LEGAL STRUCTURE

At the time an entrepreneur decides to establish a company, one of the first questions to be resolved is which type of legal structure will be used. The nature of the business activity may point to a logical or obvious legal structure. For instance, if the entrepreneur owns a truck and decides to act as a free agent in hauling materials by contracting with various customers, the entrepreneur is acting alone and is the proprietor of his own business. In situations where a single person owns and operates a business activity and makes all of the major decisions regarding the company's activity, the company is referred to as a *proprietorship*. If the business prospers, the entrepreneur may buy additional trucks and hire drivers to expand his fleet, thereby increasing business. The firm, however, remains a proprietorship even if he has 1000 employees so long as the individual retains ownership and sole control of the firm.

If a young engineer with management experience and a job superintendent with field experience decide to start a company together, this firm is referred to as a partnership. The size of a *partnership* is not limited to two persons and may consist of any number of partners. Law firms as well as other professional companies (e.g., accounting firms) are often organized as partnerships consisting of as many as 10, 12, or more partners. If two or three individuals decide to form a partnership, the division of ownership is decided by the initial contribution to the formation of the company on the part of each partner. The division of ownership may be based solely on the monetary or capital assets contributed



Public	0	40%	—	27%	20%
Close	100%	60%	—	73%	80%
Category	A	B	C	D	All

Portion of firms publicly/closely held

Figure 5.1 Forms of legal ownership in the construction industry (study by T. Gibb, Georgia Institute of Technology, 1975).

by each partner. Therefore, if three individuals form a partnership with two contributing \$20,000 and a third contributing \$10,000, the division of ownership among the partners is 40, 40, and 20%. In other cases, one of the partners may bring a level of expertise that is recognized in the division of ownership. For instance, in the example just cited, if the partner contributing the \$10,000 were the expert in the area of business activity to be pursued, his expertise could be valued at the nominal level of \$10,000, making his overall contribution to the firm \$20,000. Therefore, ownership would be equally divided among the three partners. The actual division of ownership is usually specified in the charter of the partnership. If no written charter exists, and the partnership was concluded by verbal mutual agreement only, the assumption is that the division of ownership among the partners is equal.

In some business activity the risk of failure or exposure to damage claims may be such that a corporate structure is deemed appropriate. This form of ownership recognizes the company itself as a legal entity and makes only those assets that belong to the firm attachable for settlement of claims in the event of bankruptcy or damage claims. This allows principals or stockholders in a corporation to protect their personal and private assets from being called in to settle debts or claims arising out of the firm's operation or insolvency. Therefore, if a stockholder in a corporation has private assets of \$1 million and the corporation declares bankruptcy, the \$1 million cannot be attached to settle debts of the corporation.[1] Other desirable features of corporate structure that cause firms to select this legal structure will be discussed later in this chapter.

Two types of corporations are commonly encountered. Corporations in which a small number of persons hold all of the stock in the firm are referred to as *close* or *closely held* corporations. This form of ownership is very common in the construction industry since it offers risk protection and also allows a small group of principals to control company policies and functions. A *public* corporation, in contrast to a *closely held* corporation, allows its stock to be bought and sold freely. The actual ownership of the stock varies daily as the stock is traded by brokers, in the case of large corporations, on the stock market. Figure 5.1 gives a graphical indication of the forms of legal ownership utilized by a set of building construction companies located throughout the southeastern United States. In this example, the companies have been grouped according to the volume of work done using

[1] In certain situations, stockholders may by ancillary agreement, such as bond, waive some of the protection offered by the corporate structure and find that their personal assets are subject to attachment.

fixed-price contracts versus that done using negotiated contracts. The groups were defined as follows:

Group A. Contractors doing 25% or less of their volume in negotiated contract format.

Group B. Contractors doing between 25 and 50% negotiated work.

Group C. Contractors doing between 50 and 75% negotiated work.

Group D. Contractors doing more than 75% of their work in negotiated contract format.

The figure indicates that the close corporation format is very popular.

Another form of organization that has legal implications is the joint Venture. This is not a form of ownership but a temporary grouping of existing firms defined for a given period to accomplish a given task or project. A joint-venture organizational structure is used when a very large project is to be constructed and requires the pooling of resources or expertise from several companies. Typically the companies establish a basis for division of responsibility on the job and cooperate toward the end of successfully completing the project. They are bound together for a period of cooperation by a legal agreement that defines the nature of the relationship. Joint venturing first became popular during the construction of large dams such as the Grand Coulee and Hoover Dam in the western United States and has since been used for a wide variety of large construction tasks.

5.3 PROPRIETORSHIP

The simplest form of legal structure is the proprietorship. In this form of business ownership, an individual owns and operates the firm, retaining personal control. The proprietor makes all decisions regarding the affairs of the firm. The assets of the firm are held totally by one individual and augment the individual's personal worth. All revenue to the firm is personal cash revenue to the proprietor, and all losses or expenses incurred by the firm are personal expenses to the proprietor. The proprietor is, therefore, taxed as an individual and there is not separate taxation of the firm. Consider Uncle Fudd, who has a small contracting business. The firm generated $187,000 in total volume during the calendar year. The firm has $100,000 in expenses, so that the before-tax income of the firm is $87,000. Uncle Fudd declares this income on his personal income tax return. Assuming this is his total income (i.e., he received no further income from other sources) and that he has $17,000 in deductions and exemptions, his taxable income is $70,000.

Since the owner's capital and that of the firm are one and the same, the credit that the firm can obtain and its ability to generate new capital are limited by the personal assets of the proprietor. Furthermore, any losses incurred by the firm must be covered from the personal assets of the proprietor. Any liabilities incurred by the firm are the owner's liability, and he must cover them from his personal fortune. Therefore, bankruptcy of the firm is personal bankruptcy. Since there is no limitation of liability, high-risk businesses do not normally use the proprietorship form of structure.

The life of the proprietorship corresponds to that of the owner. Upon the death of the owner, the proprietorship ceases to exist. Assets of the proprietorship are normally divided among the heirs to the proprietor's estate.

5.4 PARTNERSHIP

The partnership is similar to the proprietorship in the sense that liabilities of the firm are directly transmitted to the partners. That is, there is no limitation of liability. However, in this case, since there are two or more partners, the liability is spread among several principals. The reason for forming a partnership is based on the principle of division of risk and pooling of management and financial resources. The ownership of the firm is shared among the partners to a degree defined in the initial charter of the partnership. Since several persons come together to form a partnership, the capital base of the firm is broadened to include the personal assets of the partners involved. This increase in assets increases the line of credit available to a partnership as opposed to a proprietorship. Control of the firm, however, is divided among the principals, who are called *general partners*. Partners share the profits and losses of the firm according to their degree of ownership as defined in the partnership agreement, but since the liability of each of the partners is not limited, one partner may carry more liability in the case of a major loss. Assume that Carol, Joan, and Bob are partners in a small contracting business. The personal fortunes and percent ownership of the three principals are as follows:

Carol	$1,400,000	40% ownership
Joan	800,000	30% ownership
Bob	100,000	30% ownership

The firm loses $1,000,000 and must pay this amount to creditors. The proportionate shares of this loss are:

Carol	$400,000
Joan	300,000
Bob	300,000

However, since Bob can only cover $100,000, the remaining $900,000 must be carried by Carol and Joan in proportion to their ownership share.

A *limited partnership*, as the term implies, provides a limit to the liability that is carried by some partners. This concept allows the general partners to attract capital resources to the firm. The *limited partner* is liable only to the extent of his or her investment. Assume that Tom comes into the partnership described above as a limited partner. He makes $200,000 available for the capitalization of the firm. The percentages of ownership are redefined to provide Tom with 15% ownership. He, therefore, shares in the profit and loss of the firm in this proportion. Nevertheless, his level of loss is limited to the $200,000 he has invested. No amount beyond this investment can be attached from his personal fortune to defray claims against the firm. This provides the general partners with a mechanism to attract wealthy investors who desire liability limitation but profit participation. Limited partners have the position of a stockholder in a corporation in that loss is limited to the amount of their investment.

Limited partners have no voice in the management of the firm. Therefore, the *general partners* retain the same level of control but increase the capital and credit bases of the firm by bringing in limited partners. There must be at least one general partner in any partnership. The limited form of partnership (i.e., a partnership that includes limited partners) is more difficult to establish and subject to more regulation by state chartering bodies (usually the Office of the Secretary of State of the state in which the partnership is chartered). This is because limited partnerships realize some of the advantages available in the corporate legal structure. Corporations are subject to close control by state chartering bodies.

The contribution made by the limited partner must be tangible. That is, the limited partner cannot contribute a patent, copyright, or similar instrument. The contribution must have a tangible asset value (i.e., equipment, cash, notes. shares of stock in a corporation, etc.).

Any partnership is terminated in the event of the death of one of the partners. However, arrangements can be made to provide for the continuity of the partnership should one of the partners die. An agreement can be made among the partners that in the event of the death of a partner the remaining principals will purchase the ownership share of the deceased partner. Usually a formula that recognizes the fluctuating worth of the partnership is adopted in this agreement. The remaining partners pay this amount to the estate of the deceased partner.

General partners who are actively involved in the day-to-day management of the firm may decide to pay themselves a salary. In this way, the time and level of expertise contributed to the operation of the partnership are recognized. This level of day-to-day participation may be different from the level of initial contribution made in capitalizing the firm. In the case of Carol, Joan, and Bob, the levels of ownership were 40, 30, and 30%, respectively. If Bob is most active in the management of the partnership, he may be paid a full-time salary to recognize his commitment. Carol and Joan being active only on a part-time basis will be paid proportionately smaller or part-time salaries. Taxation, in any case, will be on both salary and earnings deriving from the operation of the partnership.

The action of one partner is binding on all partners. For instance, in the partnership described, if Joan enters into a contract to construct a building for the client, this agreement binds Bob and Carol as well. In this sense, a partnership is a "marriage," and any partner must be able to live with any commitment made on behalf of the partnership by another partner. On the other hand, it is not proper for a partner to sell or mortgage an asset of the partnership without the consent of the other partners. If the partner sells the asset, the income accrues to the partnership. If the partner utilizes a partnership asset to secure a personal note or loan, the other partners could advise the noteholder that they contest the use of this asset as security.

5.5 CORPORATION

A corporation is a separate legal entity and is created as such under the law of a state in which it it chartered. In most states, corporations are established by applying to the office of the secretary of state or similar official. This office issues a chartering document and approves the initial issuance of shares of stock in the corporation to establish the level of ownership of initial stockholders. As in the case of a partnership, the initial stockholders contribute financial capital and expertise as well as other intangible assets such as patents and royalty rights. The level of contribution is recognized by the number of shares of stock issued to each of the founding stockholders. If, in the partnership just described, Carol, Joan, and Bob decided to incorporate and the level of ownership was to remain the same, shares in the proper proportion would be issued to each principal. The number of shares and the share value defined at the initialization of a corporation are arbitrary and are selected to facilitate the recognition of ownership rather than actual value of the corporate assets. If the Carol-Joan-Bob (CJB) Corporation is established by the issuance of 1000 share of stock, Carol would receive 400 shares (40%), and Joan and Bob would receive 300 shares each (30%). For simplicity, each share could have a par value of one dollar. This assignment of one dollar per share simplifies the unit (i.e., share value) used to recognize ownership. On the other hand, the initial capital contributed to the formation of the corporation might have been $100,000. Therefore, the book value of each share of stock would be $100 per share. The book value of each share of a corporation is the net worth of the corporation divided by the number of shares issued. In this case, 1000 shares are issued and the asset value is $100,000. Therefore, each share has a book value of $100.

In addition to the par and book values associated with a share of stock in a corporation, each share has a traded or market value. This is the value that is listed on stock exchanges for those publicly traded corporation shares and that is printed in the newspaper. It indicates what the general public or stock traders are willing to pay for a share of ownership in the corporation. If the future looks good, traders will anticipate an increase in the value of the corporation's stock and will pay to own a stock that is increasing in value. If the corporation is about to experience a loss, the market price of the stock may indicate this by declining in value. To illustrate, if CJB, Incorporated, wins a contract that promises to net the corporation an after-tax profit of $100,000, the market price of the stock will tend to move up. In fact, as already noted, most construction firms hold their stock closely and do not trade it publicly. Therefore, the market value of the stock is of interest primarily to the giant construction firms that are publicly traded.

Because of the legal procedures required, the corporation is the most complicated form of ownership to establish. A lawyer is normally retained to prepare the proper documents, fees must be paid to cover actions by the chartering body (e.g., Office of the Secretary of State), printed stock is prepared, and formal meetings by the principals are required. Since the corporation can sell further stock to raise capital, it has an advantage in this respect over the proprietorship and the partnership. This power to sell stock can be and has been abused. Once a corporation is established, it may sell stock to unsuspecting buyers based on an idea or concept that is not properly presented or explained. For this reason and others, the corporation is closely controlled by the chartering agency in regard to its issuance and sale of additional stock. Federal law also dictates certain aspects of the presentation of corporate stock for sale.

The most desirable aspect of the corporate structure to businesses that are exposed to high risk such as the construction industry is its limitation of liability. Since the corporation is a legal entity of itself, only the assets of the corporation are subject to attachment in the settling of claims against and losses incurred by the corporation. This means that stockholders in a corporation can lose the value of their investment in stock, but that is the limit of their potential loss. Other assets that they own outside of the corporation cannot be impounded to offset debts against the corporation.

One disadvantage associated with the corporation is the double-taxation feature. Since the corporation is a legal entity, it is subject to taxation. The same profit that is taxed within the corporation is taxed again when it is distributed to stockholders as a dividend. This distributed profit becomes taxable as personal income to the individual stockholders. Assume that CJB Corporation has a before-tax profit (e.g., revenue − expenses) of $100,000 during the corporation's first year of operation. Let us assume the CJB Corporation is taxed by the IRS at the rate of 34% of profit provided income is in excess of $75,000. The corporation would be taxed $34,000 for $100,000 of before-tax profit.[2] The after-tax income would be $66,000. Assume the CJB decides to distribute $30,000 to the three stockholders. That is, Carol, Joan, and Bob as directors of their closely held corporation distribute $30,000 to themselves and retain $36,000 of these earnings within the corporation as working capital. In this case Carol, the major stockholder, receives a dividend of $12,000. Joan and Bob would receive $9000 each. If we assume that each stockholder pays approximately 25% on personal taxable income, Carol will pay $3000 in tax on this dividend, and Joan and Bob will pay $2250. In other words, the federal tax at the corporation and stockholder levels combined will be $34,000 plus $7500, or $41,500.

The double-taxation feature does not always prove to be a disadvantage. Returning to the situation of Uncle Fudd who is organized as a proprietorship, assume his before-tax income with the proprietorship is $147,000.[3] Assume that Uncle Fudd decides to incorporate his proprietorship and become Fudd Associates, Inc. As president of this corporation, Uncle Fudd pays himself a salary of $85,000. At this salary level, Uncle Fudd is taxed at 21% of his taxable income (i.e., his gross income minus deductions and exemptions). In the proprietorship format, his tax would be 25% of $147,000 minus $12,000 in deductions and exemptions.[4] He will pay 25% of $135,000, or $33,750 in tax. In the corporate format,

[2] Corporate taxation levels vary over time due to changes in Federal and State legislation.

[3] This example is different from the previous situation in which the taxable income was $87,000.

[4] The corporate rate for less than $75,000 taxable income is assumed to be 25%.

Uncle Fudd's tax will be:

$$
\begin{array}{rl}
\$147{,}000 & \\
-85{,}000 & \text{Fudds Salary} = \text{expense} \\
\hline
\$62{,}000 & \text{Gross income of corporation}
\end{array}
$$

$$
\begin{aligned}
\text{Corporate tax} &= 0.25(62{,}000) = \$15{,}500\,(\text{See footnote 4, page 84}) \\
\text{Personal tax} &= (0.21)\{\$85{,}000 - 12{,}000\,(\text{deductions and exemptions})\} \\
&= \$15{,}330
\end{aligned}
$$

Therefore, Uncle Fudd's tax in the corporate format will be $15,500 + $15,330 = $30,830. In this case, the corporate form of ownership yields a lower tax payment despite the double taxation. For this reason, a good tax consultant is a very valuable advisor when deciding which form of ownership is most appropriate.

Certain states provide for a special corporate structure that avoids the double-taxation feature of a normal corporation but retains the protection of limited liability. This is referred to as a subchapter "S" corporation. In a subchapter S corporation, the principals are taxed as if they were members of a partnership. That is, corporate income is taxed only once as personal income. The corporate shareholders are, however, still protected and their loss is limited to the value of the stock they possess.

As noted earlier, the corporation is very advantageous when attraction of additional capital is of interest. Figure 5.2 shows a typical stock certificate as issued at the time of incorporation. The certificate indicates that 250 shares of stock are represented. In addition, the corporation has authority to issue a total of 50,000 shares. Therefore, the directors of a corporation can decide to raise money for capital expansion by selling stock rather than borrowing money. This provides for the generation of additional capital by distributing ownership. It has the advantage that the money generated is not subject to repayment and therefore is not a liability on the company balance sheet.

The corporation also has a continuity that is independent of the stockholders. Unlike the proprietorship or partnership in which the firm is terminated on the death of one of the principals, the corporation is perpetual. Unless the corporation is bankrupt or the corporate charter lapses, the corporation continues in existence until all stockholders agree to dissolve it. In most states, clauses can be included in the corporate charter that in effect allow the control of sale of stock outside of the circle of present stockholders. That is, any stockholder who wishes to sell a block of stock must first offer the stock for sale to the other stockholders. They have an option to purchase it before it is sold to others. This allows the closed nature of a closely held corporation to be maintained. If a stockholder should die, the stockholder's heirs are committed to offer it to the present stockholders before selling it to others. The heirs can, of course, decide simply to retain the stock.

Two disadvantages that are inherent in the corporate form of ownership are the reduced level of control exercised in management decision making and certain restrictions that can be placed on the corporation when operating outside of its state of incorporation. The larger a corporation becomes the more decentralized the ownership becomes. On questions of dividend levels, the issuance of stock to generate capital, and other critical operational decisions, agreement of all stockholders must be obtained. In large corporations, this leads to involved balloting to establish the consensus of the ownership. This process is cumbersome and greatly reduces the speed with which corporations can respond to developing situations. In small closely held corporations, however, this presents no more of a problem than it does in a partnership.

When a corporation operates in a state other than the one in which it is incorporated, it is referred to as a *foreign* corporation. For instance, a corporation incorporated in Delaware

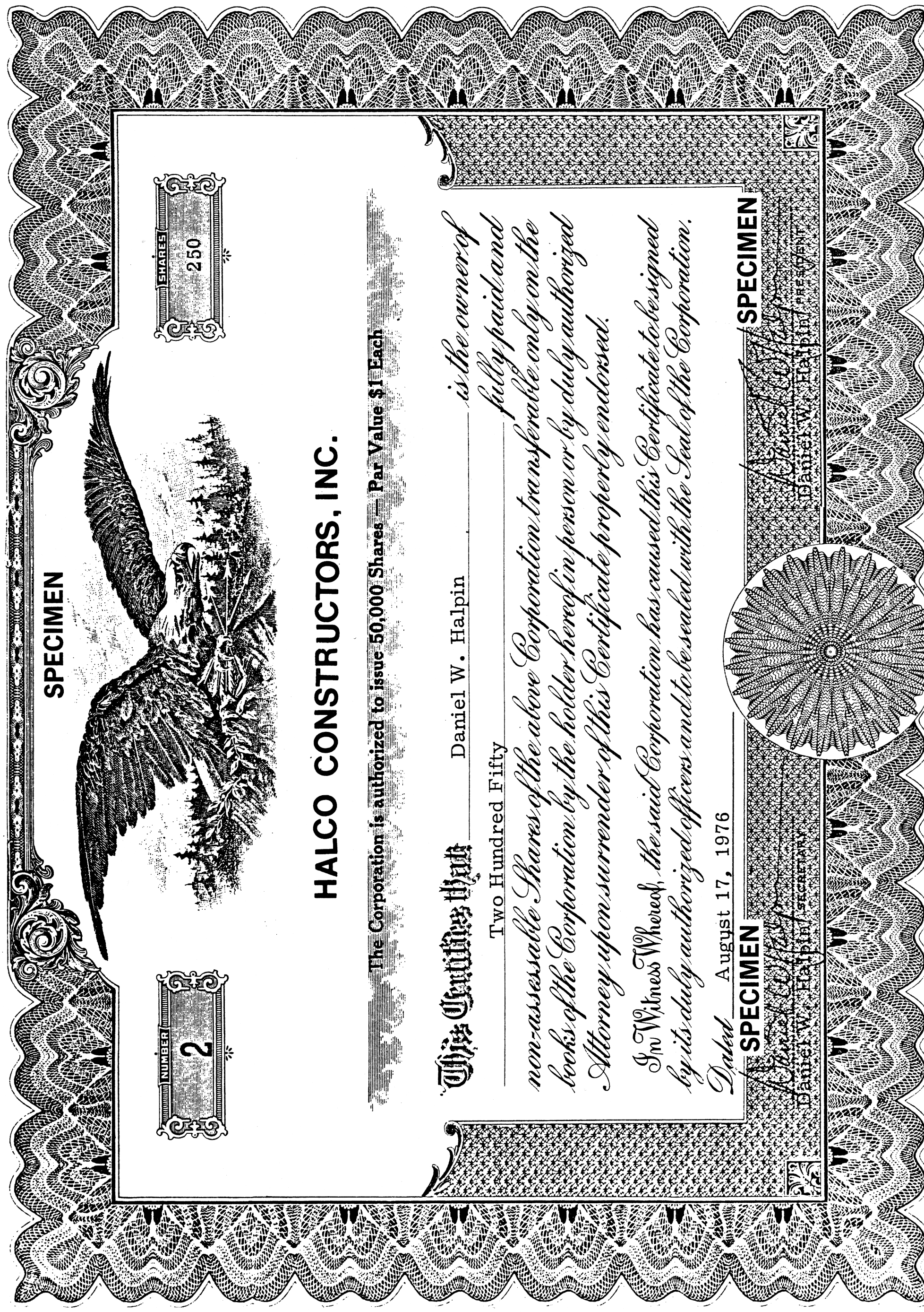


Figure 5.2 Typical stock certificate.

is considered a foreign corporation in Indiana. Corporations in certain industries may encounter restrictive laws when operating as a foreign corporation. They must establish legal representation in states in which they operate as foreign corporations. Restrictive legislation of this type cannot be applied to proprietorships and partnerships, since these entities consist of individuals who are legally recognized. The individual is protected by equal treatment under the Constitution, and what is a legal restriction when placed on a corporation is illegal when applied to a proprietorship or a partnership.

5.6 COMPARISON OF LEGAL STRUCTURES

The decision to choose a particular legal structure for the firm hinges on seven major considerations. The pluses and minuses of each type of structure are summarized in Table 5.1. These considerations have already been introduced in general form. Specifically, an owner contemplating a legal structure for the firm must consider:

1. Taxation
2. Costs associated with establishing the firm
3. Risk and liability
4. Continuity of the firm
5. Administrative flexibility and impact of structure on decision making

Table 5.1 Considerations in Choosing Legal Structure

	Proprietorship	Partnership	Corporation
Tax	Tax on personal income; tax on earnings whether or not they are withdrawn	Tax on personal salary and earnings	Lower taxes in some cases.[a] Dividends are not deductible; double taxing. Taxes on dividends, that is, money actually received
Costs and procedures in starting	No special legal procedure; apply for licenses; register with IRS	General: Easy—oral agreement Limited: More difficult—must closely adhere to state law	More complex and expensive. Meeting must be held
Size of risk	Personal liability	Personal liabilities: Extent of personal fortune. Limited: each partner is protected; loss of limited partner cannot exceed initial investment	Limited to assets of corporation
Continuity of the concern	No continuity on death of proprietor	Dissolution: No continuity on death of partner. Surviving partners can buy share if in agreement.	Perpetual (charter can expire)
Adaptability of administration	Simplicity of organization; direct control	Decisions and policies implemented by oral agreement	Directors—good if involved. Policy decisions predefined by by-laws
Influences of applicable laws	Laws are well defined; no limit on doing business in various states	Laws are also well defined; a license may be required	Foreign corporation status; requires legal counsel on permanent basis
Attraction of additional capital	Limited potential for capital expansion Borrowing; line of credit; personal fortune investment	Better; more capital; limited partner concept	Issue securities; collateral provided by corporate assets; issue stock

[a] See Fudd Associates, Inc., example in text.

6. Laws constraining operations
7. Attraction of capital

The question of taxes to be paid in each organizational format is mixed, and the anticipated balance sheet and cash flow of each firm must be studied to arrive at a "best" solution. The corporation has the disadvantage that the firm is taxed twice, once on corporate profit and a second time when the stockholders must pay tax on the dividends received as distributed income. The subchapter S type of firm circumvents this to a degree in that the stockholders are taxed as individuals as if the firm were a partnership. The normal proprietorship and partnerships have the disadvantage that all income is taxed whether or not it is withdrawn from the firm. Thus, as in the example of Uncle Fudd, incorporating yields a benefit despite the double-taxation feature.

Costs and procedures associated with establishing the firms are generally minimal for a proprietorship, slightly more involved for a simple partnership, and a major financial consideration for limited partnerships and corporations. Normally whatever costs and procedures are associated with local, state, and federal tax registration and the purchasing of a license are all that must be considered in establishing a proprietorship or simple partnership. These as well as significant legal costs ($2000 to $5000) must be considered in establishing limited partnerships and corporations. These costs may be justified, however, based on the limitation of liability achieved and the benefits of medical, health, and insurance plans that can be implemented in a corporate format.

Corporations and limited partnerships limit the level of loss in the event of a default or bankruptcy to the level of investment. That is, stockholders cannot lose more than the value of their shares. The loss of a limited partner cannot exceed the amount of his investment. If he initially invested $20,000, he can lose this amount, but his other assets cannot be attached in the event of bankruptcy or default. The assets of stockholders in a subchapter S corporation are similarly protected. Personal assets are used to pay creditors in the proprietorship or simple partnership form of ownership. This can lead to personal bankruptcy.

Proprietorships also have the disadvantage that they terminate when the proprietor dies. This may present a problem, particularly if the firm as an asset must be divided among several heirs. It can be circumvented in part by willing the firm and its market and "goodwill" to one heir (who will carry on the business) and providing that the heir will compensate the other heirs for their share. If a partner dies, the partnership is dissolved. Again, however, provisions in the partnership agreement can provide the means for surviving partners to purchase the deceased partner's share from his estate. Corporations are perpetual, and the stock certificates are transferred directly as assets to heirs of the estate.

Policy decisions are relatively simple in the proprietorship and partnership formats. Principals make all decisions. In the corporate format, certain decisions must be approved by the stockholders, which may impact the corporation's ability to react to a developing need or situation. In closely held corporations, however, this is no problem since the partners are able to call ad hoc board meetings to react quickly. Corporations with large numbers of shareholders are not as flexible in this regard. The chief operating office or president handles the day-to-day decision making. A board of directors is charged with intermediate-range and strategic planning and decision making. Major decisions, however, such as stock expansion and acquisition of other firms or major assets, must often be approved by all stockholders in a formal vote.

Local laws may encourage the formation of small and local businesses by placing restrictive constraints and burdensome additional cost on out-of-state, or foreign, corporations. These discriminating practices must be investigated when bidding construction work in a state other than the one in which the construction corporation is chartered. Special licenses and fees are sometimes required of foreign corporations. Proprietorships and partnerships that consist of individuals are protected against these discriminatory practices by the Constitution and enabling "equal rights" legislation.

In raising capital, proprietorships and simple partnerships must rely on the personal borrowing of the principals to generate capital for expansion. The unique feature of the corporation that permits it to sell stock allows corporate entities to attract new capital by further distributing ownership. The corporate assets as well as future projections of business provide a collateral basis to attract new stockholders. This mechanism is not always viable, however. From time to time, corporations may be unable to sell large issues of stock for capital expansion and will be forced to go to the commercial banks to borrow. In periods of economic uncertainty, sale of stock as a method of attracting capital may be limited.

Good information regarding the advantages and disadvantages of various legal forms of organization are contained in the Small Business Administration management guides available from the Government Printing Office.

REVIEW QUESTIONS AND EXERCISES

5.1 Name the three principle forms of business ownership in construction and state the liability limits of the owners in each case.

5.2 Which legal structure is most difficult to establish and why?

5.3 Name three types of partnerships.

5.4 Describe briefly two advantages and two disadvantages of a corporate form of business organization as compared to a partnership.

5.5 Jack Flubber, who owns Sons of Flubber Construction Co. and runs it as a proprietorship, had gross profits last year of $80,000. His personal and family expenses are $52,000 and he has $7000 in exemptions and deductions. He paid $17,000 in taxes. If he paid himself a salary of $55,000 taxed at 20%, would it be advantageous for him to incorporate as a closely held corporation? Explain.

5.6 What is meant by the term foreign corporation?

5.7 What would be the advantages of organizing as a subchapter S corporation?

5.8 Is it possible to characterize the legal structures of local contractors using the Yellow Pages as a guide?

5.9 What steps must be taken to set up a partnership? How can a partnership be dissolved?

5.10 In problem 5.5, what taxes would Jack pay if he organized as a closely held corporation (as described) and, after paying his salary, also issued himself a dividend of $10,000?

5.11 What is the difference between par and book values of corporate stock? If an incorporated construction company wins a large cost plus fixed-fee contract, what impact might this have on the market value of the company's stock?

5.12 Uncle Fudd has decided to sell his ownership in the Cougar Construction, Inc. to Cousin Elmer. How would the legal firm handling this transaction determine a fair price per share?

Chapter 6

Project Planning

Web-Based Project Management

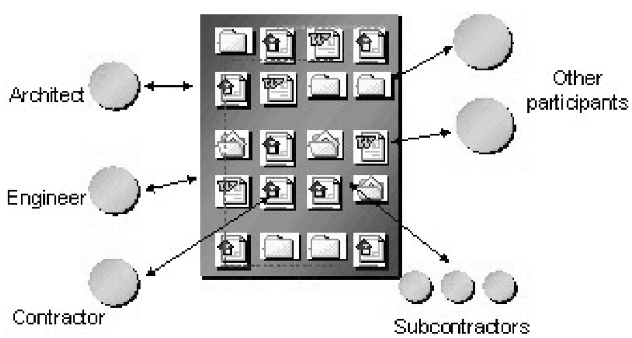
The Need

Considering that 1 to 2% of project cost is simply paperwork, multimillion dollar amounts are expended to support communication and information transfer. Geographically dispersed team members need to share information, documents, drawings, and strategies. The likelihood of errors, miscommunication, or missed deadlines is reduced through web-based project management tools.

Most web-based project management tools enable project teams to share all relevant project information which includes directory, specification, correspondence, sketches, meeting notes, shop drawing logs, field reports, requests for information (RFIs), and CAD drawings, etc.

The Technology

With the Internet acting as the ultimate communications medium, web-based project management applications provide an instant, on-demand, secure online solution for all team members to communicate, share documents, and collaborate. The general features include document management, workflow analysis, schedule/calendar development and management, messaging, conferencing, discussion function, directory service, revision control, and project camera, etc.



Centralization of Data on Server

6.1 INTRODUCTION

The planning of a project involves the concept of an objective or facility, and a *scope of work* defining the work product or deliverable. The bid package consisting of the plans and specifications establishes the scope of work to be performed. In order to be properly managed, the scope of work must be broken into components which define work elements or building blocks which need to be accomplished in order to realize the end objective. The assumption is that the project is the summation of its sub-elements.

Definition of the sub-elements is important since it determines how the project is to be realized in the field. The sub-elements are often referred to as work packages. The summation of the work packages can be shown in a hierarchical format called a work breakdown structure or WBS. Figure 6.1 is an example of a WBS for a small building.

The *building* defined at Level I is sub-divided into major sub-systems at Level II. The *foundation* work is again broken into major work activities at Level III. Similarly, the *pile cap* consists of work tasks such as forming, installation of reinforcement, etc.

Development of a WBS requires a thorough understanding of the project scope of work. Experience in building is key to establishing a functional WBS. The WBS and the hierarchy of work packages of which it is composed are used to determine the status of a project and to manage the project from a time, cost, and quality perspective. Mentally, building a WBS structures the work which must be physically accomplished to realize the project and its end objective.

Planning can be thought of as the definition and sequencing of the work packages within a given project. That is:

PLANNING = WORK BREAKDOWN + WORK SEQUENCING

Planning leads to a refinement of the Scope of Work as established in the contract documents. A good plan reduces uncertainty and improves efficiency.

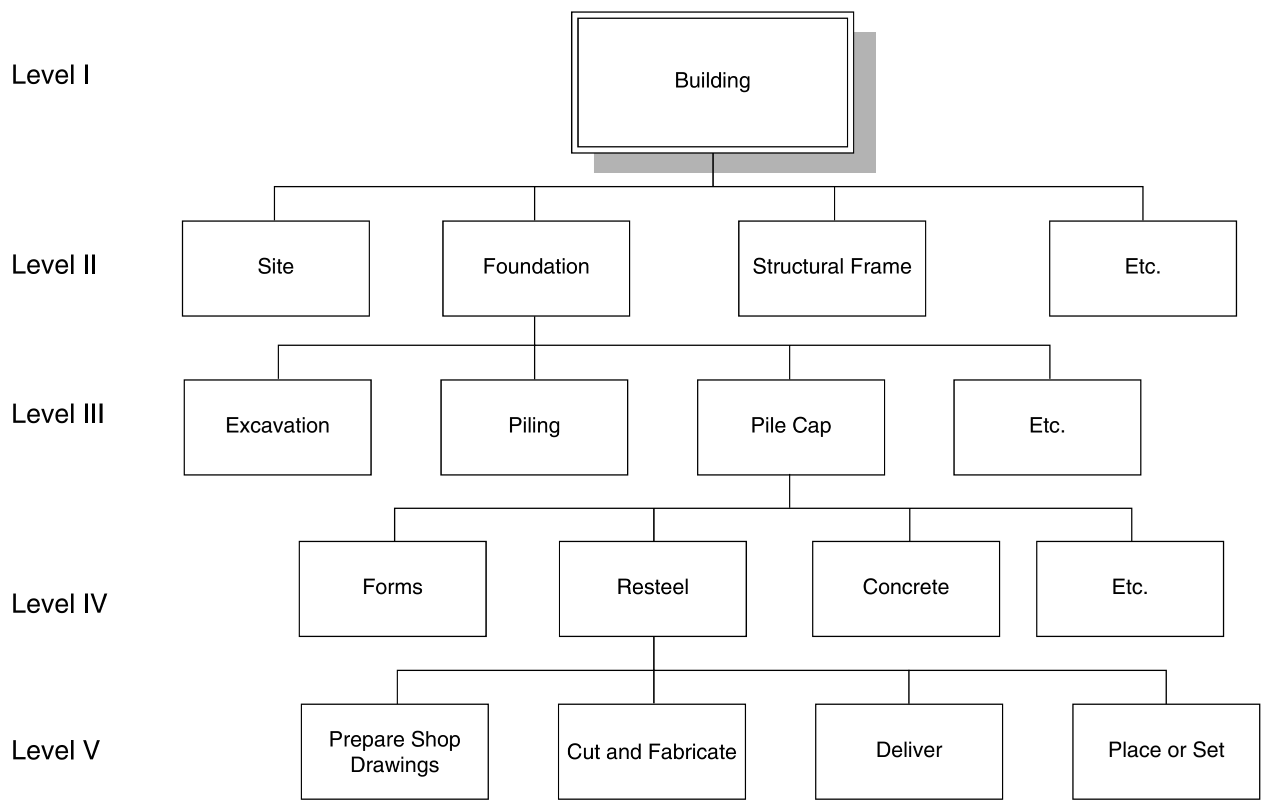


Figure 6.1 Work Breakdown Structure (WBS) Example.

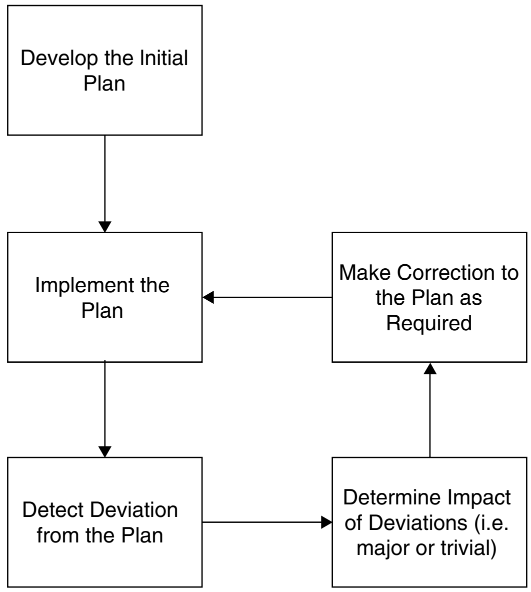


Figure 6.2 The Planning/Management Cycle.

The WBS also assists in determining the amount of planning needed. That is, it defines the level of planning required. For instance, if we are traveling to Washington, D.C., certain major elements of the travel should be planned. If we are traveling by air we need to book an airline ticket. We need to determine what to pack. Typically, we will need a place to stay, so we probably will reserve a hotel room unless we are staying with friends. At a lower level in our planning hierarchy, we must determine how to get from the airport to the hotel. If time is critical, we may reserve a limousine to meet us at the airport. On the other hand, we may decide to make a decision upon arrival as to whether to take a cab, a shuttle bus, or the Washington Metro MassTransit system. In effect, the development of the WBS and the definition of work packages is an exercise in “thinking things out ahead of time.” It provides an orderly mechanism which facilitates planning. How detailed and comprehensive the WBS must be will vary with the situation and the complexity of the project.

Planning allows us to develop a framework for project execution, monitoring, and control. This minimizes uncertainty, clarifies sub-objectives within the overall objective, assists in establishing sequencing of activity, and helps to avoid crisis management.

Planning is, however, an ongoing task and continues throughout the life of the project—General Dwight D. Eisenhower once said “Plans are nothing, Planning is everything.” Initial planning is inevitably impacted by events which cause changes to the plan. The success of a project is tied to the manager’s agility in identifying deviations from the plan and solving the challenges precipitated by these deviations. Figure 6.2 reflects this cycle of planning in terms of a simple flow chart. Once the WBS has been developed, it provides the framework within which planning can proceed throughout the life of the project. It becomes the vehicle for identifying deviations, assessing their impact, and making appropriate corrections to the existing plan. Therefore, “planning is everything.”

6.2 DEVELOPING THE WORK BREAKDOWN STRUCTURE

Work packages are the building blocks of the Work Breakdown Structure (WBS). They should be defined to assist the manager in determining the project status or the level of completion of the project. One definition of the WBS is “the progressive hierarchical breakdown of the project into smaller pieces to the lowest practical level to which cost is applied.”

When monitoring and controlling a project, cost and time are areas of primary interest. The WBS is extremely useful in developing both cost and time (schedule) plans.

In establishing the WBS, the following guidelines need to be considered:

1. Work packages must be clearly distinguishable from other work packages.
2. Each work package must have unique starting and ending dates.
3. Each work package should have its own unique budget.
4. Work packages should be small enough that precise measurement of work progress is possible.

For example, in Figure 6.1 one work package at Level IV defines work associated with the installation of reinforcing steel in a pile cap. This work package is (1) clearly defined and separate from other work packages, (2) has a starting and ending date, and (3) has a cost budget which is unique and is small enough for accurate progress measurement. The work packages at Level V become more generic and more difficult to distinguish as unique. For instance, tasks such as cutting and setting steel are very short and assigning a unique budget to this level of work becomes difficult. Therefore, the Level V work packages in Figure 6.1 can be viewed as sub-tasks which are pro-rated to the more unique Level IV work packages.

6.3 A WORK BREAKDOWN EXAMPLE

In order to better understand the concept of work breakdown, consider the small gas station project for which simplified plans and concept drawings are shown in Appendix I.

In construction, the various aspects of the work that contribute to breakdown of the project into packages relate to:

1. Methods used to place work
2. Skills needed for the work
3. Craft workers involved
4. Critical Resources (e.g., cranes, crews, etc.)

The definition of work packages can be facilitated by using four categories which help in establishing a level of uniqueness. These categories are:

1. Location or Area within the Project (e.g., foundation – pile cap)
2. Material Type (e.g., concrete, resteel, etc.)
3. Method of placement (e.g., excavation)
4. Organizational Resources Required (e.g., labor and equipment needed)

In the gas station project, the construction requires a *foundation* for the load bearing walls. The foundation can be thought of as a location (as well as a structural support system). The LOCATION or AREA of the work is a physical part of the construction. That is, one can walk up and touch the location of the package. A work package defining the floor slab in Section A on the 3rd floor of an academic building is something we can locate and physically touch in the completed facility. The fact that the slab is concrete (i.e., rather than wood or metal) is another important parameter. It has implications from a procurement, as well as from a placement and work content point of view.

LOCATION and MATERIAL TYPE will influence the method of placement or installation. The METHOD OF INSTALLATION and the material type will determine the human skills and equipment resources needed for installation. The method of placement or installation dictates the TYPES OF RESOURCES required, thus differentiating one package from another. For instance, in one case we may be placing concrete using a concrete pump, where as in another situation the concrete may be transported using concrete buggies. In each case, labor and equipment resources, the budget, and the productivity of the concrete placement will be different.

6.4 WORK PACKAGES FOR THE GAS STATION PROJECT

Let's develop a set of work packages and a WBS for the gas station construction. First, locations which are work package related will be determined. As noted above, the building foundation can be considered a location. It would be important to know whether the scope of work includes the parking and service area surrounding the station. For the purposes of this exercise, we will assume it is within the scope of work. LOCATION work packages would be as follows:

1. Parking and Service Area
2. Foundation
3. Building Walls/Structural Panels
4. Building Roof
5. Interior Floors/Slabs (separate from the Foundation)
6. Interior Finishes
7. Exterior Finishes
8. Electrical Systems
9. Mechanical Systems

Adding the category of MATERIAL TYPE expands the number of work packages as shown in Table 6.1. Although this listing is, by no means, complete, it indicates the level of detail which must be considered even in a relatively small project (when only two levels of hierarchy are defined).

If mechanical work is expanded to cover location, material type, methods and resources the following partial list of work packages would be added to the hierarchy of the WBS.

1. Excavation of Waste Water System
2. Drainage Tile installation—Waste Water
3. Septic Tank installation
4. Fresh Water lines (piping)
5. Sinks, basins, toilets installation
6. Hot Water System installation
7. Pneumatic Air System installation

Table 6.1 Work Packages for the Gas Station Project

(1) Earthwork for Parking and Service (P&S) Area	(10) Interior Built-ins (e.g., Cabinets, etc.)
(2) Asphalt Paving for P&S Area	(11) Interior Painting
(3) Concrete Hardstands in P&S Area	(12) Interior Drywall
(4) Concrete Foundations	(13) Interior Doors, Frames, Hardware, etc.
(5) Walls–Masonry Bearing Walls	(14) Interior Floor Coverings (if required)
(6) Walls–Prefab Metal Sandwich Panels	(15) Exterior Brick Façade
(7) Interior Concrete Floors	(16) Exterior Glazing
(8) Built-up Roof	(17) Exterior Doors and Signage
(9) Roof Gutters/Drainage	(18) Mechanical Systems
	(19) Electrical Systems

Figure 6.3 shows a work breakdown structure based on this partial development of work packages.

6.5 DETERMINING SEQUENCE OF WORK PACKAGES

Having broken the work in to work packages, activities which facilitate time management and control can be defined and logically placed in sequence. The word ACTIVITY is generally used when discussing time control or scheduling to refer to the work elements which appear in the schedule in their expected sequence or logical order. As mentioned in Chapter 1, the word "technology" implies that operations have a logic or sequence. An understanding of this logic is a key to successful project management.

In arranging the work package sequence for time control, the criteria of (1) *location* (2) *material* (3) *method* and (4) *required resources* developed in Section 6.3 must be reconsidered from the perspective of how these criteria impact the order or sequence of work activities. For instance, location can determine sequence. It is normal to complete the structural frame for the 1st floor of a building before beginning work on the structural frame for the 2nd floor. This could be considered a *physical* constraint since the 2nd floor frame cannot be supported until the first floor frame is completed. Such physical constraints or *physical logic* are common and characteristic of construction operations (e.g., the floor must be complete before installing the floor covering, etc.). Locational aspects of a work package may, therefore, determine its sequence in the overall project.

In some cases, physical requirements do not dictate order or sequence. For instance, in finish work relating to a rest room, fixtures such as sinks, commodes and partitions must be installed. Wall and floor finishes such as ceramic tiles must also be completed. Since there is no physical constraint, it is a management decision as to whether the walls and floors are completed first or the fixtures are installed first. In this case, the situation is controlled by a management decision (e.g., the fixture subcontractor is available first and is instructed to proceed) and the sequence is driven by *management logic*.

Again, consider the small gas station project. A preliminary sequencing of the work packages is shown in Figure 6.4. One activity is defined to address mobilizing men, material, and machines to the site and preparation of the site. Then the locational or area work packages are ordered in sequence starting with the foundation and completing with the interior and exterior finishes and the mechanical and electrical systems which can be worked on at the same time (i.e., in parallel). This preliminary sequencing provides the framework for a more detailed schedule development to be presented in Chapter 7.

Following the preparation of the site, the footers and pier foundations are to be poured. After the footers and pier foundations have reached sufficient strength, the building structure is erected. It should be noted that, in this case, the floor slabs of the service bays, the show room, and the office areas as well as the utility room and toilets are not poured until the building structure is erected. Since the foundation consists of a "ring" footing[1] and individual piers to support walls and columns, etc., the building shell and roof can be completed prior to casting the various floor slabs throughout the building. When the roof is completed and the building is "closed in," work inside the building can proceed without concern for the weather.

As a more detailed time plan (i.e., schedule) is developed, consideration must be given to other time consuming activities which are not necessarily identified using the location, material, method, and resource criteria.

1. Administrative actions such as inspections, permit issuance, noise constraints, etc. must be considered in developing the time schedule logic.

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[1] A ring footing is a footing that supports the periphery of the building.

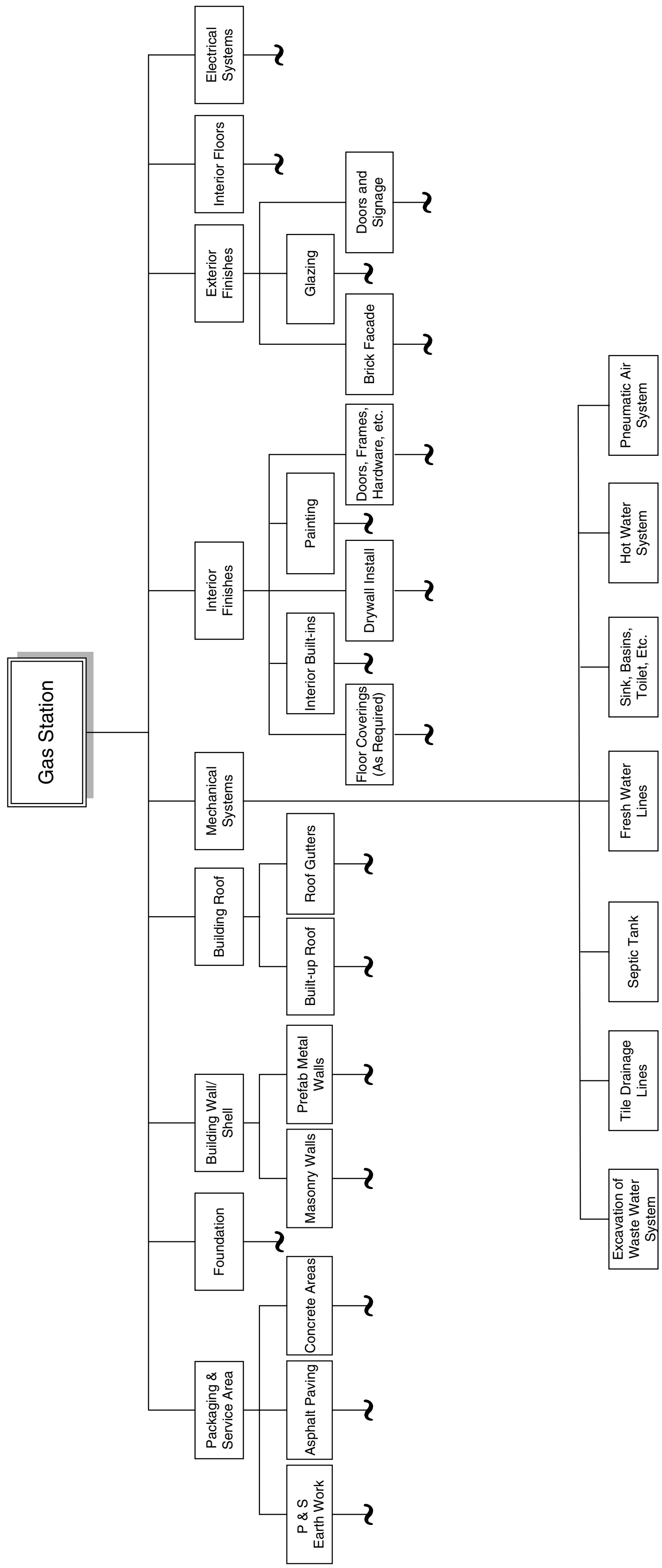


Figure 6.3 WBS for Gas Station Project.

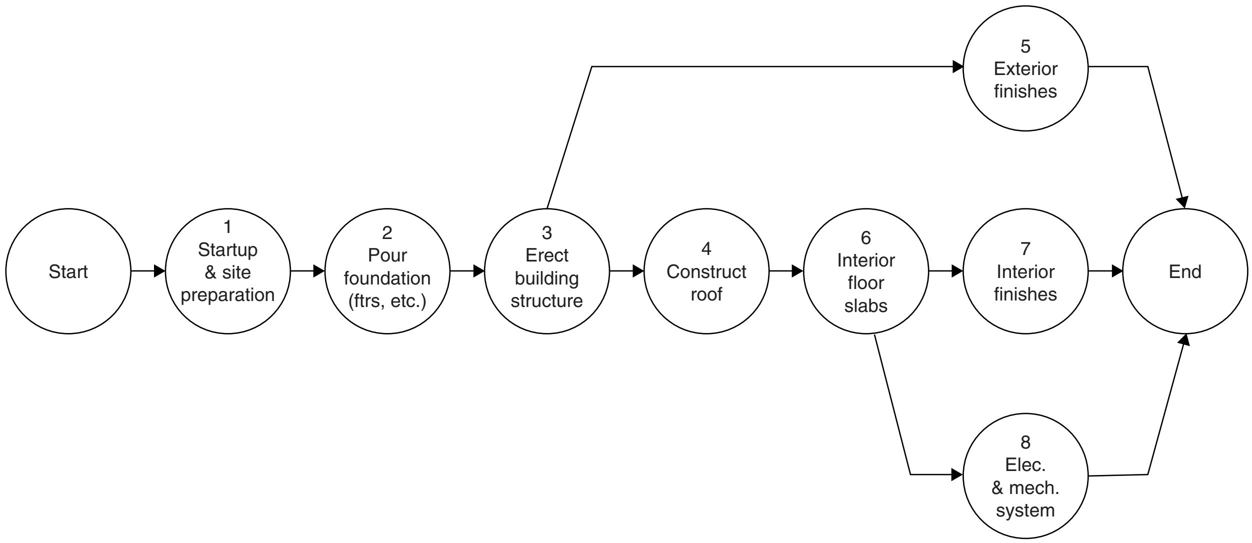


Figure 6.4 Preliminary project breakdown.

2. Deliveries of materials and similar logistically issues must also be factored into the schedule.
3. Finally, certain special activities tied to the physical properties of the materials or procedures required (e.g., curing of concrete, moisture content measures for soil compaction, etc.) must be included in the time schedule.

A well defined WBS facilitates the development of both preliminary and detailed schedules.

6.6 ESTIMATE DEVELOPMENT AND COST CONTROL RELATED TO THE WBS

A good WBS facilitates cost control during the life of the project.[2] Work packages are defined so that they have their own unique budgets. When referring to work packages in the context of cost control, the terminology “cost accounts” or “control accounts” is often used. During the bidding process, the contractor prepares an estimate of cost which becomes the basis for the bid price submitted for the proposed work. If the bid is accepted, the detail estimate used for bid submittal is converted to a *budget* which serves as a cost baseline to control spending during the life of the project. The concept of cost control is shown schematically in Figure 6.5.

Based on a refinement of the bid estimate, a control budget is prepared. The budget structure is tied to the breakdown of the project into major cost elements. For small and simple projects, such as the paving of a residential driveway the cost breakdown of the budget may consist of relatively few elements (e.g., labor, materials, equipment, special item, etc.). For larger and more complex projects however, the structure and level of detail of the cost breakdown is key to effective control of project spending. In the case of the gas station project, for instance, budgets for each of the work packages shown in Figure 6.3 would be developed. The summation on these individual work package budgets can then be used to track total project costs and determine an overall cost status for the project at any time during construction.

In large and complex projects (e.g., large buildings, manufacturing plants, etc.), a comprehensive WBS is required. Literally thousands of work packages must be defined and a consistent and reliable system of referring to these elements of the work breakdown

[2] If a WBS is used, the major items are work packages and the control accounts which are sub-elements of the work packages.

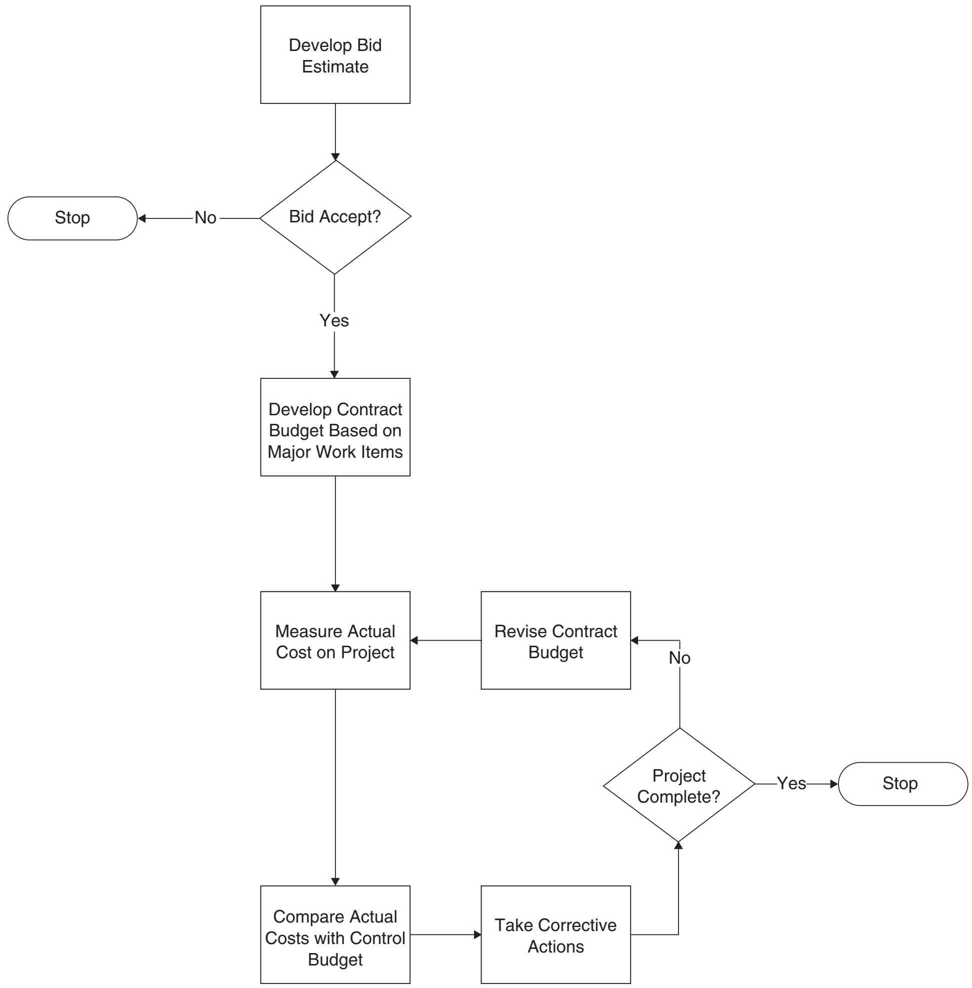


Figure 6.5 Cost Control Cycle.

is essential. To provide consistency and structure to the management of large cost control systems, a *code of accounts* is used as a template or guide in defining and cataloging the cost centers within a project. Several cost coding systems are presented in Chapter 15.

To be consistent with the WBS, such *cost coding systems* utilize a numerical or alphanumerical labeling which is multi-level or hierarchical in nature. This numerical labeling must be (1) suitable for computerization, (2) compatible with the company's financial accounting system, and (3) facilitate gathering and reporting of information for broad cost categories (e.g., cost of all slab concrete) and for highly detailed information (e.g., cost of labor for pump installation-pump 101 in the cooling tower). The cost accounting system should facilitate the aggregation or "rolling up" of costs. The hierarchical or multi-level nature of the WBS provides an excellent format for the collection and review of cost throughout the life of a complex project.

6.7 ROLE OF CODE OF ACCOUNTS

The development of cost coding systems is discussed in some detail in Chapter 15. In general, these labeling or coding systems focus on the multiple or hierarchical levels of cost spending typical of complex construction projects. Defining work packages, location of the work, material type, method of installation, and resources required help to establish the various levels of the breakdown. In cost code development, these identifiers can be

Table 6.2 Cost Code Structure (Example)

Level	Project	Area	Discipline	Trade
1	21300			
2		804		
3			724	
4				112

Cost Code = 21300 − 804 − 724 − 112

characterized in many ways. A typical cost code might define (1) the project designator, (2) area of work, (3) work discipline (e.g., civil, mechanical, electrical, etc.), and (4) the trade specialty required. Table 6.2 gives an example of how such a code might be developed. The code in Table 6.2. is 14 digits long. Therefore, computer databases which are used to store and retrieve cost information must be able to handle long numerical designators or labels such as the one shown here.

On complex or unique projects, preparation of work package budget control sheets may be appropriate. Such a sheet allows for collection of data regarding actual costs versus estimated cost for each work element or package. A typical sheet for the interior slab construction on the small gas station project is shown in Figure 6.6.

The sheet acts as documentation of the control budget for each work package. Locations for the base cost calculations for each resource type (e.g., materials, installed equipment, labor, and equipment) are provided. As work packages are completed, the "as-built" cost and productivity achieved are recorded. This is "back-up" material for the cost estimating database and can be used as a reference when estimating the cost of similar work in future. It also supports the comparison activity (e.g., Compare Actual Costs with Control Budget) in the flow chart of Figure 6.5.

Work Package Identification 06-123 Description: Concrete Placement Interior Floor Slabs						
	Materials					Actual Productivity
Resource Code	**Description**	**Unit**	**Qty**	**Unit Cost**	**Extension**	
101	Concrete, 2500psi	CY	30	40.00	1200.00	
	Installed Equipment					Notes
	Crew Labor	**NR**	**Hours**	**Cost/Hr**	**Extension**	Cost Summary
020	Foreman	1	8	30.00	240.00	Actual Cost
029	Laborer	4	8	15.00	480.00	Labor =
022	Finisher	1	8	20.00	160.00	Materials =
063	Pump Operator	1	8	25.00	200.00	Equipment =
				Total	1080.00	Variation from Budget
	Equipment Not Charged As Indirects					
		NR	**Hours**	**Cost/Hr**	**Extension**	
505	Vibrator	1	8	10.00	80.00	
517	Finisher	1	8	15.00	120.00	
308	Concrete Pump	1	8	150.00	1200.00	
				Total	1400.00	

Figure 6.6 Work Package Control Account Sheet.

6.8 SUMMARY

Construction project planning focuses heavily on time and cost control. Planning is a continuous task. Deviations from the original plan are the norm rather than the exception. Therefore, an organized approach to identifying change from the original plan is critical. It has been noted that:

> "In order to MANAGE, one should be able to CONTROL.
> In order to CONTROL, one should be able to MEASURE.
> In order to MEASURE, one should be able to DEFINE.
> In order to DEFINE, one should be able to QUANTIFY."
>
> D. Burchfield, 1970

The Work Break System (WBS) approach provides a rigorous way to quantify, define, measure, and control the elements or work packages of a given scope of work. Breaking a construction project into work elements to be managed is essential for both time and cost planning. In addition to time and cost planning, a number of other planning efforts are needed when constructing a facility. Decisions and supporting plans must be developed to address many dimensions of the project. The following is a partial list of other plans that must be developed:

1. Procurement Plan
2. Safety Plan
3. Subcontracting Plan
4. Quality Plan
5. Communication Plan
6. Organizational Plan
7. Completion and Start-up Plan

The effective manager is constantly involved in developing and updating plans. Planning is a never ending task. Therefore, one is continuously improving and perfecting the plan. "Planning is Everything."

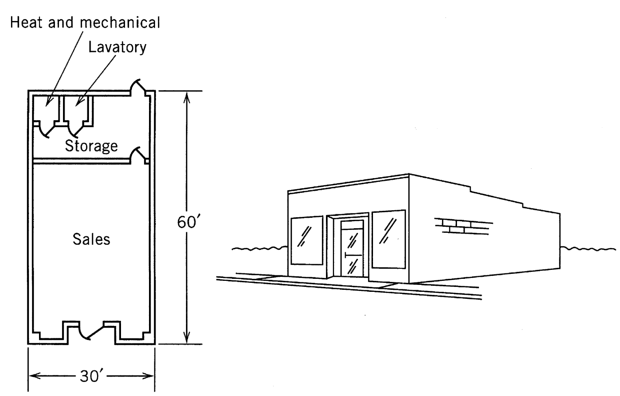
REVIEW QUESTIONS AND EXERCISES

6.1 Develop a two level Work Breakdown Structure consisting of at least 16 work packages for the building of the Brooklyn Bridge as described in Chapter 1.

6.2 Develop a preliminary work breakdown structure (WBS) for a small one-story commercial building to be constructed on the site of an existing small-frame structure. It is 30 by 60 ft in plan (see illustration). The exterior and interior walls are of concrete block. The roof is constructed of bar joists covered with a steel roof deck, rigid insulation, and built-up roofing. The ceiling is suspended acoustical tile. The floor is a concrete slab on grade with an asphalt tile finish. Interior finish on all walls is paint.

a. Show the first level of this structure for the total project (WBS is developed from top to the bottom).

b. Select one work package (or building system) of the first level and develop the second-level structure for this work package.



6.3 Describe how you would develop a subcontracting plan for the construction of a small child-care facility.

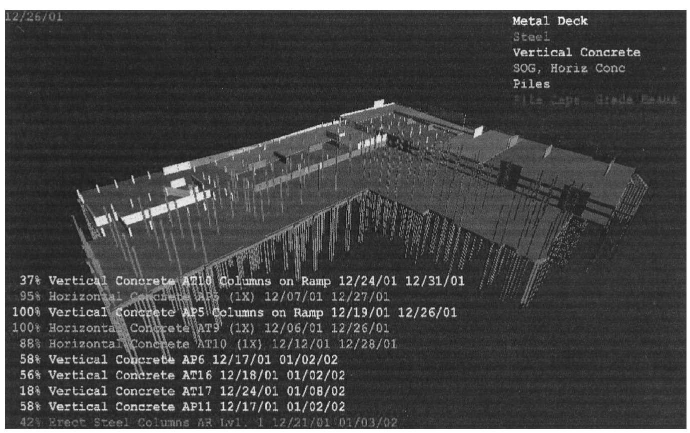
Chapter 7

Project Scheduling

4D Modeling

The Need

Traditional design and construction planning tools, such as 2D drawings and network diagrams, do not support the timely and integrated decision making necessary to move projects forward quickly. They do not provide the information modeling, visualization, and analysis environment necessary to support the rapid and integrated design and construction of facilities. Synthesis of construction schedules from design descriptions and integrated evaluation of design and schedule alternatives are still mainly manual tasks. Furthermore, the underlying representations of a design and a construction schedule are too abstract to allow the multiple stakeholders to visualize and understand the cross-disciplinary impacts of design and construction decisions.



Example of a 4D model. (Courtesy of M. Fischer, Common Point Technologies, Inc. and DPR Construction, Inc.)

4D technologies are now being used by planners, designers, and, engineers to analyze and visualize many aspects of a construction project, from the 3D design of a project to the sequence of construction to the relationships among schedule, cost, and resource availability data. These intelligent 4D models support computer-based analysis of schedules with respect to cost, interference, safety, etc., and improve communication of design and schedule information.

The Technology

Extending the traditional planning tools, visual 4D models combine 3D CAD models with construction activities to display the progression of construction over time. However, 4D models are very time-consuming to generate manually and cannot currently support analysis programs. The difficulty and cost of creating and using such models are currently blocking their widespread adoption. The construction knowledge necessary to build 4D models has been formalized and developed by a methodology that guides project planners in generating 4D models from 3D product models. This formalized knowledge enables project managers to create and update realistic schedules rapidly and to integrate the temporal and spatial aspects of a schedule as intelligent 4D models.

7.1 INTRODUCTION

As noted in the previous chapter, time planning is among the most important aspects of successful project management. The concept of project scheduling addresses the issues associated with time planning and management. Early scheduling methods utilized simple bar charts or Gannt charts to achieve a very simple and straightforward representation of time and work activity sequencing. During the past 40 years network based scheduling methods have become the norm, and many contracts require the use of network schedules to reflect project progress to the owner/client. Simple barcharting concepts as well as network scheduling concepts will be introduced in this chapter.

7.2 BAR CHARTS

The basic modeling concept of the bar chart is the representation of a project work item or activity as a time scaled bar whose length represents the planned duration of the activity. Figure 7.1(a) shows a bar representation for a work item requiring four project time units (e.g., weeks). The bar is located on a time line to indicate the schedule for planned start, execution, and completion of the project work activity.

In practice the scaled length of the bar is also used as a graphical base on which to plot actual performance toward completion of the project work item see Fig. 7.1(b). In this way the bar chart acts both as a planning-scheduling model and as a reporting-control model. In this use of the bar chart, the length of the bar has two different meanings:

1. The physical length of the bar represents the planned duration of the work item.

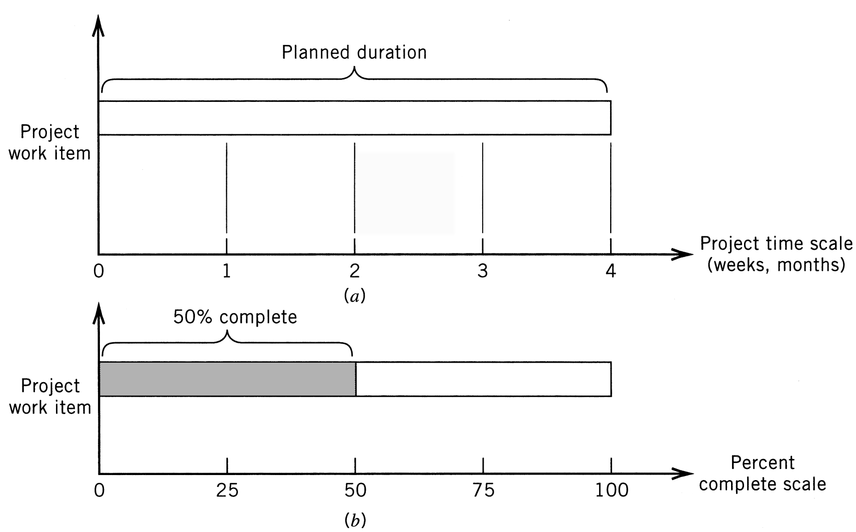


Figure 7.1 Bar chart model: (a) plan focus and (b) work focus.

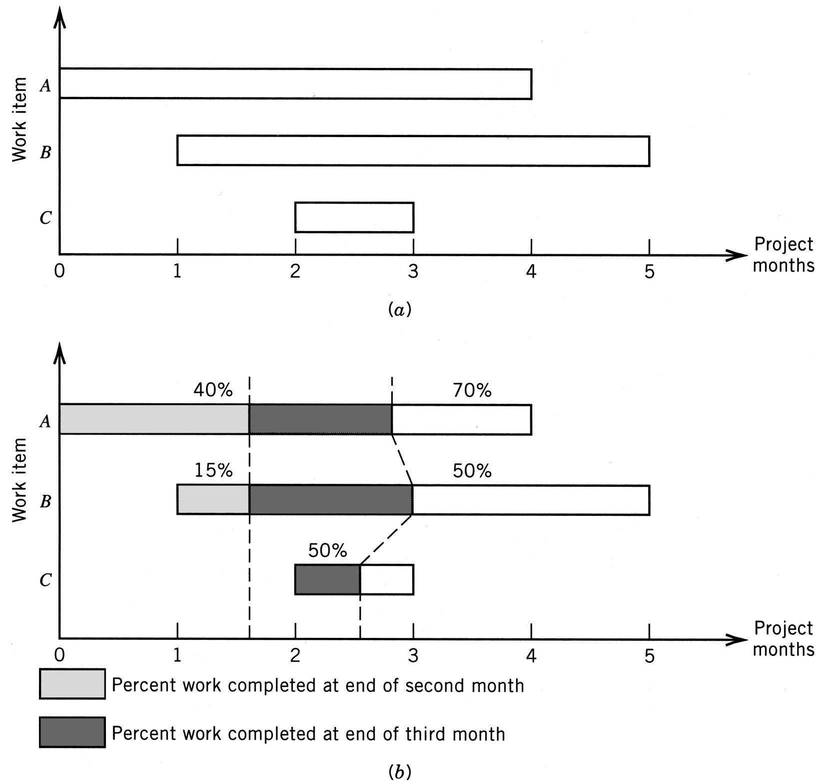


Figure 7.2 Bar chart project models: (a) bar chart schedule (plan foucs) and (b) bar chart updating (control focus).

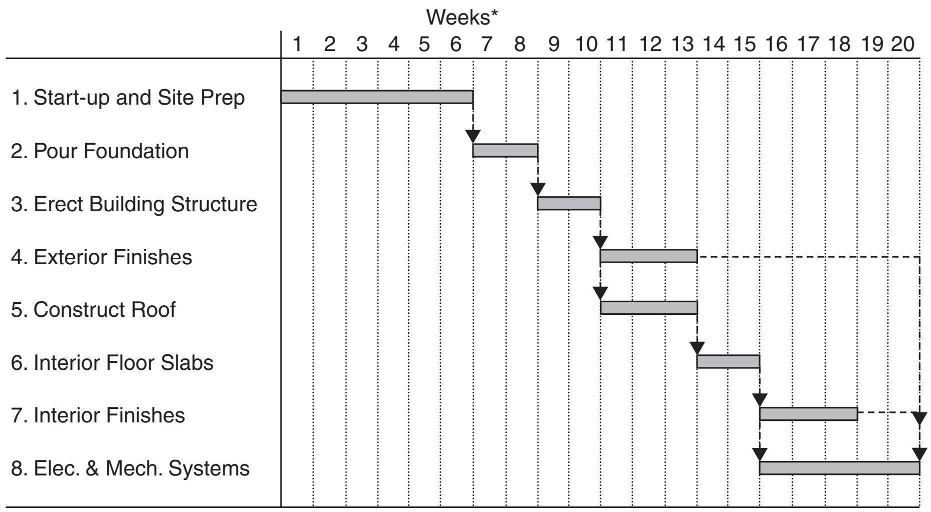
2. It also provides a proportionally scaled baseline on which to plot at successive intervals of time, the correct percentage complete.

Figure 7.1(b) shows a bar for a project work item that has been half completed. In a situation where the work rate is constant and field conditions permit, this would occur in half the planned duration. If, however, actual work rates vary from time to time according to resource use and field conditions, then the work will be half completed sooner or later than half the planned duration. In this modeling concept actual work progress is modeled independently of the actual time scale of the bar chart.

Figure 7.2(a) shows a schedule for a project consisting of three activities. Activity A is to be carried out in the first four months, activity B in the last four months, and activity C in the third month. Actual progress in the project can be plotted from time to time on these bars as shown in Figure 7.2(b).

In this manner, project status contours can be superimposed on the bar chart as an aid to management control of the project. By using different shading patterns, the bar chart can indicate monthly progress toward physical completion of the activities.

Project bar chart models are developed by breaking down the project into a number of components. In practice the breakdown rarely exceeds 50 to 100 work activities and generally focuses on physical components of the project. If a project time frame is established, the relative positioning of the project work activities indicates the planned project schedule and the approximate sequence of the work. One disadvantage of the traditional bar chart is the lack of precision in establishing the exact sequence between activities. This problem can be addressed by using directional links or arrows connecting the bars to give a precise indication of logical order between activities. This connected diagram of bars is referred to as a bar-net.



*Weeks are assumed to be working weeks consisting of 5 working days.

Figure 7.3 Preliminary Bar-Net Schedule for the Small Gas Station.

A bar-net showing the major activities defined in the preliminary project breakdown diagram for the small gas station (Figure 6.4) is shown in Figure 7.3. The bars are positioned in sequence against a time line. The sequence or logic between the bars is formalized by connecting the end of the preceding bar to the start of the following bar. For instance, the end of bar 3. Erect Building Structure is connected using a directional link or arrow to the two activities that follow it (activities 5 and 4). The use of directional arrows to connect preceding and following activities leads to the development of a preliminary scheduling document called a bar-net. This is a schedule that combines the graphical modeling features of the bar (e.g., length to indicate duration, and scaling to a time line) with the sequencing features of directional arrows. Positioning the eight activities as bars in their logical sequence using the arrow connectors against a time line plotted in weeks allows us to visually determine that the duration of the entire project is roughly 20 weeks.

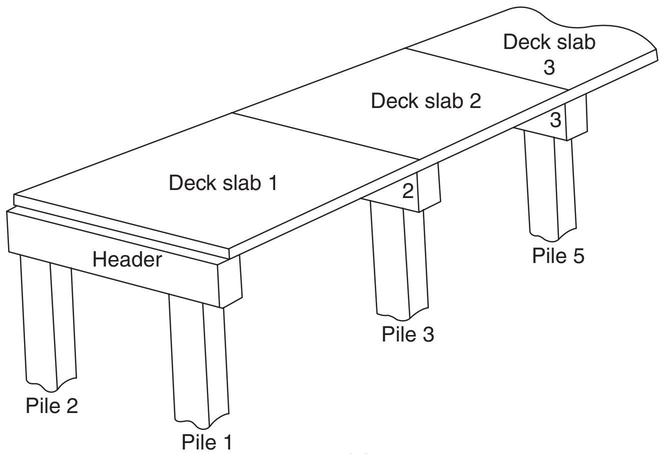
This bar-net diagram also allows one to determine the expected progress on the project as of any given week. For example, as of week 11, activities 1, 2, & 3 should be completed. Activities 4 and 5 should be in progress. If we assume a linear rate of production (i.e., half of a two-week activity is completed after one week), we could assume that 1/3 of 4 and 5 will be completed as of the end of week 11.

A bar-net is a somewhat more sophisticated version of a bar chart which emphasizes the sequencing of the activities by using arrow connectors. Use of this arrow connection approach to show logical order will be a key element of developing network schedules to be discussed later in Section 7.5.

7.3 SCHEDULING LOGIC

In order to develop a schedule, the logical sequence or scheduling logic which relates the various activities to one another must be developed. In order to gain a better understanding of the role played by sequencing in developing a schedule, consider, a simple pier made up of two lines of piles with connecting headers and simply supported deck slabs.

A schematic view of a portion of the pier is shown in Figure 7.4(a). The various physical components of the pier have been identified and labeled. An exploded view of the pier is shown in Figure 7.4(b), which shows each physical component individually separated but



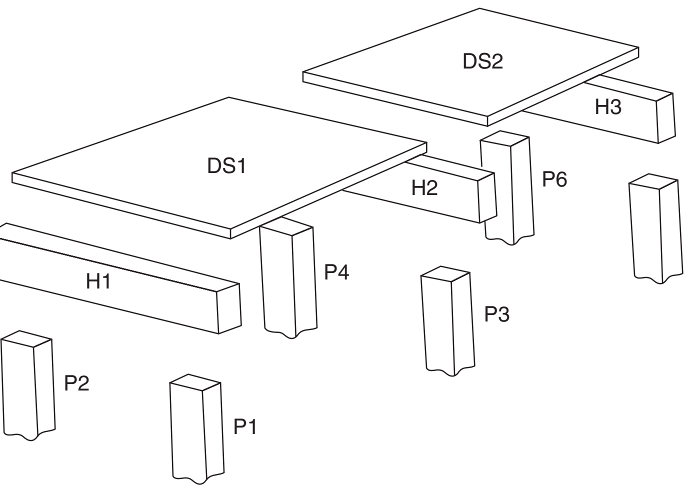


Figure 7.4 Simple schematic models. (a) Schematic view of pier. (b) Exploded view of pier. (Antill and Woodhead, 1982).

in the same relative positions. Notice that abbreviated labels have now been introduced. Clearly, these figures are schematic models (i.e., not physical models), but they have rather simple conceptual rules so that the physical relationship between the components of the structure is clear.

Now suppose that each component or element is represented by a labeled circle (or node). Figure 7.5 gives a "plan" view of the pier components shown in Figure 7.4. Such an abstraction or model can be used as the basis for portraying information about the physical makeup of the pier or about the order in which the physical components will actually appear on the site.

For example, an indication of the adjacency of physical components or the relational contact of physical components may be required. A model to portray these properties requires a modeling element (say a line) to indicate that the property exists. Assuming the modeling rationale of Figure 7.6(a), the various nodes of Figure 7.5 can be joined by a series of lines to develop a graph structure portraying the physical component adjacency or contact nature of the pier. If the idea of contact is expanded to indicate the order in which elements appear and physical contact is established, a directed line modeling rationale may be used, as shown in Figure 7.6(b). Using this conceptual modeling rule, Figure 7.7 can

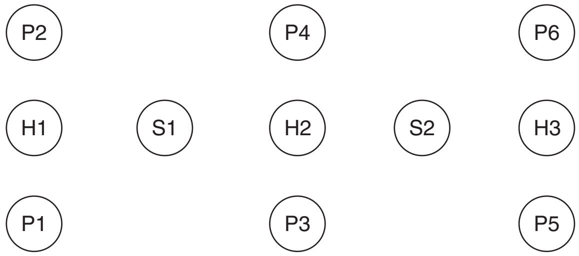


Figure 7.5 Conceptual Model of Pier Components.

be developed. This figure shows, for example, that header 1 (H1) can only appear (i.e., be built) after piles 1 and 2 (i.e., P1, P2) appear; in fact, header 1 is built around, on top of, and therefore in contact with piles 1 and 2. Finally, if the order of appearance of physical elements is to be modeled for all elements, whether or not in contact, a directional arrow such as that shown in Figure 7.6(c) may be necessary.

As an example of the above modeling techniques, consider the pier pile driving operation. A number of possible pile driving sequences are shown in Figures 7.8(a), (b), and (c). In Figure 7.8(a) it is assumed that the pile driving rig is swung by its mooring cables to drive the piles alternatively from one line to the next (i.e., P1, P2) before being relocated for the next set of piles (P3, P4), and so forth. In Figure 7.8(b) the pile driving sequence is along one line first (i.e., piles P1, P3, P5) and then along the other line (P2, P4, P6, etc.). Figure 7.8(c) shows a situation that may result if field events interrupt the planned sequence. In this case the figure indicates a situation where, for example, pile 2 (P2) is broken or lost during pile driving operations, so that to conserve time the pile driving rig moves on to drive piles P4 and P3 and then returns to re-drive a new pile P2 before resuming normal pile driving sequences. This situation is common in practice and indicates the major difficulty with scheduling models in relation to what actually happens in the field.

Figure 7.8(d) indicates the basic modeling rationale of bar charts wherein specific identification with individual piles is hidden. First, it implies the concept that each pile requires a certain time to appear in its driven position on site; second, it implies that the actual sequence of driving piles on the site is not absolutely fixed or essential to field management.

In order to schedule a project, the sequence of activities and their relationship to one another must be defined. The use of directional links or arrows provides a flexible modeling technique which establishes the scheduling logic or sequence of activities within a project.

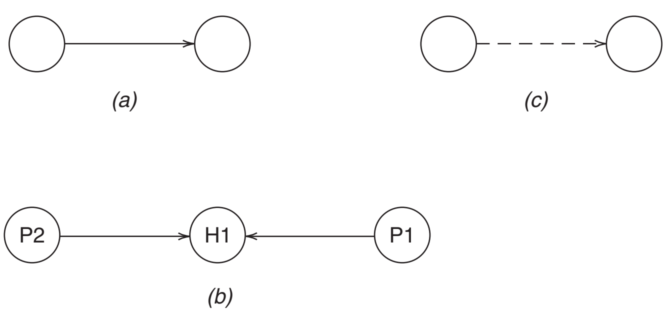


Figure 7.6 Logical modeling rationales. (a) Adjacency of contact modeling. (b) Physical structure order modeling. (c) Physical construction order modeling.

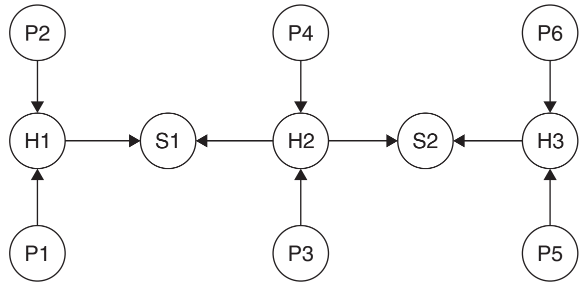


Figure 7.7 Conceptual model of pier component relationships.

7.4 SCHEDULING NETWORKS

A scheduling network consists of nodes and links. Depending on the notation, the nodes may represent events in time or activities. In Figure 7.9(a), nodes are used to represent events marking the beginning or ending of an activity. In Figure 7.9(b), a single larger node is used to represent an activity (e.g., "Activity A") with a duration of 10 days. Similarly, links may be used to represent activities or to indicate the logical sequence between activities. In order to show sequence, links become directional and are converted to arrows by the addition of an arrowhead. In Figure 7.9(a), the directional link represents an activity which begins on node i and ends on node j. The length of the link implies duration similar to the length of a bar in a bar chart. The arrow head implies that the activity begins on one node (i.e. "i") and ends on another. Figure 7.9(b) shows directional links which place activity "A" in a logical sequence relating it to other activities. The left-hand arrow links A to a preceding activity. The right-side arrow leads to a following activity.

Networks of activities can be constructed using the nodes and directional links or arrows. In Figure 7.10(a), a network of activities is shown in which nodes represent the activities and arrows represent the sequence or relationship of the various activities to one another. For instance, activity E is preceded by activities B and C. Activity E is followed by activity F. This network format is called *activity on node* or *precedence notation*.

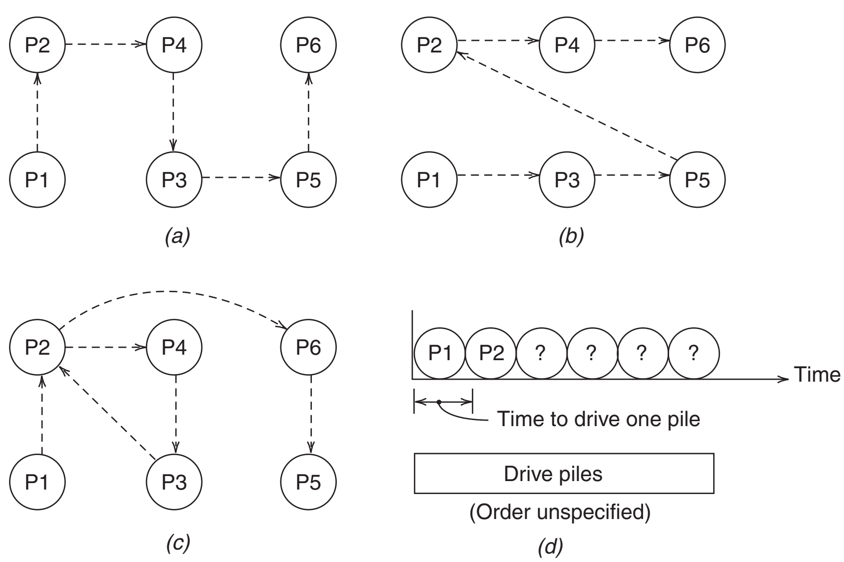


Figure 7.8 Construction sequence and activity modeling. (a) Alternate row pile driving. (b) Sequential row pile driving. (c) Field mishap alteration to pile driving sequence. (d) Bar chart model of pile driving operation. (Antill and Woodhead, 1982.)

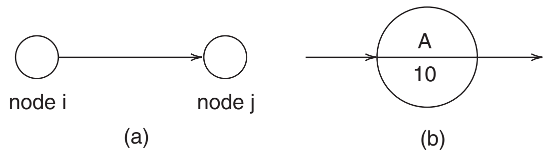


Figure 7.9 (a) node to represent an event. (b) node to represent an activity.

In Figure 7.10(b), the same group and sequence of activities are shown with the nodes representing events in time and the arrows representing activities. The nodes represent the beginnings and endings of activities (i.e., events in time). It will be noted that in order to indicate that activity E is preceded by both activities B and C, an extra activity called a "dummy" activity has been inserted between nodes 3 and 4. The reason the dummy activity is needed is to avoid a logical anomaly or mistake. If activity B ends directly on node 4 as shown in Figure 7.11, the sequence is incorrect. Activity B does precede both activities D and E (correct), but now the logic indicates that activity C precedes both activities D and E. We know, however, from Figure 7.10(a), that C only precedes E and has no connection with activity D. Therefore, the network in Figure 7.11 is not equivalent to that shown in Figure 7.10(a). To correct for this, the "dummy" activity (shown as a dashed arrow) is inserted. Now activity B is connected to activity E, but C has no connection with D. The use of the arrows to represent activities is called *Activity on Arrow*, *AOA* or *arrow notation*. It is sometimes referred to as "i-j" notation since, as noted in Figure 7.9(a), the activities are defined as beginning on a generic node i and end on a node j.

Activity networks have become the most common method for scheduling projects involving complex sequences of activities or activity paths. In the late 1950s, Kelly and Walker demonstrated that in activity networks a longest path of activities can be identified using simple mathematical methods.[1] The longest path or paths define a set of activities which control the total duration of the project represented by the network. The set of activities represented by the longest path can also be considered "*critical*," since if one or more of the critical activities are delayed, the total project duration will be extended. Kelly and Walker called their approach to scheduling the *Critical Path Method* or CPM.

At the time Kelly and Walker developed the basis for network scheduling and Critical Path calculations, they were involved in the management of complex industrial facilities being constructed by the DuPont Corporation. Methods such as bar charting could not capture the complex interlinking and interaction of scheduled activities. Knowledge of this interaction and its implication for meeting project completion dates required a more formal approach to include mathematical rigor and the ability to quickly update large and complex schedules. It was also important to be able to determine whether activity criticality was changed due to duration changes or scheduling delays. Within this framework, the iterative method we now call CPM or network scheduling was developed.

7.5 TYPICAL CPM ACTIVITY SEQUENCES

The network diagrams in Figure 7.12 illustrate some of the logical sequences used to develop CPM schedules using arrow notation. In part (1), it is obvious that A must precede B, and B must precede C. In (2), A must precede both B and C. In (3), A and B must precede C. In (4), A must precede C, and B must precede D. In (5), A must precede C and D, and B must precede D; this necessitates using a connecting arrow (called a dummy) to maintain

[1] Kelley, J. E. and M. R. Walker, *Critical Path Planning and Scheduling*, Proceedings of the Eastern Joint Computer Conference, December 1959, pp. 160–173.

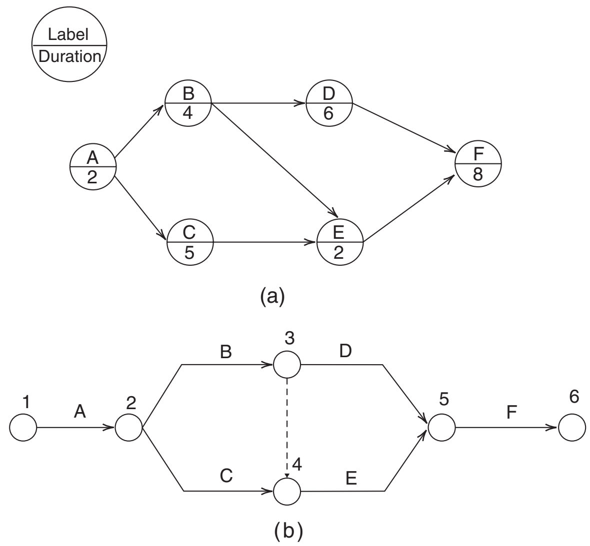


Figure 7.10 (a) Activity Network in Precedence Network. (b) Activity Network in Arrow Notation.

the logical sequence of events between A and D. Dummy activities have zero time duration; they are shown by broken arrows. Dummies may also be required to maintain specific activity identification between events, as shown in (6), where A must precede B and C, and B and C must precede D. Events and activities should be labeled, and they are usually numbered for computer identification of the network elements.

Figure 7.13 shows elements of a precedence notation network corresponding to the same activity sequences shown in Figure 7.12 in arrow notation.

Consider the simple construction of concrete footings, which involves earth excavation, reinforcement, formwork, and concreting. A preliminary listing of activities might be:

A. Lay out foundations.
B. Dig foundations.
C. Place formwork.
D. Place concrete.
E. Obtain steel reinforcement.
F. Cut and bend steel reinforcement.
G. Place steel reinforcement.
H. Obtain concrete.

Examination of the list of activities shows that some grouping is obvious (see Figure 7.14). Thus, considering physical constraints only, the following physical chains can be developed.

1. From a consideration of the actual footings: A, B, C, G, D.

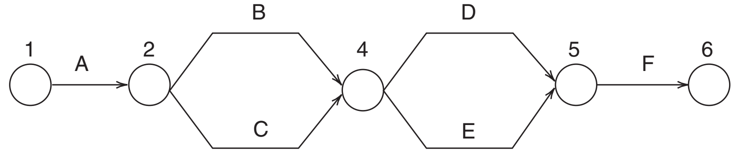


Figure 7.11 Mistake in Logical Sequence.

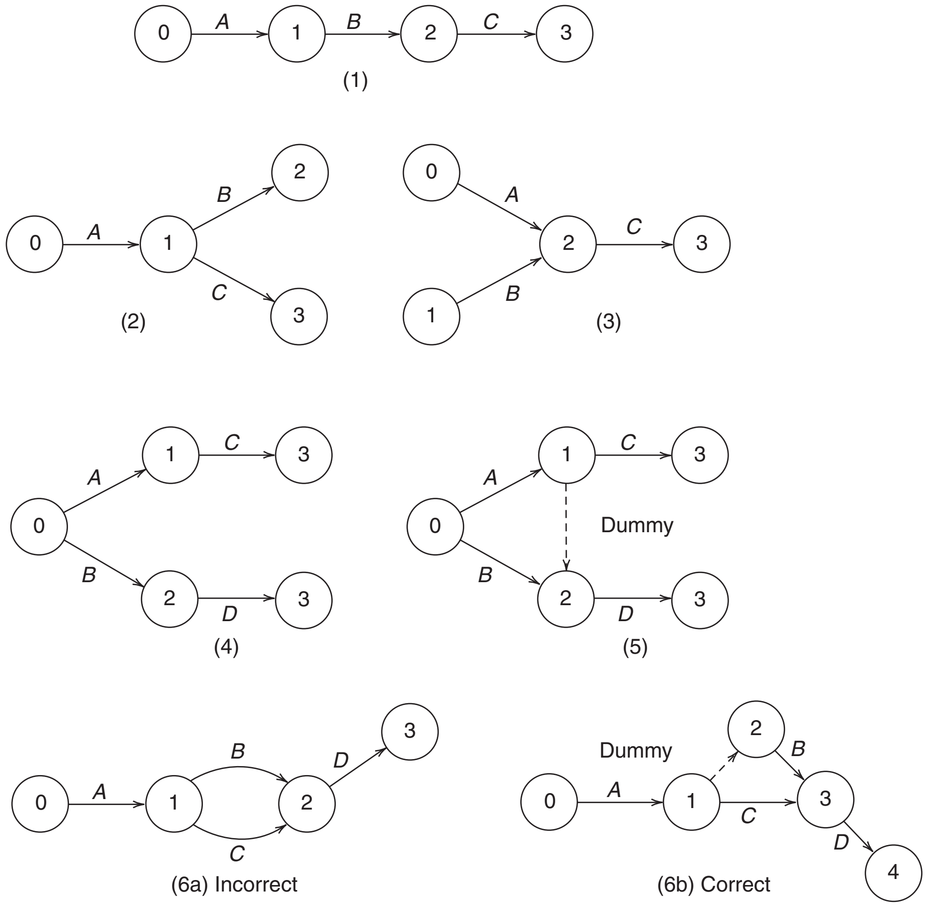


Figure 7.12 Elements of an arrow network. (After Antill and Woodhead, 1982).

2. From a consideration of the steel reinforcement: E, F, G, D.
3. From a consideration of the concrete only: H, D.

When the project is seen from these different viewpoints, individual chains of activities emerge; but, on viewing the job as a whole, it is obvious that interrelationships exist. For example, it is useless to pour concrete before the steel reinforcement is placed and the formwork is installed. Therefore, all the chains must merge before pouring the concrete. And if steps are to be taken to obtain the steel and the concrete immediately when work begins (this would be a management decision or constraint), then the chains all start at the same point or event with the laying out of the foundations.

The development of a preliminary network for the project is possible at this stage because first, a list of activities has been defined and second, a rough construction logic has emerged.

The actual representation and appearance of the network depend on the modeling form adopted and on the spatial locations of the symbols as drawn. As mentioned previously, there are two basic ways in which activities can be modeled: (1) when the activities are represented by "arrows" in an activity-oriented network and (2) when the activities are represented by "nodes."

In Figure 7.14 a preliminary network is developed, in both arrow and circle forms, from the above information.

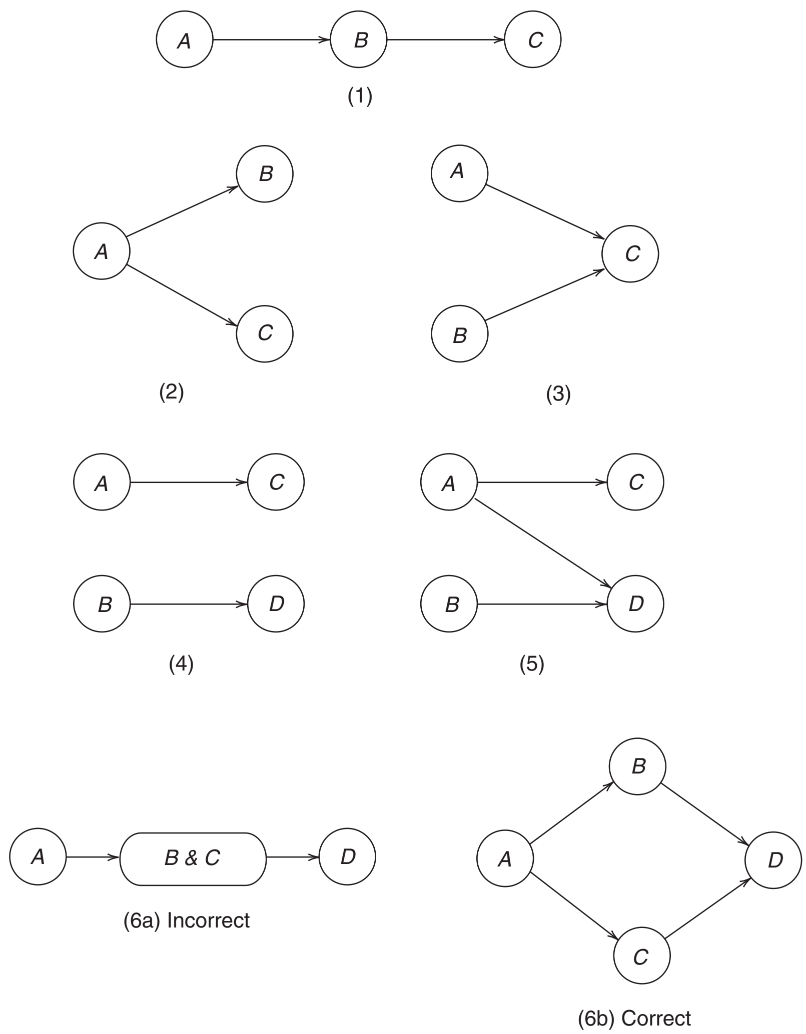


Figure 7.13 Elements of a precedence network. (After Antill and Woodhead, 1982).

7.6 NETWORK SCHEDULE ANALYSIS USING PRECEDENCE NOTATION[2]

The objective of analyzing a project network is to:

1. Find the critical set of activities that establishes the longest path and defines the minimum duration of the project.
2. Calculate the early start times for each activity.
3. Calculate the late start times for each activity.
4. Calculate the float, or time, available for delay for each activity.

By definition, critical activities cannot be delayed without extending the project duration. Therefore, the float or amount of delay time associated with critical activities is zero. Activities that are critical lie along the longest path through the network.

In order to determine which path is the longest, a variety of methods have been developed. In this chapter, a method based on the use of two algorithms is used to identify the

[2] A discussion of network scheduling calculations using arrow notation is presented in Appendix E.

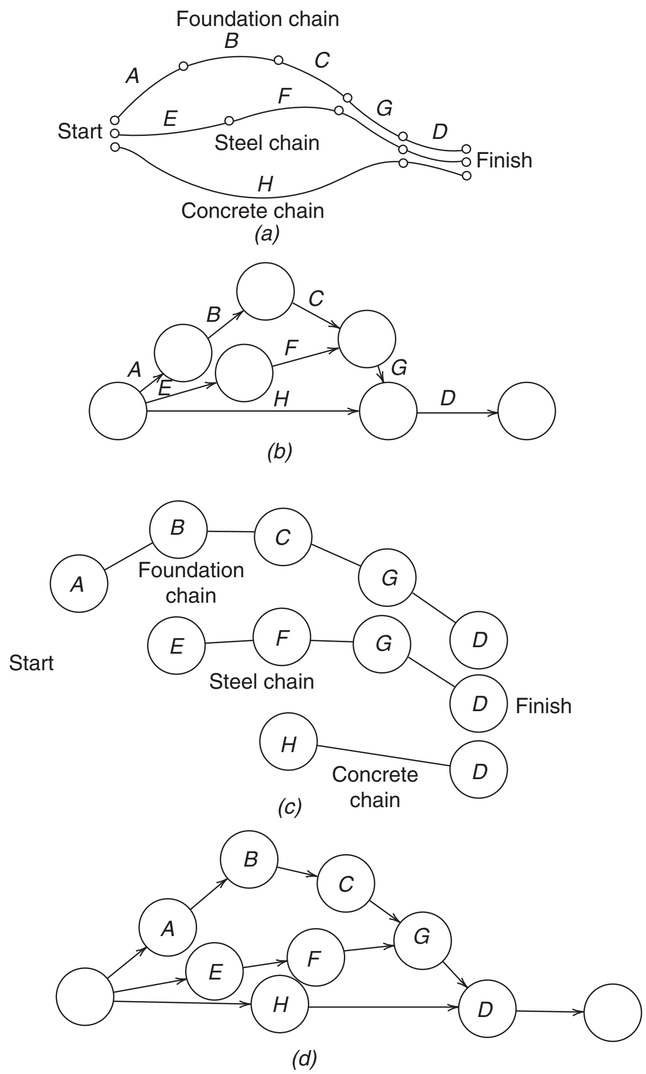


Figure 7.14 Preliminary network diagram. (a) Initial sketch, arrow notation. (b) First draft – arrow notation. (c) Initial sketch – precedence notation. (d) First draft – precedence notation. (After Antill and Woodhead, 1982).

longest and critical path. An algorithm is a formula, or recipe, that is repetitively applied to solve a problem in a stagewise manner. In solving for the critical path(s),[3] the *forward-pass algorithm* is used to calculate the earliest event times for each node. It also allows calculation of the minimum duration of the project. The *forward-pass algorithm* is not sufficient, however, to calculate the critical path consisting of the critical set of activities in the project.

In order to identify the critical path, a second algorithm, called the *backward-pass algorithm*, is needed. This algorithm allows for the calculation of the latest event times for each of the activities. Once the latest event times for each node have been determined, the critical activities and hence the critical path can be identified. Those activities for which the earliest and latest start times are the same are critical since they cannot be delayed without

[3] Sometimes there are multiple longest pathes which are equal in duration.

causing a delay in the total project completion time. Since the earliest and latest start times are the same, these activities have zero float.

Activities for which the earliest and latest start times are not the same can be delayed to a degree without delaying the total project. The amount (e.g., number of days) by which they can be delayed as noted above is called *float*. Such activities will have positive float and, therefore, are not critical. These activities can be delayed to the degree established by the float available without impacting the completion time of the total project.

When working in precedence notation, the forward-pass algorithm is applied to the first or source activity in the network. If there are multiple starting activities (i.e., nodes), then these multiple starts are connected to a single node called START to allow for a common source node to be used for commencing application of the algorithm. In effect, the calculations start at the leftmost or start activity node and the algorithm is applied in a "boot strapping" fashion until calculation of the late finish time of the final or END activity of the network has been calculated.

In order to demonstrate this method, consider the small precedence notation network shown below as Figure 7.15. The activities are shown as nodes or circles. The label for each activity is shown in the upper half of the circle, and the activity duration is shown in the lower half of the circle.

Four values will be calculated for each activity as shown in Figure 7.15 on the reference circle. These are:

$$\begin{aligned}
\text{EST(I)} &= \text{Early start time of activity I} \\
\text{EFT(I)} &= \text{Early finish time of activity I} \\
\text{LST(I)} &= \text{Late start time of activity I} \\
\text{LFT(I)} &= \text{Late finish time of activity I}
\end{aligned}$$

These four values for each activity will be calculated by starting at activity A and proceeding from left to right in the network. This calculation moving from left to right in time is called a "forward pass." Two equations form the basis of the forward pass algorithm as follows:

$$\boxed{\text{EFT(I)} = \text{EST(I)} + \text{DUR(I)}} \tag{7.1}$$

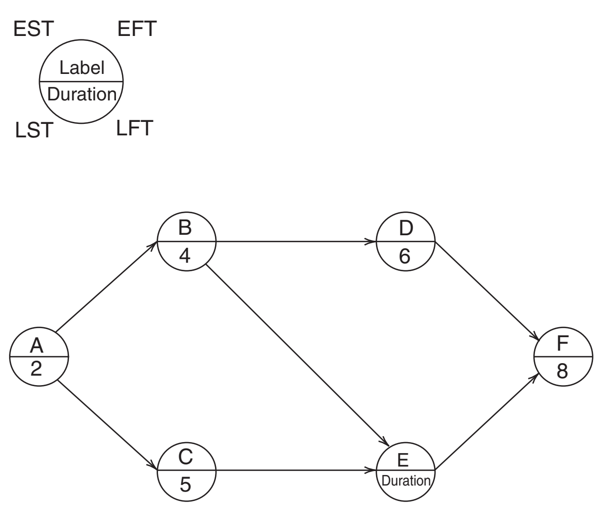


Figure 7.15 Precedence Notation Scheduling Network.

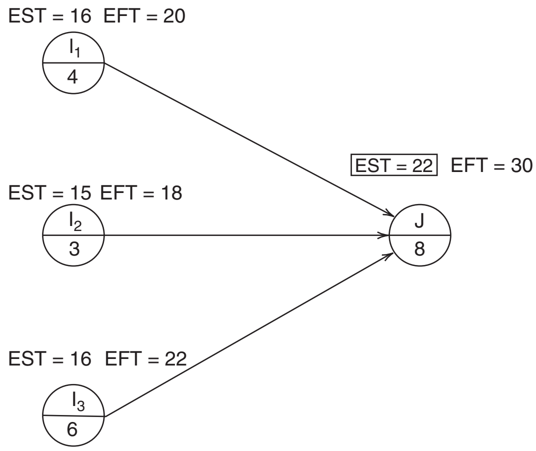


Figure 7.16 Calculation of EST(J).

where DUR(I) is the duration of the activity being considered. The early start is calculated based on the EFTs of the activities directly preceding the activity of interest as follows:

$$\boxed{\mathrm{EST}(J) = \max_{I \in M}^{\text{all } I} [\mathrm{EFT}(I)]} \tag{7.2}$$

where I is a member activity of the set of M activities that precede activity J.

A graphical illustration example of this equation is shown in Figure 7.16.

The EFT values of the three preceders shown in Figure 7.16 are 20, 18, and 22. Since the largest of these values is 22, the EST(J) = 22. The EFT values for each of the preceders were calculated using EFT(I) = EST(I) + DUR(I). Equations 7.1 and 7.2 define the calculations needed to perform the forward-pass algorithm.

Applying the forward-pass algorithm to the network shown in Figure 7.15 yields the following results for activities A through F.

Activity	Calculation	
A	EST(A) = 0	EFT(A) = 2
B	EST(B) = max[EFT(A)] = 2	EFT(B) = 2 + 4 = 6
C	EST(C) = max[EFT(A)] = 2	EFT(C) = 2 + 5 = 7
D	EST(D) = max[EFT(B)] = 6	EFT(D) = 6 + 6 = 12
E	EST(E) = max[EFT(B), EFT(C)] = max[6, 7] = 7	EFT(E) = 7 + 2 = 9
F	EST(F) = max[EFT(D), EFT(E)] = max[12, 9] = 12	EFT(F) = 12 + 8 = 20

This set of equations (algorithmic calculations) tells us that the earliest completion time for activity "F" is 20 days (assuming the durations given are in days). Therefore, the duration of the entire project is at least 20 days. In fact, the forward pass is sufficient to tell us that the duration of both the entire project and the critical or longest path is 20 days. The EST and EFT values for the network are shown plotted on each activity in Figure 7.17.

In order to identify the critical set of activities, a backward pass must be done. The backward pass provides for the calculation of the Late Start and Late Finish times for each activity. The critical set of activities and consequently the critical path within the network

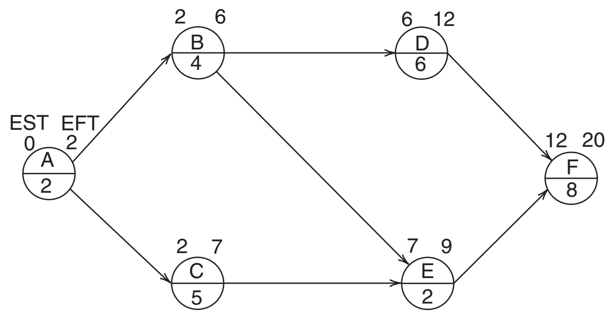


Figure 7.17 Calculation of the EST/EFT Values.

is defined by those activities which have LSTs and ESTs which are the same. (The LFTs and EFTs will also be the same for all critical activities). Since the early start and late start times are the same, any delay associated with a critical activity will cause the total project duration to be extended.

The backward-pass calculations utilize the following two equations.

$$\boxed{\text{LST(J)} = \text{LFT(J)} - \text{DUR(J)}} \tag{7.3}$$

$$\boxed{\text{LFT}(I) = \min_{J \in M}^{\text{all } J} [\text{LST}(J)]} \tag{7.4}$$

where J is a member activity of the set of activities M that follows activity I.

A graphical version of the application of Equation 7.4 is shown in Figure 7.18. The minimum of the LSTs for the three following activities is 28. Therefore the LFT(I) = 28.

Again, to get started on the backward pass, the LFT of the last activity F is assumed to be equal to the EFT of F. That is, LFT(F) = EFT(F) = 20. Calculations move from right to

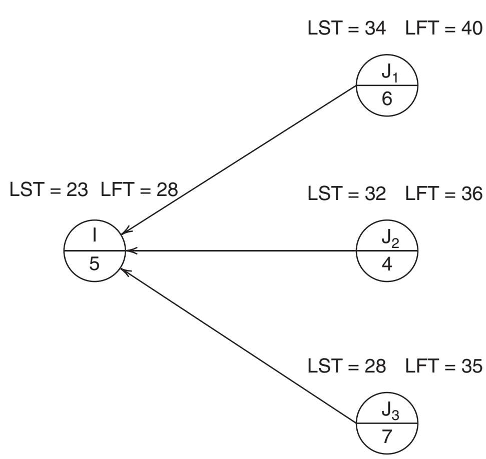


Figure 7.18 Calculation of LFT(I).

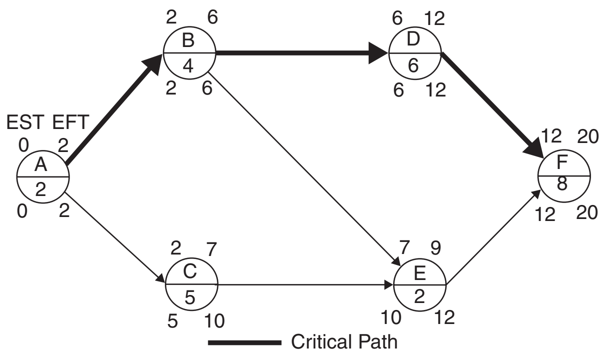


Figure 7.19 EST, EFT, and LST, LFT values for small precedence notation network.

left. Therefore,

$$\text{LST(F)} = \text{LFT(F)} - \text{DUR(F)} = 20 - 8 = 12$$

The other backward-pass calculations are as follows:

Activity	Calculation
E	LFT(E) = min[LST(F)] = 12
	LST(E) = LFT(E) − DUR (E) = 12 − 2 = 10
D	LFT(D) = min[LST(F)] = 12
	LST(D) = LFT(D) − DUR(D) = 12 − 6 = 6
C	LFT(C) = min[LST(E)] = 10
	LST(C) = LFT(C) − DUR(C) = 10 − 5 = 5
B	LFT(B) = min[LST(D), LST(E)]
	= min(6, 10) = 6
	LST(B) = LFT(B) − DUR(B) = 6 − 4 = 2
A	LFT(A) = min[LST(B) − LST(C)]
	= min(2, 5) = 2
	LST(A) = LFT(A) − DUR(A) = 2 − 2 = 0

If the calculations are performed correctly, the EST and LST of the initial activity (e.g., Activity A) should be zero (0). That is, the forward- and backward-pass calculations should close to an EST of zero for the source activity.

The critical path activities will satisfy the following relationship:

$$\text{LST(I)} = \text{EST(I)} \quad \text{which is equivalent to}$$
$$\text{LFT(I)} = \text{EFT(I)}$$

Therefore, all of the activities with ESTs and LSTs that are the same will be critical. The critical activities are A, B, D, and F.

Figure 7.19 shows the EST, EFT, LST, LFT values for all activities (A to F) as well as the critical path for this simple precedence notation network.

7.7 FLOAT CALCULATIONS WITH PRECEDENCE NOTATION

All activities that are not on the critical path can be delayed a certain number of time units (e.g., days) without causing an extension of the project duration. For noncritical activities four types of float can be defined. Of these four types of float, three have a practical interpretation within the context of a construction project. The four types of float are shown schematically in Table 7.1. The table also includes the formula for calculating each type of float.

Total float is the total, or maximum, number of time units that an activity can be delayed without increasing the total project duration. In calculating the amount of float, it is useful to think in terms of the "window" of time available for each activity to occur. For a critical activity, the window available for it in the schedule is just large enough to fit the duration of the activity. Therefore, a critical activity has zero float. For non-critical activities, the window is larger and accommodates some amount of delay without impacting the total project duration. The window of time available is defined by the Early Start Time (EST) and the Late Finish Time (LFT) of the activity being considered. This opens the window of time available to its maximum position. Given this maximum open position of the available time window, the activity is inserted as shown in Table 7.1.

The bar representing the activity is placed so that its start is at the EST(I) position. Having positioned the activity bar in this manner, the amount of time between the LFT(I) and the EFT(I) is the total float. Written as a formula:

$$\mathrm{TF(I)} = \mathrm{LFT(I)} - \mathrm{EFT(I)}$$

Consider Activity E in the network of Figure 7.19. Then TF(E) = LFT(E) – EFT(E) = 12 – 9 = 3. This implies the Activity E can be delayed 3 days (e.g., time units) without delaying the overall duration of the project. The same calculation for Activity D yields:

$$\mathrm{TF(D)} = \mathrm{LFT(D)} - \mathrm{EFT(D)} = 12 - 12 = 0$$

This is what we would expect since D is a critical activity. Since the TF is zero, we cannot delay Activity D without causing an increase in the total project duration.

Use of all of the total float available to an activity may reduce the float available to activities that follow it in sequence. For instance, the TF(C) = LFT(C) – EFT(C) = 10 – 7 = 3. For each day that C is delayed, the float available to activity E will decrease. IF 2 days of float on C are used, this will decrease the total float available to E to one day. Therefore, total float cannot be used without potentially having an effect on following activities.

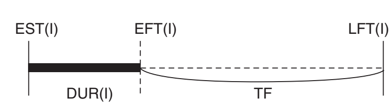
The second type of float that is important is *free float*. Free float is the amount of time (e.g., number of time units) that an activity can be delayed without impacting activities that follow it. In other words, the float is free in the sense that it can be used without reducing

Table 7.1 Four Types of Activity Float

Total Float

$$\mathrm{TF(I)} = \mathrm{LFT(I)} - [\mathrm{EST(I)} + \mathrm{DUR(I)}]$$
$$= \mathrm{LFT(I)} - \mathrm{EFT(I)}$$

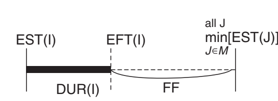
Where I is a member of the set of preceding activities.



Free Float

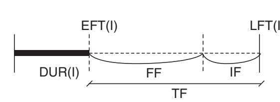
$$\mathrm{FF(I)} = \min_{J \in M}^{\text{all } J} [\mathrm{EST(J)}] - \mathrm{EFT(I)}$$

Where J is a member of the set of follower activities.



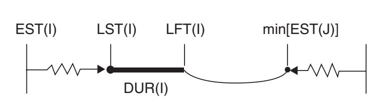
Interfering Float

$$\mathrm{IF(I)} = \mathrm{TF(I)} - \mathrm{FF(I)}$$



Independent Float

$$\mathrm{Ind.\ F} = \min_{J \in M}^{\text{all } J}[\mathrm{EST(J)}] - \mathrm{LFT(I)}$$



the float available to following activities. Again, the idea of the window of available time is useful in determining the free float. The left side of the window remains as it was for total float. That is, the left side of the window is defined by the EST(I) as shown in Table 7.1. The right side of the "window," however, closes to the point defined by the minimum EST of the following activities. This may reduce the overall "width" of the window. Therefore, the formula for free float is:

$$\mathrm{FF(I)} = \min_{J \in M}^{\text{all } J}[\mathrm{EST(J)}] - \mathrm{EFT(I)}$$

where M is the set of activities which follow I and J is a member of that set. In the next section, this formula will be used to determine whether there is FF available on any of the activities in a more complex network schedule. Applying this formula to activities C and E we find:

$$\mathrm{FF(C)} = \min\,[\mathrm{EST(E)}] - \mathrm{EFT(C)} = 7 - 7 = 0$$
$$\mathrm{FF(E)} = \min\,[\mathrm{EST(F)}] - \mathrm{EFT(E)} = 12 - 9 = 3$$

This implies that any use of the TF(C) is not "free" and may, as we have discussed, take float away from activities which follow it. TF(E) and FF(E) are both 3. Therefore, using any float available to activity on E will not "rob" float available on following activities. In this sense, use of this float is free.

Interfering float is the amount of the total float utilized that interferes with the following activities. It is defined as:

$$\mathrm{IF(I)} = \mathrm{TF(I)} - \mathrm{FF(I)}$$

The interfering float for activity C is:

$$\mathrm{IF(C)} = \mathrm{TF(C)} - \mathrm{FF(C)} = 3 - 0 = 3$$

This implies that although 3 days of delay can occur on activity C without impacting the total project duration, each day of IF used in conjunction with activity C will "interfere" with the float available for following activities.

The last type of float to be considered here is called the *independent float*. In this case, the left side of the window shown in Table 7.1 is defined by the LST of the activity rather than the EST. The right side of the window is the same as for free float. The independent float is given by the formula:

$$\begin{aligned}\mathrm{Ind.\ F(I)} &= \min_{J \in M}^{\text{all } J}\,[\mathrm{EST(J)}] - (\mathrm{LST(I)} + \mathrm{DUR(I)})\\ &= \min_{J \in M}^{\text{all } J}\,[\mathrm{EST(J)}] - [\mathrm{LFT(I)}]\end{aligned}$$

In some cases, the independent float will be negative. This can occur in some situations since the EFT(I) is later in time than the earliest EST of the following activities. In effect, the left side of the "window" is near or later than the right side. If the Ind. F is positive, this implies that float exists even if preceding activities use all of their float and no float is taken from the following activities.

As a practical matter the two floats that are of greatest interest are the *total float* and the *free float*. Floats not only indicate the amount of flexibility available for the activities that are not critical. Floats are also used in situations where one contractor is accused of delaying the project through failure to complete at the times specified in the schedule. In such disputes, it is important to determine how much float was available, who utilized the float, and who "owned" the float. The owner of the float is the party who is authorized to allocate the use of float. This may be a matter established in the contract documents or, failing contractual specification, may be determined by case law and legal precedent.

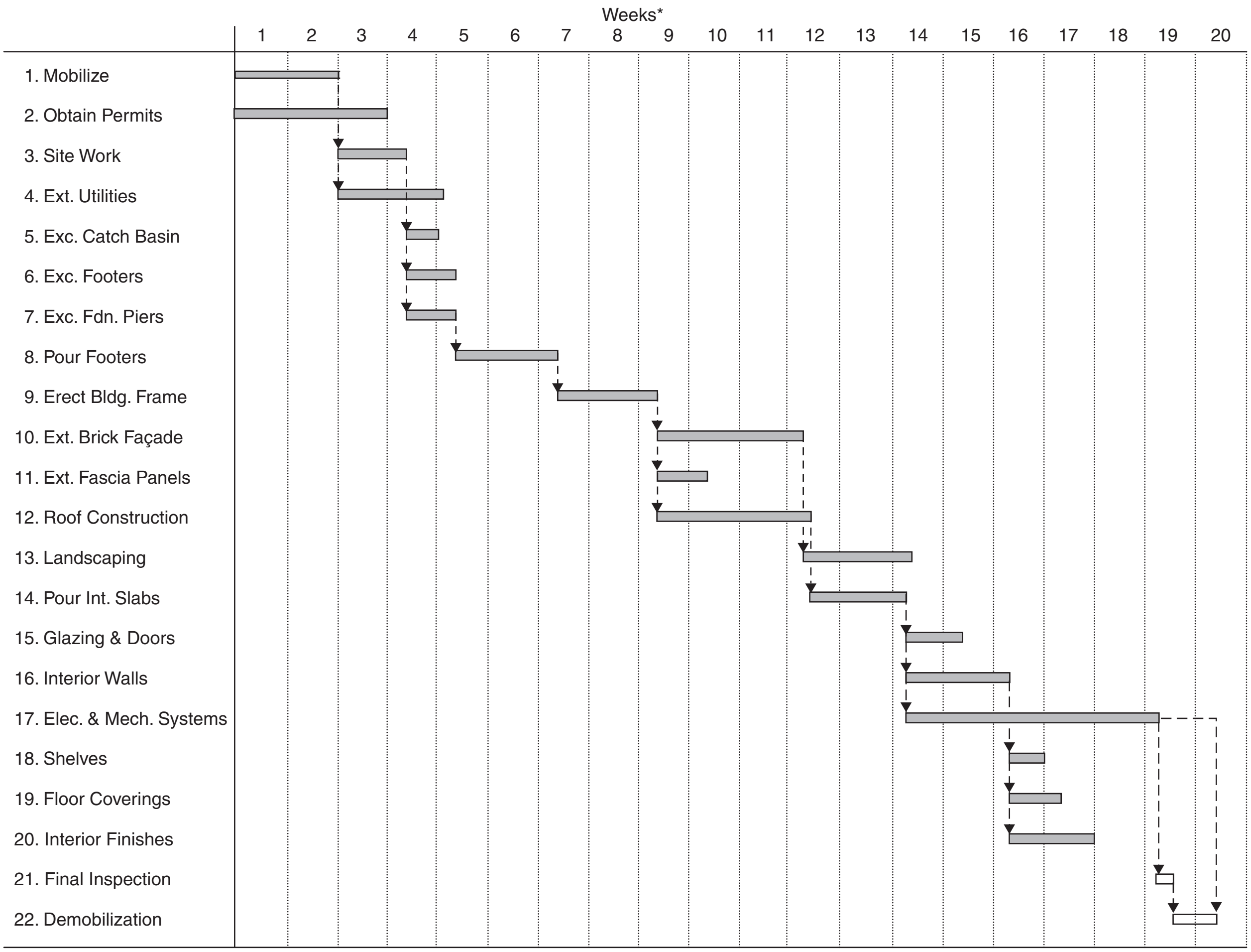
7.8 DEVELOPING A SCHEDULE FOR THE SMALL GAS STATION (PRECEDENCE NOTATION)

Using the bar-net shown in Figure 7.3 and information from the WBS given in Figure 6.3 for the small gas station, the original eight activities can be expanded to a set of 22 activities providing a more comprehensive scheduling framework for this project. The next step in scheduling is to assign durations to each of the activities. The scheduler must consult with field personnel and get the best estimate of the duration for each activity based on the methods selected for accomplishing the work, the resources available, and the experience the field management has in estimating productivity and time durations with these methods and resources.

For instance, based on the crew size, the equipment available, and the method of placement, the field superintendent can establish how long it will take to cast the concrete footers. The superintendent will know whether the concrete is to be mixed on site or brought in using a transit mix truck. He will also know the type of forms to be used, the nature of the reinforcement to be installed, the nature of any embedments and penetrations required, and the placement and number of anchor bolts required for the building structure. The estimate of duration for a given activity is given in working days. Table 7.2 gives a listing of the expanded list of activities together with estimated durations for each activity. An expanded

Table 7.2 Durations of Activities for the Small Gas Station

Activity	Title	Duration (Days)
1	Mobilize	10
2	Obtain permits	15
3	Site work	8
4	Exterior utilities	12
5	Excavate catch basin	2
6	Excavate footers	5
7	Excavate foundation piers	6
8	Pour footers, etc.	8
9	Erect bldg. frame	10
10	Exterior brick facade	14
11	Exterior fascia panels	4
12	Roof construction	15
13	Landscaping	12
14	Pour interior slabs	10
15	Glazing and doors	6
16	Interior walls	10
17	Elec. & mech. Systems	25
18	Shelves	3
19	Floor coverings	6
20	Interior finishes	8
21	Final inspection	1
22	Demobilization	3



*Weeks are assumed to be work weeks consisting of 5 working days.

Figure 7.20 Expanded Bar-Net Schedule for the Small Gas Station.

bar-net based on Table 7.2 and including the logical sequencing of the 22 activities is shown in Figure 7.20.

The bar-net has been used to develop a precedence network model of the small gas station project. This network is shown in Figure 7.21. The values of the ESTs and EFTs are shown above the circle representing each activity. Similarly, the LSTs and LFTs are shown below the activity circle.

The forward-pass algorithm is applied repetitively starting at the source node labeled START. All events related to the START node are given the value zero. Two activities (e.g., 1 and 2) follow the START node. Calculations for all of the activities are shown in Table 7.3. Calculated EST and LST values are shown on each activity in Figure 7.13. Based on the calculations in Table 7.3, it can be seen that the duration of the longest and therefore critical path in the network is 96 working days.[4] The minimum project duration based on this critical path analysis is 96 working days or slightly over 19 working weeks. If we are plotting the project duration in calendar days, this will equate to $(19 \times 7) + 1$ or 134 calendar days. If

[4] Working days are differentiated from calendar days. There are typically 5 working days in a week as opposed to 7 calendar days.

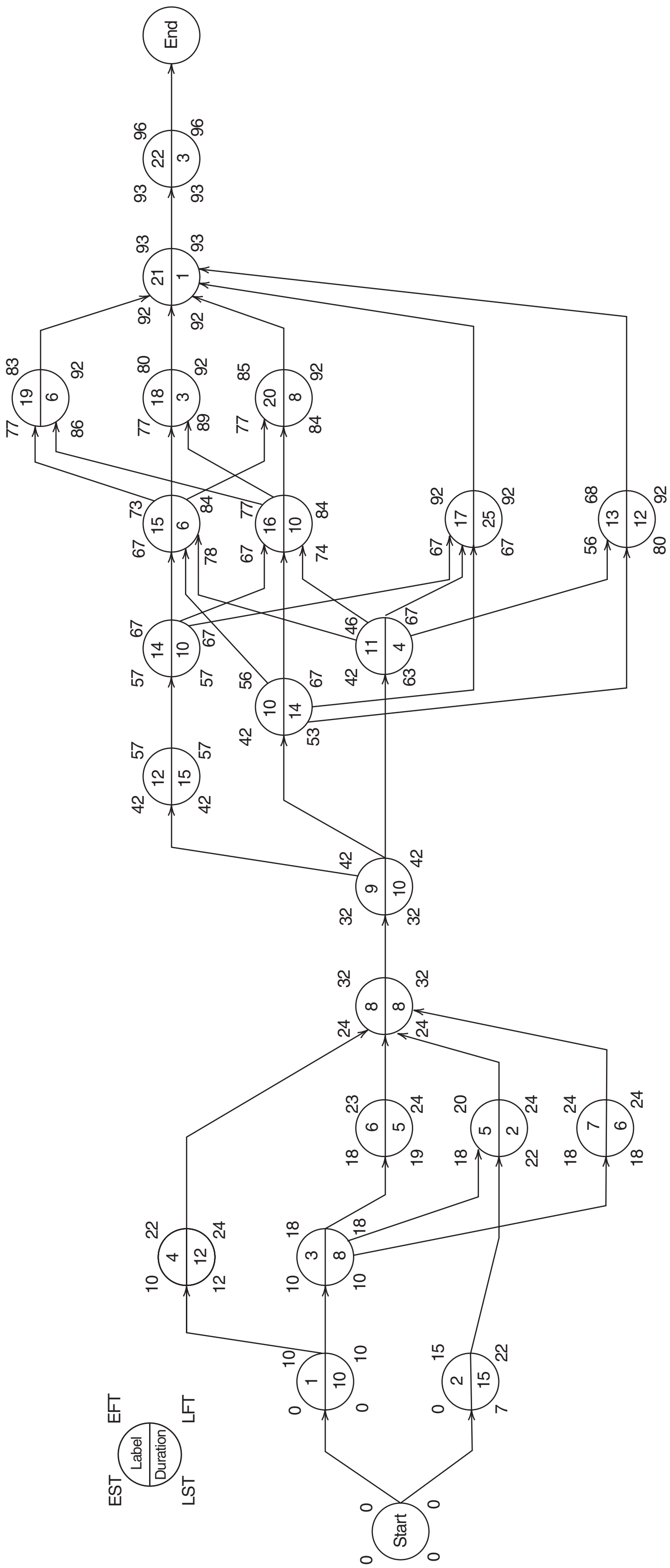


Figure 7.21 Expanded Network Schedule for the Small Gas Station Project.

Table 7.3 Forward-Pass Calculations for the Small Gas Station Project

Activity	Calculations	
Start	EST(START) = 0	EFT(START) = 0
1	EST(1) = max[EFT(START)] = 0	EFT(1) = 0 + 10 = 10
2	EST(2) = max[EFT(START)] = 0	EFT(2) = 0 + 15 = 15
3	EST(3) = max[EFT(1)] = 10	EFT(3) = 10 + 8 = 18
4	EST(4) = max[EFT(1)] = 10	EFT(4) = 10 + 12 = 22
5	EST(5) = max[EFT(2), EFT(3)] = 18	EFT(5) = 18 + 2 = 20
6	EST(6) = max[EFT(3)] = 18	EFT(6) = 18 + 5 = 23
7	EST(7) = max[EFT(3)] = 18	EFT(7) = 18 + 6 = 24
8	EST(8) = max[EFT(4), EFT(5), EFT(6), EFT(7)] = 24	EFT(8) = 24 + 8 = 32
9	EST(9) = max[EFT(8)] = 32	EFT(9) = 32 + 10 = 42
10	EST(10) = max[EFT(9)] = 42	EFT(10) = 42 + 14 = 56
11	EST(11) = max[EFT(9)] = 42	EFT(11) = 42 + 4 = 46
12	EST(12) = max[EFT(9)] = 42	EFT(12) = 42 + 15 = 57
13	EST(13) = max[EFT(10), EFT(11)] = 56	EFT(13) = 56 + 12 = 68
14	EST(14) = max[EFT(12)] = 57	EFT(14) = 57 + 10 = 67
15	EST(15) = max[EFT(10), EFT(11), EFT(14)] = 67	EFT(15) = 67 + 6 = 73
16	EST(16) = max[EFT(10), EFT(11), EFT(14)] = 67	EFT(16) = 67 + 10 = 77
17	EST(17) = max[EFT(10), EFT(11), EFT(14)] = 67	EFT(17) = 67 + 25 = 92
18	EST(18) = max[EFT(15), EFT(16)] = 77	EFT(18) = 77 + 3 = 80
19	EST(19) = max[EFT(15), EFT(16)] = 77	EFT(19) = 77 + 6 = 83
20	EST(20) = max[EFT(15), EFT(16)] = 77	EFT(20) = 77 + 8 = 85
21	EST(21) = max[EFT(13), EFT(17), EFT (18), EFT(19), EFT(20)] = 92	EFT(21) = 92 + 1 = 93
22	EST(22) = max[EFT(21)] = 93	EFT(22) = 93 + 3 = 96

the project is to begin on Monday March 1, the estimated project completion date will be July 12, 20xx.

The forward-pass calculations establish the minimum project duration (based on no delays to the critical activities). It does not, however, identify the critical path. In order to identify the critical set of activities that constrain the project to a minimum duration of 96 days, we must apply the backward-pass algorithm. To start the backward-pass algorithm, the LFT (END) is set to 96 days. This is equivalent to setting the LFT for activity 22 to 96 days. As we have just seen, based on our forward-pass calculations, the LFT of activity 22 cannot be less than 96 days. If we set LFT (22) to a duration greater than 96 days, the finish date for the project will be extended.

The calculations for the backward-pass are given in Table 7.4, and the LST and LFT values for each activity are shown in Figure 7.21.

7.9 FLOAT CALCULATIONS AND THE CRITICAL PATH

The critical set of activities can be identified as those which have zero float. Once the critical activities are identified, the critical path linking these activities can be established. Now that the forward-and backward-pass calculations have been completed, the floats can be calculated. The total, free, and interfering float for all activities in the small gas station network have been calculated in Table 7.5.

Table 7.4 Backward-Pass Calculations for the Small Gas Station Project

Activity	Calculations	
END	LFT(END) = 96	LST(END) = 96
22	LFT(22) = min[LST(END)] = 96	LST(22) = 96–3 = 93
21	LFT(21) = min[LST(22)] = 93	LST(21) = 93–1 = 92
20	LFT(20) = min[LST(21)] = 92	LST(20) = 92–8 = 84
19	LFT(19) = min[LST(21)] = 92	LST(19) = 92–6 = 86
18	LFT(18) = min[LST(21)] = 92	LST(18) = 92–3 = 89
17	LFT(17) = min[LST(21)] = 92	LST(17) = 92–25 = 67
16	LFT(16) = min[LST(18), LST(19), LST(20)] = 84	LST(16) = 84–10 = 74
15	LFT(15) = min[LST(18), LST(19), LST(20)] = 84	LST(15) = 84–6 = 78
14	LFT(14) = min[LST(15), LST(16), LST(17)] = 67	LST(14) = 67–10 = 57
13	LFT(13) = min[LST(21)] = 92	LST(13) = 92–12 = 80
12	LFT(12) = min[LST(14)] = 57	LST(12) = 57–15 = 42
11	LFT(11) = min[LST(13), LST(15), LST(16), LST(17) = 67	LST(11) = 67–4 = 63
10	LFT(10) = min[LST(13), LST(15), LST(16), LST(17)] = 67	LST(10) = 67–14 = 53
9	LFT(9) = min[LST(10), LST(11), LST(12)] = 42	LST(9) = 42–10 = 32
8	LFT(8) = min[LST(9)] = 32	LST(8) = 32–8 = 24
7	LFT(7) = min[LST(8)] = 24	LST(7) = 24–6 = 18
6	LFT(6) = min[LST(8)] = 24	LST(6) = 24–5 = 19
5	LFT(5) = min[LST(8)] = 24	LST(5) = 24–2 = 22
4	LFT(4) = min[LST(8)] = 24	LST(4) = 24–12 = 12
3	LFT(3) = min[LST(5), LST(6), LST(7)] = 18	LST(3) = 18–8 = 10
2	LFT(2) = min[LST(5)] = 22	LST(2) = 22–15 = 7
1	LFT(1) = min[LST(3), LST(4)] = 10	LST(1) = 10–10 = 0

Those activities with zero float are noted in Table 7.5 with an asterisk. The critical set of activities consists of activities 1, 3, 7, 8, 9, 12, 14, 17, 21, and 22. Based on the activities which have zero total float, the critical path can be identified in Figure 7.21. As a practice exercise verify that the duration the critical chain of activities is 96 days. Now take several paths through the network and verify that the total duration of each of these non-critical paths is less than 96 days.

To better understand the concepts of float in this project network consider the non-critical activity 15. This activity has 11 days of total float. The window of time available for installing glazing and doors allows for slippage of up to 11 days without extending the total duration of the project. Since the free float is 4 days, this means that the activity can be delayed 4 days from its EST without impacting any following activities. The interfering float is 7 days, so that after four days of delay, float used will impact activities which follow activity 15 (e.g., 18, 19, and 20).

7.10 SUMMARY

A number of techniques exist for time planning, scheduling, and control of construction projects. Each has strengths and weaknesses. In this chapter, the concepts of bar charting, bar-nets, and network scheduling have been introduced. These techniques are used widely, and critical path analysis or CPM is often required by contract when constructing even relatively small projects. For complex projects with numerous activities being worked

Table 7.5 Float Values for the Small Gas Station Project

Activity	Total Float	Free Float	Interfering Float
* 1	TF(1) = 10–10 = 0	FF(1) = 10–10 = 0	IF(1) = 0–0 = 0
2	TF(2) = 22–15 = 7	FF(2) = 18–15 = 3	IF(2) = 7– 3 = 4
* 3	TF(3) = 18–18 = 0	FF(3) = 18–18 = 0	IF(3) = 0–0 = 0
4	TF(4) = 24–22 = 2	FF(4) = 24–22 = 2	IF(4) = 2–2 = 0
5	TF(5) = 24–20 = 4	FF(5) = 24–20 = 4	IF(5) = 4–4 = 0
6	TF(6) = 24–23 = 1	FF(6) = 24–23 = 1	IF(6) = 1–1 = 0
* 7	TF(7) = 24–24 = 0	FF(7) = 24–24 = 0	IF(7) = 0–0 = 0
* 8	TF(8) = 32–32 = 0	FF(8) = 32–32 = 0	IF(8) = 0–0 = 0
* 9	TF(9) = 42–42 = 0	FF(9) = 42–42 = 0	IF(9) = 0–0 = 0
10	TF(10) = 67–56 = 11	FF(10) = 56–56 = 0	IF(10) = 11—0 = 11
11	TF(11) = 67–46 = 21	FF(11) = 56–46 = 10	IF(11) = 21–10 = 11
* 12	TF(12) = 57–57 = 0	FF(12) = 57–57 = 0	IF(12) = 0–0 = 0
13	TF(13) = 92–68 = 24	FF(13) = 92– 68 = 24	IF(13) = 24– 24 = 0
* 14	TF(14) = 67–67 = 0	FF(14) = 67–67 = 0	IF(14) = 0–0 = 0
15	TF(15) = 84–73 = 11	FF(15) = 77–73 = 4	IF(15) = 11–4 = 7
16	TF(16) = 84–77 = 7	FF(16) = 77–77 = 0	IF(16) = 7–0 = 7
* 17	TF(17) = 92–92 = 0	FF(17) = 0–0 = 0	IF(17) = 0–0 = 0
18	TF(18) = 92–80 = 12	FF(18) = 92–80 = 12	IF(18) = 12–12 = 0
19	TF(19) = 92–83 = 9	FF(19) = 92–83 = 9	IF(19) = 9–9 = 0
20	TF(20) = 92–85 = 7	FF(20) = 92–85 = 7	IF(20) = 7–7 = 0
* 21	TF(21) = 93–93 = 0	FF(21) = 0–0 = 0	IF(21) = 0–0 = 0
* 22	TF(22) = 96–96 = 0	FF(22) = 0–0 = 0	IF(22) = 0–0 = 0

simultaneously and complex sequences of procurement and installation, critical path network scheduling may by the only adequate means of planning and scheduling. When the number of activities in a network schedule exceeds 200 to 300, updating and control become extremely tedious. Such projects are almost always scheduled and controlled using specialty software based on the CPM algorithms discussed here.

As computers continue to make tedious calculations more tractable, greater complexity can be addressed to include the impact of available resources (e.g., crews, cranes, trucks, etc.) in determining a realistic sequence of work. Our discussion in this chapter assumes that all resources required are available and the logic developed makes the same assumption (i.e., the network as presented is not resource constrained). That is, the network is calculated as if an infinite pool of the resources required is available. This, of course, is not realistic.

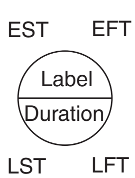
Several activities scheduled for the same day may require trucks. If the total number of trucks needed is 12 and only 9 trucks are available, there is a resource conflict or constraint. If additional trucks cannot be found, this means that at least one and maybe more than one activity must be delayed. Scheduling techniques are beginning to focus on this aspect of project management to a much greater extent. Since the construction of a project is very sensitive to the number of resources available, one speaks of construction as being a resource-driven industry. As a practical matter, both time and resource availability are critical. Resource constrained project models can be considered to be advanced project scheduling systems.

REVIEW QUESTIONS AND EXERCISES

7.1 Develop the precedence diagram network for the following project and then calculate the total float, free float, and interfering float for each activity.

Activity	Duration	Immediately Following Activities
a	22	*dj*
b	10	*cf*
c	13	*dj*
d	8	—
e	15	*cfg*
f	17	*hik*
g	15	*hik*
h	6	*dj*
i	11	*j*
j	12	—
k	20	—

7.2 Make a clear and neat sketch of the network specified below using precedence notation.
On the precedence diagram calculate and show the early start (EST), early finish (EFT), late start (LST), late finish (LFT), and total free and interfering float in each activity using the notation shown below. Start calculations with day zero 0. Show the critical paths with colored pencil.



The activity logic and durations are as follows:

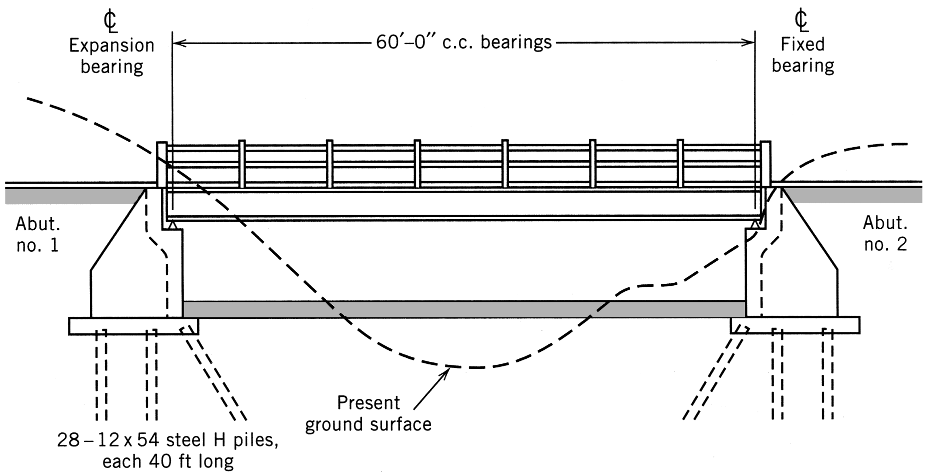
Label	Duration	Must Follow Operations
A	2	—
B	4	*A*
C	7	*A*
D	3	*A*
E	5	*A*
F	7	*B*
G	6	*B*
H	7	*F*
I	5	*G*
J	3	*G*
K	8	*C,G*
L	9	*H,I*
M	4	*F,J,K*
N	7	*D,K*
O	8	*E,K*
P	6	*M,N*
Q	10	*N,O*
R	5	*L,O,P*
S	7	*Q,R*

7.3 From the following network data, determine the critical path, starting and finishing times, and total and free floats.

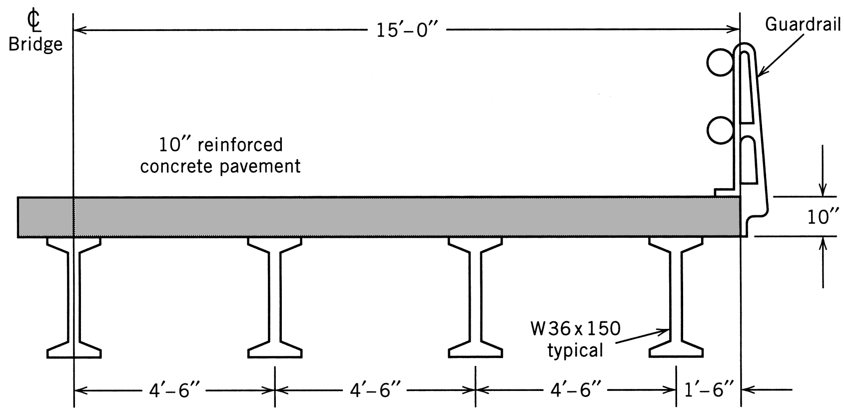
Activity	Description	Duration
1–2	Excavate stage 1	4
1–8	Order and deliver steelwork	7
2–3	Formwork stage 1	4
2–4	Excavate stage 2	5
3–4	Dummy	0
3–5	Concrete stage 1	8
4–6	Formwork stage 2	2
5–6	Dummy	0
5–9	Backfill stage 1	3
6–7	Concrete stage 2	8
7–8	Dummy	0
7–9	Dummy	0
8–10	Erect steel work	10
9–10	Backfill stage 2	5

Draw the network in precedence notation.

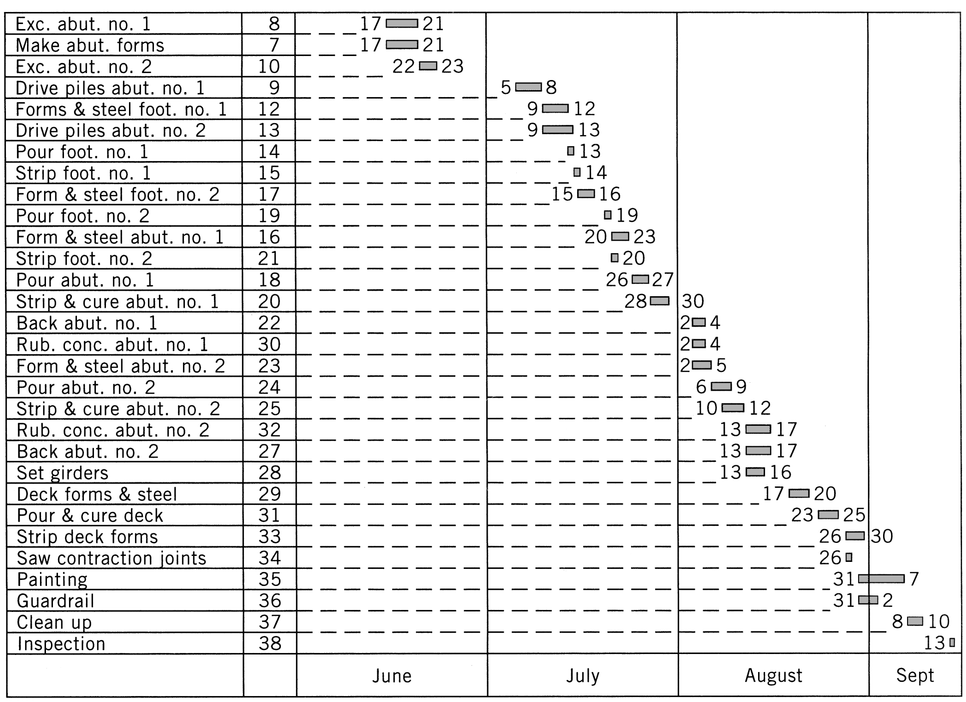
7.4 Using the information given in figures shown, develop a precedence notation CPM net-work for the bridge project



Example project, bridge profile.



Example project, bridge transverse section for problem 7.4.



Bar chart schedule for bridge project for problem 7.4. (based on an example in Clough and Sears, *Construction Project Management*) described. Certain logical relationships are implied by the bar chart that has been supplied to you by the field superintendent who has been chosen to run the job. According to contract specifications your company must submit a network scheduling (CPM) to the owner. Knowing that you are a CPM expert, your boss has given you the job of setting up the network. He also has asked you to calculate the project duration in working days. The duration of each activity can be developed from the dates given on the bar chart.

MOBILIZATION AND PROCUREMENT ACTIVITY ARE AS FOLLOWS:

Act	Duration	Description	Followers
1	10	Shop drawings, abutment, and deck steel	11
2	5	Shop drawings, foot steel	6
3	3	Move in	7,8
4	15	Deliver piles	9
5	10	Shop drawings, girders	26
1	15	Deliver abutment and deck steel	16
6	7	Deliver footer steel	12
6	25	Deliver girders	28

Hint

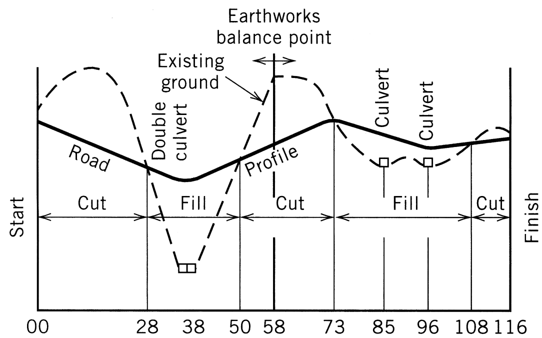
1. There is only one excavation crew.
2. There is one set of formwork material for footers and abutments.
3. Project duration should be approximately 65 days long.
4. General sequence of activities:
   - **a.** Excavataion ··· piles driven ··· footer ··· abutment ··· deck ···
   - **b.** Forming ··· pouring ··· curing ··· stripping ···
5. In order to calculate the work days from the bar chart, assume June 17 is a Thursday. Workdays are Monday through Friday.

7.5 A new road section with concrete pavement, shown in longitudinal section, is 11,600 ft long. It is to be constructed in accordance with the following conditions:

a. The balanced earthworks from station 00 to 58(00) may be done at the same time as the balanced earthworks from station 58(00) to 116(00) using two separate independent crews.

b. The double-box culvert will be built by one crew, and another crew will build the two small culverts. Concrete may be supplied either from the paving batch plant or from small independent mixers at the culvert sites, whichever is expedient.

c. One small slip-form paver will do all the concrete paving work, and all the shouldering will then follow with one crew after the concrete pavement is cured.



d. Seeding the embankments with grass must be left as late as possible.

Prepare a network diagram and determine the minimum possible project duration.

If independent concrete mixers are used for the culverts, what is the latest day for delivery of the paving batch plant to the site, so that the paving crew may have continuity of work (no idle time at all)?

Activity Description	Duration
Deliver rebars—double-box culvert	10
Move in equipment	3
Deliver rebars—small culverts	10
Set up paving batch plant	8
Order and deliver paving mesh	10
Build and cure double-box culvert, station 38	40
Clear and grub, station 00–58	10
Clear and grub, station 58–116	8
Build small culvert, station 85	14
Move dirt, station 00–58	27
Move part dirt, station 58–116	16
Build small culvert, station 96	14
Cure small culvert, station 85	10
Cure small culvert, station 96	10
Move balance dirt, station 58–116	5
Place subbase, station 00–58	4
Place subbase, station 58–116	4
Order and stockpile paving materials	7
Pave, station 58–116	5
Cure pavement, station 58–116	10
Pave, station 00–58	5
Cure pavement, station 00–58	10
Shoulders, station 00–58	2
Shoulders, station 58–116	2
Guardrail on curves	3
Seeding embankments with grass	4
Move out and open road	3

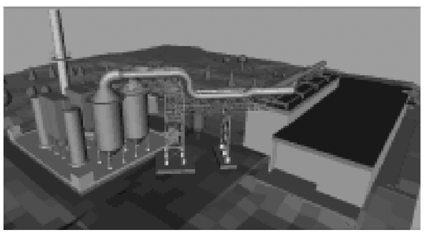
Chapter 8

Scheduling – PERT Networks and Linear Operations

VRML Applications in Construction

The Need

Traditionally, construction process information is communicated with paper documents and 2D CAD drawings. Recently, the industry has embraced many kinds of web-based technologies, but construction still uses document-based models. It is believed that transition to model-based information can be done through web-based 3D user interfaces. Moreover, there is a need to easily model structures to be used in a web-based user interface.

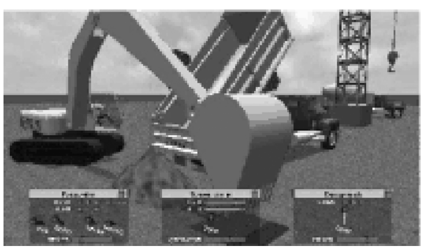


VRML Model of the NIST Fire Research Facility Emissions Control System

The Technology

The applicability of the Virtual Reality Modeling Language (VRML) is being investigated for visualizing the activities at a construction site and creating an advanced web-based 3D user interface for construction process information. The Computer-Integrated Construction Group at the National Institute for Standards and Technology (NIST) in Gaithersburg, MD is developing this concept.

In principle, VRML is an open standard that offers the possibility of accessing many types of construction project data using readily available and well-accepted graphical user interfaces. These interfaces are based on web-based 3D visualizations of a model. In order to view the VRML world, the users should have a VRML browser, which can be a stand-alone application, a helper application, and/or a plug-in. Using this environment, models such as these pictured on this page can be readily developed.



VRML Excavator, Tower Crane, and Dump Truck

8.1 INTRODUCTION

Bar charts and critical path method (CPM) networks assume that all activity durations are constant or deterministic.[1] An estimate is made of the duration of each activity prior to the commencement of a project, and the activity duration is assumed to remain the same (e.g., a nonvariable value) throughout the life of the project. In fact, this assumption is not realistic. As soon as work begins, due to actual working conditions, the assumed durations

[1] Logic is also considered to be constant or invariable throughout the life of the project.

for each activity begin to vary. The variability of project activities is addressed in a method developed by the U.S. Navy at approximately the same time as CPM. This method was called the Program Evaluation and Review Technique. It is now widely known as the PERT scheduling method.

PERT incorporates uncertainty into the project by assuming that the activity durations of some or all of the project activities are variable. The variability is defined in terms of three estimates of the duration of each activity as follows:

1. Most pessimistic duration
2. Most optimistic duration
3. Most likely duration

Let's assume that a 20,000-sq ft slab on grade is to be cast in place. For scheduling purposes, the project superintendent is asked for three durations (i.e., most pessimistic, etc.) rather than for a single constant duration. The three estimates are used to calculate an expected activity duration. The calculations are loosely based on concepts from mathematical probability. The expected duration, t_e, is assumed to be the average value of a probability distribution defined by the three-estimate set. The expected duration, t_e, of each activity with variable characteristics is given as:

$$t_e = \frac{[t_a + 4t_m + t_b]}{6}$$

where t_a is the most optimistic duration estimate

t_m is the most likely duration estimate
t_b is the most pessimistic duration estimate

For instance, if for the slab pour, the three estimates from the superintendent are:

$$t_a = 5 \text{ days}$$
$$t_m = 8 \text{ days}$$
$$t_b = 12 \text{ days}$$

the expected activity duration is calculated as:

$$t_e = \frac{5 + 4(8) + 12}{6} = 49/6 = 8.17 \text{ days, say 9 working days}$$

The expected value for each activity with a constant value, k, is $t_e = k$.

Once the t_e values for each variable duration activity have been calculated, the longest path and project duration are determined using the same methods developed in CPM. The probability of completing the project within a predetermined time duration is calculated by assuming that the probability distribution of the total project duration is normally distributed with the longest path of t_e values as a mean value of the normal distribution.

The normal distribution is defined by its mean value $\bar{x}$ (i.e., in this case the value of the longest path through the network) and the value, σ, which is the so-called "standard deviation" of the distribution. The standard deviation is a measure of how widely about the mean value the actual observed values are spread or distributed. Another parameter called the variance is the square of the standard deviation or σ^2. It can be shown mathematically that 99.7% of the values of normally distributed variables will lie in a range defined by three

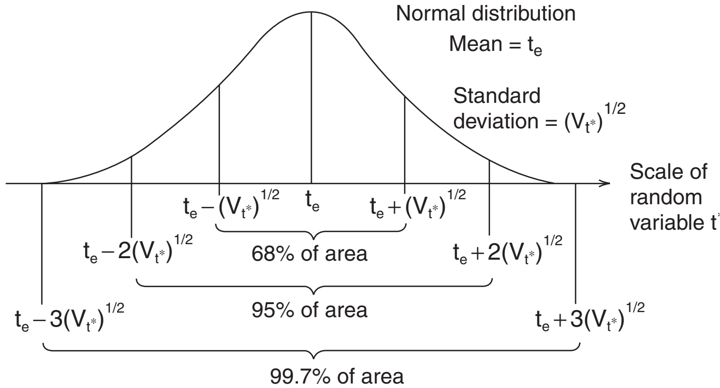


Figure 8.1 Selected areas under the normal distribution curve.

standard deviations below the mean and three standard deviations above the mean (see Fig. 8.1).

In PERT, the standard deviation[2] σ of the normal distribution for the total project duration is calculated using the variance of each activity on the critical path. The variance for each PERT activity is defined as:

$$\sigma^2 = \left[\frac{(t_b - t_a)}{6}\right]^2$$

If the variance of each activity on the longest path is summed, that value is assumed to be the variance of the normal distribution of the entire project duration values.

The fact that the Normal distribution is used to represent the probability distribution of the possible total project durations is based on a basic concept from probability theory called the Central Limit Theorem. This is explained by Moder and Phillips as follows:

"Theorem":

Suppose *m* independent tasks are to be performed in order; (one might think of these as the *m* tasks that lie on the critical path of a network). Let $t_1{}^*, t_2{}^*, \ldots t_m{}^*$ be the times at which these tasks are actually completed.

Note that these are random variables with true means $t_1, t_2, \ldots, t_m$, and true variances $V_{t1}{}^*, V_{t2}{}^*, \ldots V_{tm}{}^*$, and ... actual times are unknown until these specific tasks are actually performed. Now define T^* to be the sum:

$$T^* = t_i{}^* + t_2{}^* + \cdots + t_m{}^*$$

And note that T^* is also a random variable and thus has a distribution. The Central Limit Theorem states that if *m* is large, say four or more, the distribution of T^* is approximately normal with mean T and variance $V_T{}^*$ given by

$$T = t_1 + t_2 + \cdots + t_m$$
$$V_T{}^* = V_{t1}{}^* + V_{t2}{}^* + \cdots + V_{tm}{}^*$$

That is, the mean of the sum, is the sum of the means; the variance of the sum is the sum of the variances; and the distribution of the sum of activity times will be normal regardless of the shape of the distribution of actual activity performance times (Moder and Phillips, 1964)."

[2] The variance is the standard deviation squared.

Table 8.1 Three Estimate Values and Calculated Values for Each Activity

Activity	t_m	t_a	t_b	t_e	Var
1	3	1	5	3	0.44
2	6	3	9	6	1.00
3	13	10	19	13.5	2.25
4	9	3	12	8.5	2.25
5	3	1	8	3.5	1.36
6	9	8	16	10	1.23
7	7	4	13	7.5	2.25
8	6	3	9	6	1.00
9	3	1	8	3.5	1.36

8.2 AN EXAMPLE PERT NETWORK

To demonstrate the use of the PERT approach, consider the small arrow notation network shown in Figure 8.2. Three estimate durations for each activity in this activity network are given in Table 8.1.

The t_e values shown for each activity are calculated using the formula:

$$t_e = \frac{(t_a + t_m + t_b)}{6}$$

For instance, t_e for activity 7 is:

$$t_e = \frac{4 + 4(7) + 13}{6} = \frac{45}{6} = 7.5$$

The variance for each activity is approximated by the equation

$$\sigma^2 = \left[\frac{(t_b - t_a)}{6}\right]^2$$

For activity 7, the variance is var(7) =

$$\left[\frac{13-4}{6}\right]^2 = \left[\frac{9}{6}\right]^2 = 2.25$$

Using the forward and backward pass methods described in Chapter 7, two paths have an expected duration of 17.5 days. These pathes are shown below.

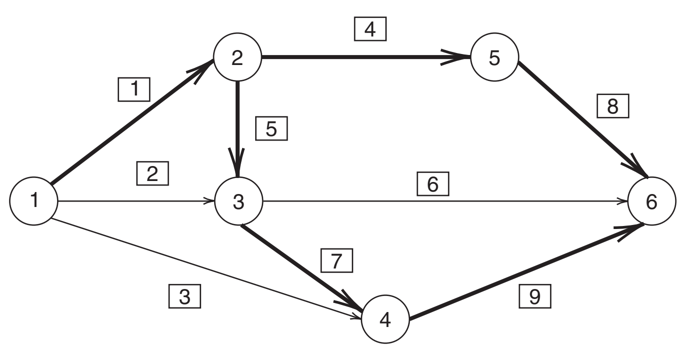


Figure 8.2 Small PERT network.

	DURATION	VARIANCE
Path 1 (1-4-8)	3 + 8.5 + 6 = 17.5	Var = .444 + 2.25 + 1.0 = 3.694
Path 2 (1-5-7-9)	3 + 3.5 + 7.5 + 3.5 = 17.5	Var = .444 + 1.361 + 2.25 + 1.361 = 5.416

The mean of the normal distribution is therefore assumed to be 17.5 days. The variances of the two longest paths are calculated by adding variances of the individual activities in each path. The variance of path two (5.416) is greater than that of path one (3.694). Since this means a greater spread of the probable total project durations, the variance of path two is selected as the variance to be used for further PERT calculations. The PERT normal distribution for Total Project Duration is shown in Figure 8.3.

The normal distribution is symmetrical about the mean. The standard deviation will be $\sigma = \sqrt{5.416} = 2.327$. PERT answers the question: "What is the probability (given the variable durations of the activities) that the project can be completed in N days?" The probability of completing the project is given by the area under the normal distribution to the left of the value N selected for investigation. Since we know that 99.7% of the area (representing probability) under the normal distribution is in the range of 3 σ below the mean 3 σ above the mean, we can say that there is a better than 99.7% chance that the project can be completed in [x + 3 σ] or [17.5 + 3 (2.327)] = 24.5 days or less. That is, at least 99.7% of the area under the normal curve is to the left of the value 24.5 days in Figure 8.3. In other words, we can be almost 100% sure that the project can be completed in 25 days or less.

What if we want to know the probability of completing in 19 days?[2] Given the values of the mean and the variance, we can use a cumulative normal distribution function table such as that shown in Appendix K to calculate the area under the curve left of the value 19. First, we must calculate the Z value for a given value (e.g., 19):

$$Z = \frac{\text{Mean} - x}{\sqrt{\text{Variance}}} \quad \text{or} \quad Z = \frac{(\overline{X} - x)}{\sigma}$$

where σ is the standard deviation of the cumulative normal distribution.
In our case:

$$Z = \frac{|17.5 - 19|}{\sqrt{5.416}} = \frac{1.5}{2.327} = 0.644$$

Consulting the cumulative normal distribution function table given in Appendix K with a Z value of 0.644 yields a value of .7389 or 73.89% probability of completing the project in 19 days. What would be the probability of completing the project in 16 days?

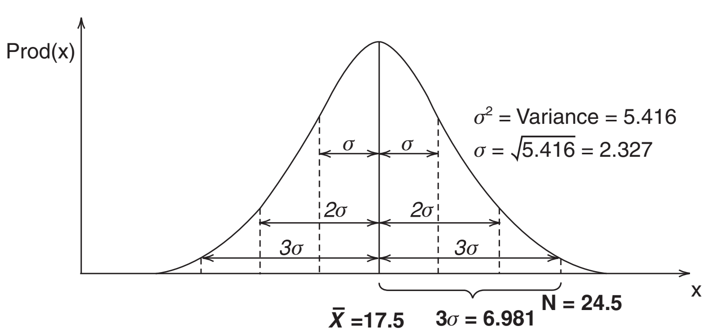


Figure 8.3 Normal distribution of total project durations for small PERT network.

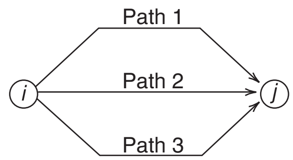


Figure 8.4 Merge event bias.

8.3 PERT SHORTCOMINGS

In fact, the PERT results are too optimistic. The method of using the $t_e$value to determine the longest path through the project network and assuming that the duration of this path is the most probable value for the total project duration is not totally accurate. Although PERT introduces elements of probability into the calculation of the project duration, it consistently underestimates the duration. The principal cause of this underestimation is a condition known as "merge event bias." Briefly, merge event bias occurs when several paths converge on a single node. Figure 8.4 is a simplified depiction of how several paths in a schedule network might converge on a single node.

PERT calculations give the early expected finish time of this node as the summation of times on the longest path leading to the node. This path then becomes part of the longest path through the network that determines expected project duration. However, since the duration of the activities on the paths are random variables, it is possible that some other path converging on the node could have an activity with a random duration longer than its expected (mean) duration. Thus, this longer path would determine the early finish time of the node. That this potential longer path is *not* taken into account in the PERT calculation leads to an underestimation of project duration.

Additionally, the PERT method assumes statistical independence between activities. This assumption allows the variance of activities along a path to be added, giving the variance of the duration of the project. The assumption of independence, however, may not always be appropriate. For instance, weather can create a positive correlation between activities, and a delay in one activity may create a negative correlation between activities.

One solution to the difficulties noted above is computer simulation. Because Monte Carlo simulation of schedule networks does not use a single number to represent activity durations, it avoids the merge event bias described above.

8.4 LINEAR CONSTRUCTION OPERATIONS

Often construction sites have linear properties that influence the production sequence. Road construction, for instance, is worked in sections which require that a set of work processes be completed in a particular sequence before the section is completed. The individual sections can be thought of as "processing through" a series of workstations.

For example, a road job may be subdivided into 14 sections that must be completed see Figure 8.5 (a). This type of breakdown is typically established based on centerline stationing (e.g., section 1 is defined as running from station 100 to station 254.3). Each of the 14 stations must undergo the following work activities: (1) rough grading, (2) finish grading, (3) aggregate base installation, (4) 5-in. concrete pavement, (5) 9-in. concrete pavement, and (6) curb installation.

Each of the 14 sections can be thought of as being processed by crews and equipment representing each of the six work processes. Since the site is linear, the normal way for the work to proceed would be to start with section 1, then go on to the second section, and so forth. This implies that the sections will first be rough graded, then finish graded, then

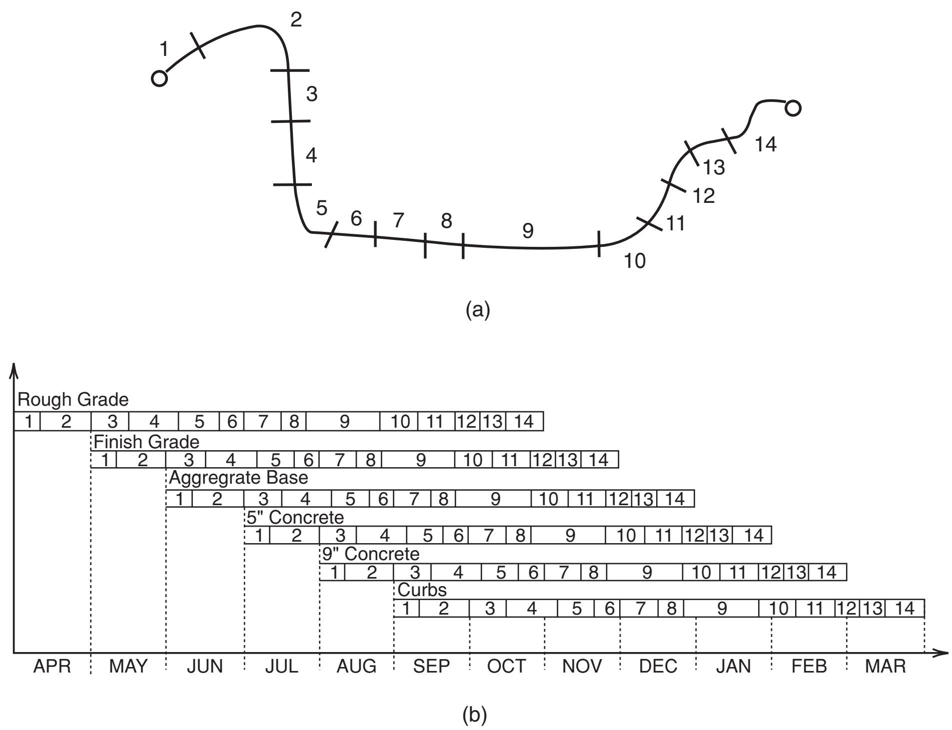


Figure 8.5 Road project divided into 14 sections.

aggregate base will be placed, and so on. A bar chart indicating this sequence of activity is shown in Figure 8.5(b).

The bar chart indicates that work activity overlaps such that several operations are in progress simultaneously during the middle of the job. The required sequentiality leads to a "train" effect. That is, a section must complete 5-in. concrete before preceding to 9-in. concrete. Therefore, the sections can be thought of as a "train" or "parade" of work that must pass each station represented by the six construction processes.

Many types of projects exhibit this kind of rigid work sequence. A high-rise building, for instance, requires each floor to pass through a set of operations. Each floor can be thought of as a "car" in the "train" of work to be completed. Construction processes such as erect formwork, install reinforcing steel and imbedments, and pour concrete can be viewed as workstations through which each floor must pass.

Tunnels are worked in sections in a fashion similar to road or pipeline work. Each section must be processed through work processes such as drill, blast, remove muck, and advance drilling shield. This again leads to a repetitive sequence that is rigidly sequenced.

8.5 PRODUCTION CURVES

Bar charts and network schedules provide only limited information when modeling linear operations and projects. They typically do not readily reflect the production rate or speed with which sections or units are being processed. Since the rate of production will vary across time, this has a major impact on the release of work for following work processes. Delays in achieving the first units of production occur as a result of mobilization requirements. As the operation nears completion, the rate of production typically declines because of demobilization or closeout considerations. The period of maximum production is during the midperiod of the process duration. This leads to a production curve with the shape of

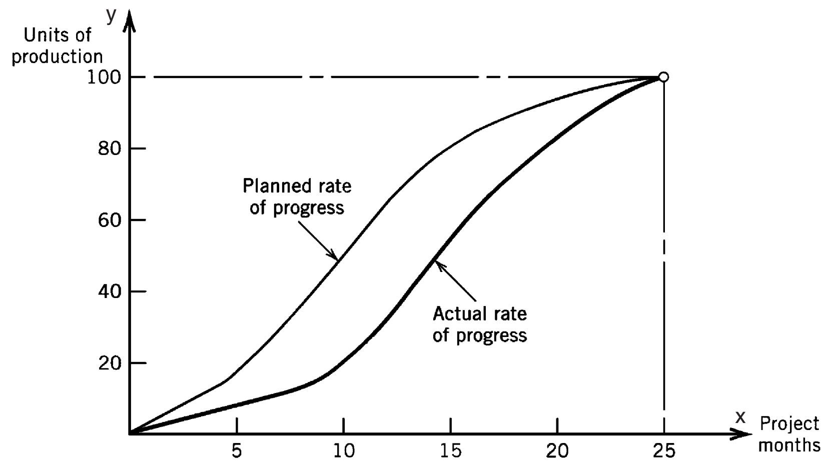


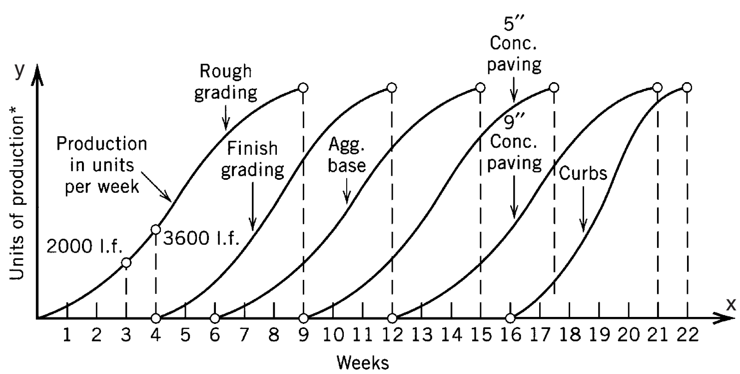
Figure 8.6 Production curve.

a "lazy S," as shown in Figure 8.6. The slope of the curve is flat at the beginning and the end, but steep in the midsection. The slope of the curve is the production rate.

These curves are also called time-distance, time-quantity, or velocity diagrams since they relate units of production (i.e., quantities or distance) on the y axis (vertical, ordinate) with time plotted on the x axis (horizontal, abscissa). The slope of the curve relates the increase in production units on the y axis with the increment of time as shown on the x axis. The slope of the curve, therefore, represents the number of units produced over a given time increment. This is the rate of production.

The production curves for a typical road job are shown in Figure 8.7. The curves indicate the beginning and ending points in time for each of the processes. The slope of each curve is the production rate for each process. The distance between the beginning points of each process establishes the lag between processes. The aggregate base operation begins in week 6 and lags the finish-grading operation by two weeks. This means that two weeks of work (i.e., completed finish-grade sections) are built up before the aggregate base operation is started.

Leading processes generate work area or availability so that follow-on processes have a "reservoir" of work from which to operate. Reservoirs of work are cascaded so that units of work must be available from an "upstream" process reservoir before work is available at a



* Units of production (e.g., l.f. for rough and finish grading, tons of aggregate base, cu. yd. or sq. ft. of paving, etc.)

Figure 8.7 Velocity diagrams for a road construction project.

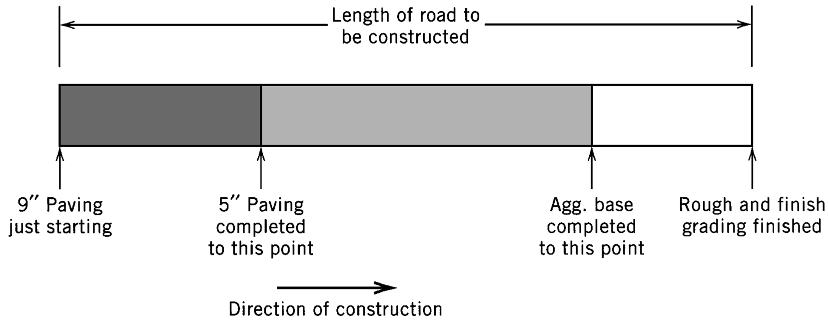


Figure 8.8 Planned status of construction as of week 12.

following process reservoir. This illustrates that workflow moves from leading to following processes.

In addition to indicating the rate of production, production curves or velocity diagrams are helpful in establishing the project status. The planned status of the job as of week 12 can be determined by simply drawing a vertical line at week 12 on the x axis of Figure 8.7. This will intersect the aggregate base and 5-in. concrete curves. It also represents the beginning of work on the 9-in. concrete pavement (overlaying the 5-in. base concrete). It can be readily determined that:

1. Both rough and finish grading should be completed.
2. Approximately 80% of the aggregate base has been placed.
3. Placement of the 5-in. concrete base is approximately 30% complete.
4. Placement of 9-in. concrete is just commencing.

The planned status of construction as of week 12 is shown in Figure 8.8.

There is a definite advantage in balancing the production rates between processes. Balancing rates means ensuring that the slopes of the production curves which interact are roughly parallel and do not intersect. If rates are not balanced, the situation shown in Figure 8.9 can develop. In this example, the slope (production rate) of process *B* is so steep that it catches or intersects the process *A* curve at time *M*. This requires a shutdown of process *B* until more work units can be made available from *A*. Again, at time *L*, process *B* overtakes

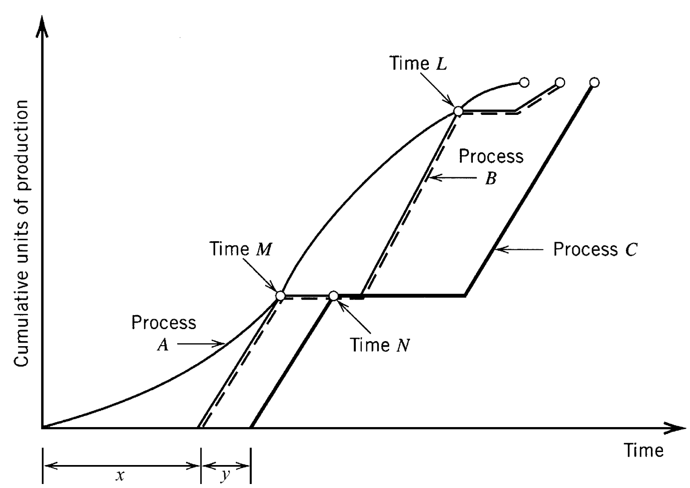


Figure 8.9 Unbalanced process production rates.

the production in process A, resulting in a work stoppage. This is clearly inefficient since it requires the demobilization and restarting of process B. The stoppage of process B at M also causes a "ripple" effect since this causes a shutdown of process C at time N.

It should be clear that these stoppages are undesirable. Thus, processes should be coordinated so as to avoid intersections of production curves (e.g., times M, N, and L). Obviously, one way to avoid this is to control production in each process so that the slopes of the curves are parallel. This implies the need to design each process so that the resources utilized result in production rates that are roughly the same for all interacting construction processes. Since the six curves for the road job are roughly parallel, we can assume that the production rates have been coordinated to avoid one process overtaking its leading or preceding process.

8.6 LINE-OF-BALANCE CONCEPTS

Line of balance (LOB) is a graphical method for production control integrating barcharting and production curve concepts. It focuses on the planned versus actual progress for individual activities and provides a visual display depicting differences between the two. Indication of these discrepancies enables management to provide accurate control in determining priorities for reallocation of labor resources. Those activities indicated ahead of schedule can be slowed by directing part or all of their labor crews to individual activities that lag behind schedule. This obviously assumes that resources are interchangeable. This can present a limitation to the application of this procedure in construction.

The LOB method serves two fundamental purposes. The first is to control production and the second is to act as a project management aid. Each objective is interrelated through development and analysis of four LOB elements. These elements provide the basis for progress study on critical operations throughout the project duration. The four elements are:

1. The objective chart
2. The program chart
3. The progress chart
4. The comparison

The *objective chart* is a segmental curve showing cumulative end products to be produced over a calendar time period. The number of end products may be specified in the contract. Assume that the units being considered in this example are precast panels for the exterior of a high-rise building. A typical objective chart is shown in Figure 8.10.

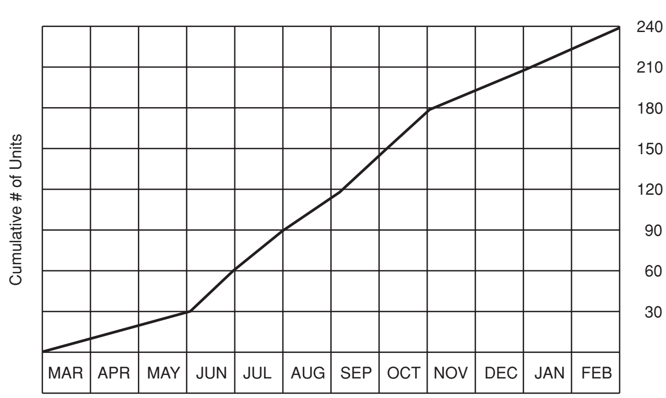


Figure 8.10 Objective chart.

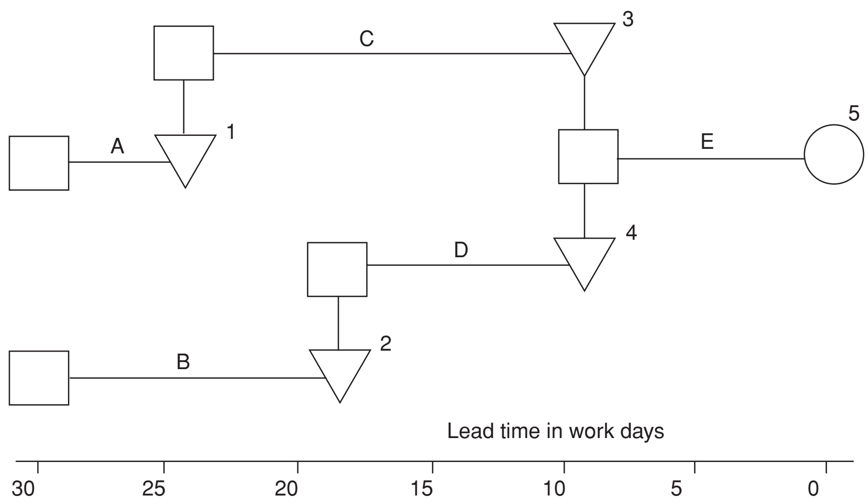


Figure 8.11 Program chart with lead time in workdays.

This example indicates a total of 30 units to be delivered or completed by June 1, 60 units to be delivered and completed by July 1, 180 units to be delivered and completed by November 1, and a total of 240 units to be delivered and completed by February 28. The contract start date is shown as March 1.

The *program chart* is the basic unit of the LOB system. It is a flow process chart of all major activities, illustrating their planned, sequenced interrelationships on a "lead-time" basis. Three aspects to consider in development of the program chart are determination of (1) operations to be performed, (2) the sequence of operations, and (3) processing and assembly lead time.

The program chart indicated in Figure 8.11 describes the production process for the 240 units mentioned in the objective chart. Each activity (A through E) has associated with it a lead time (latest start time) signified by an event starting symbol (□) and an event coordination symbol (Δ) signifying its end or completion. These event coordination symbols, referred to as *progress monitoring points*, are labeled from top to bottom and from left to right. All five activities must be completed before one unit can be ready for delivery. This takes 30 working days as shown on the program chart's lead-time scale.

The *progress chart* is drawn to the same vertical scale as the objective chart and has a horizontal axis corresponding to the progress monitoring points labeled in chronologic order. Vertical bars represent the cumulative progress or status of actual performance at each monitoring point, usually based on visiting the site and measuring actual progress (e.g., assessing status of completion).

The progress chart of Figure 8.12 indicates that on a given day when inventory was taken, 120 units had passed through monitoring point 5. In other words, the vertical height of bar 5 is equal to the number of units actually having completed station 5. This corresponds to completion of activity *E* in the program chart, which is the last activity in the production process. Similarly, activity *D* (bar 4) had completed 120 units and activity *C* (bar 3) had completed 130 units; activity *B* (bar 2) had completed 150 units; and activity *A* (bar 1) had completed 180 units.

In the comparison, actual progress is compared to expected progress. The objective, program, and progress charts are then utilized to draw the "line of balance" or LOB by projecting certain points from the objective chart to the progress chart. This results in a step-down line graph indicating the number of units that must be available at each monitoring point for actual progress to remain consistent with the expected progress as given by the objective chart. Figure 8.13 indicates the LOB and the method used to project it from the

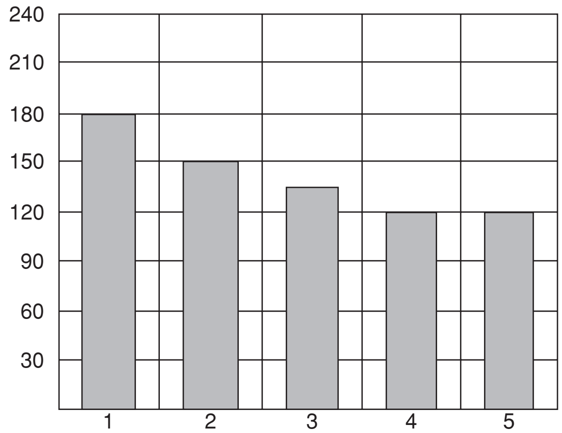


Figure 8.12 Progress Chart

objective chart to the progress chart. The procedure for striking the line of balance is as follows:

1. Plot the balance quantity for each control point.
   a. Starting with the study date (e.g., Sept 1) on the horizontal axis of the objective chart, mark off to the right the number of working days (or weeks or months, as appropriate) of lead time for that control point. This information is obtained from the program chart.
   b. Draw a vertical line from that point on the horizontal axis to the cumulative objective curve.
   c. From that point draw a horizontal line to the corresponding bar on the progress chart. This is the balance quantity for that bar.
2. Join the balance quantities to form one stair-step-type line across the progress chart.

Analysis of the LOB reveals that activities 2 and 5 are right on schedule while activities 3 and 4 show deficit units. Activity 1 shows surplus. This surplus is the difference between the 180 units actually completed by activity 1 and the 157 units indicated as necessary by the LOB. On the other hand, activities 3 and 4 are lagging by 5 and 15 units, respectively. The LOB display enables management to begin corrective action on activities 3 and 4 to ensure that they do not impede the progress rate of the remaining units.

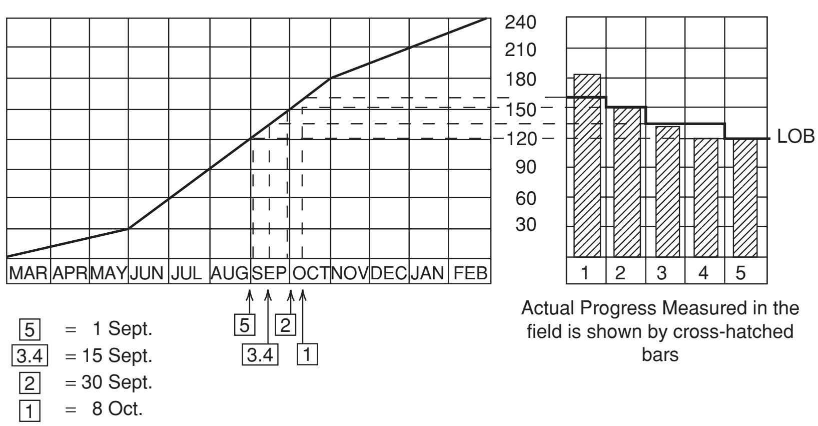


Figure 8.13 Progress Chart with Line of Balance.

8.7 LOB APPLIED TO CONSTRUCTION

To illustrate the use of LOB in a construction context, consider a high-rise building in which repetitive activity sequences are a part of the floor-to-floor operation. In order to ensure a smooth flow of production, a schedule would be necessary that accounts for the interrelationships between different activities. This becomes even more obvious when an additional constraint such as limited formwork is involved. Each floor consists of four sections (A, B, C, and D). These sections can be viewed as processed units.

Each floor section must be processed through the following work activities:

1. Erect Forms
2. Place Reinforcing Steel
3. Place Concrete
4. Dismantle Forms
5. Place Curtain Wall (Exterior Façade)
6. Place Windows

Figure 8.14 shows a schematic of the status of activities at a given point in time. At the time illustrated, work is proceeding as follows:

1. Erect forms section A, floor N +5
2. Place reinforcing steel, section D, floor N +4
3. Place concrete section C, floor N + 4
4. Dismantle forms sections B, floor N +1
5. Place curtain wall section D, floor N
6. Place windows section D, floor N −1

Crews proceed from section A to B to C to D.

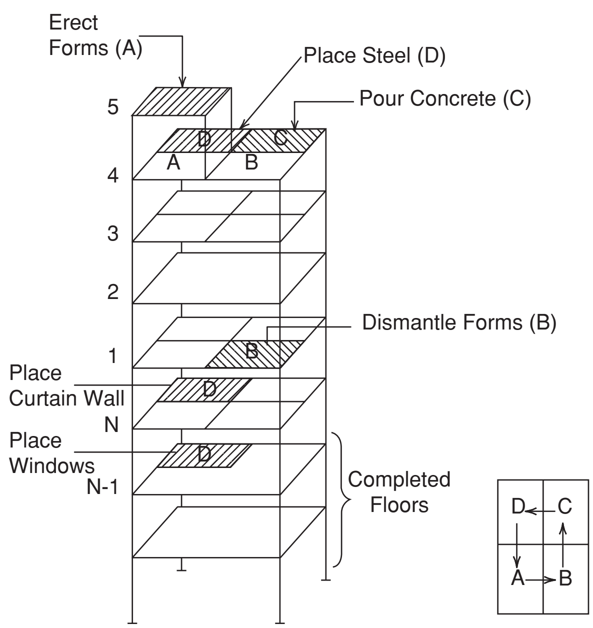


Figure 8.14 Schematic of floor cycle work tasks.

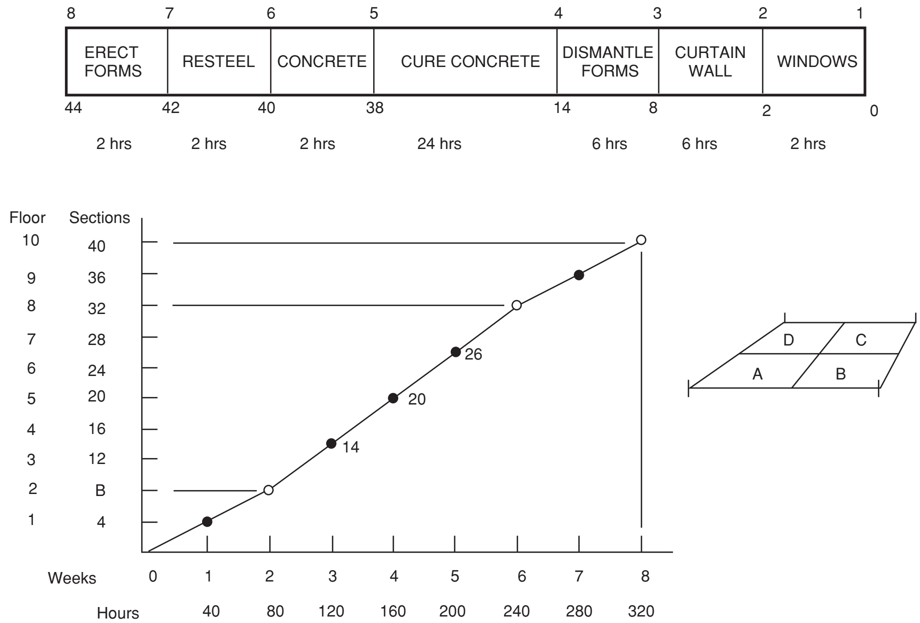


Figure 8.15 Program chart and objective.

The diagram in Figure 8.15 shows the LOB objective chart for a 10-story building. The program chart for a typical section is shown above the objective chart. During the first two weeks the floor cycle required is one floor (four sections) per week. For weeks 2 through 6 the rate of floor production is 1.5 floors (six sections) per week. That is, six floors must be completed in the four-week period from week 2 to week 6. In the last two weeks, the rate is reduced to one floor per week. The lead times required for various activities are shown on the bar program chart above the objective. To strike a line of balance for the beginning of week 5, the lead times are projected as described in Section 8.6. A diagram of this projection is shown in Figure 8.16. The LOB values can be calculated by determining the slope relating horizontal distance (lead time) to vertical distance (required sections). The slope of the objective during weeks 5–6 is six sections (1.5 floors) per 40 hr (one week) or 6/40 sections per hour.

During the remaining weeks, the slope is four sections (one floor) per 40 hr or 1/10 section per hour. The LOB for control point I is given as:

$$\text{LOB(I)} = \text{Section completed as for week 5} \\ +[(\text{slope}) \text{ X } (\text{lead time of control point I})]$$

The number of sections to be completed as of week 5 is 6.5 or 26 sections (6.5×4). Therefore,

$$\begin{aligned}
\text{LOB}(1) &= 26 \\
\text{LOB}(2) &= 26 + (6/40)2 = 26.3 \\
\text{LOB}(3) &= 26 + (6/40)8 = 27.2 \\
\text{LOB}(4) &= 26 + (6/40)14 = 28.1 \\
\text{LOB}(5) &= 26 + (6/40)38 = 31.7 \\
\text{LOB}(6) &= 26 + (6/40)40 = 32
\end{aligned}$$

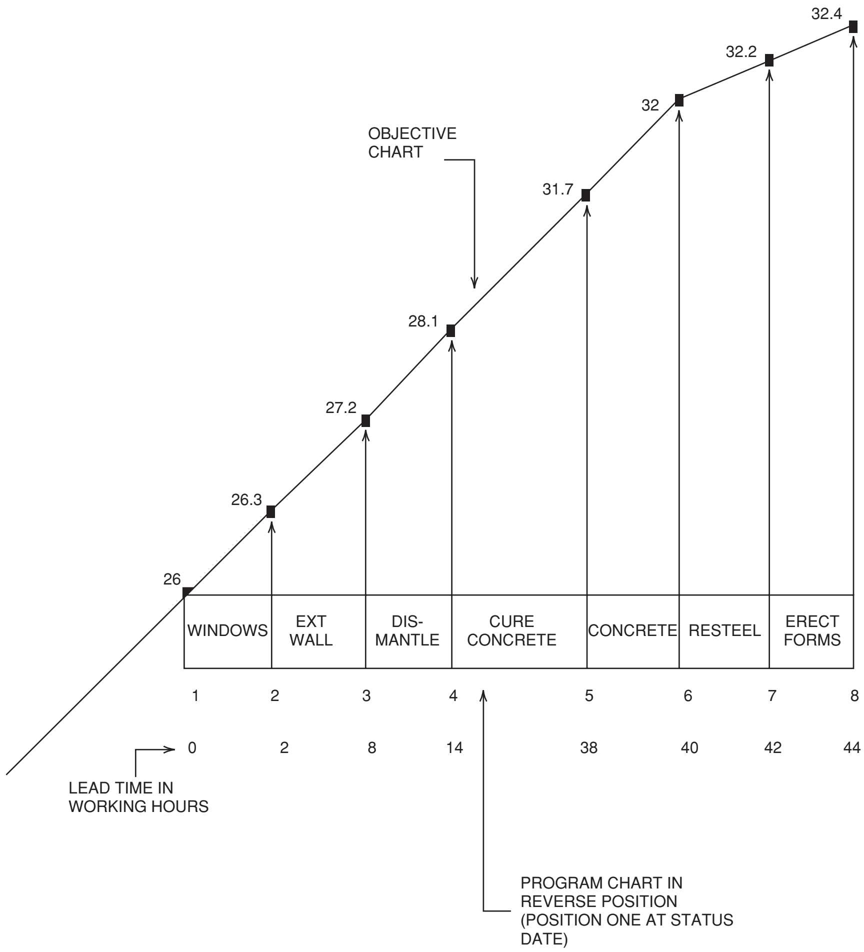


Figure 8.16 Enlarged projection of program chart onto objective chart.

Control points 7 and 8 plot to the flatter portion of the objective:

$$\mathrm{LOB}(7) = 32 + (1/10)(42 - 40) = 32.2$$
$$\mathrm{LOB}(8) = 32 + (1/10)(44 - 40) = 32.4$$

The line of balance for week 5 is shown in Figure 8.17. Field reports would be utilized to establish actual progress, and a comparison will determine whether actual progress is consistent with expected progress.

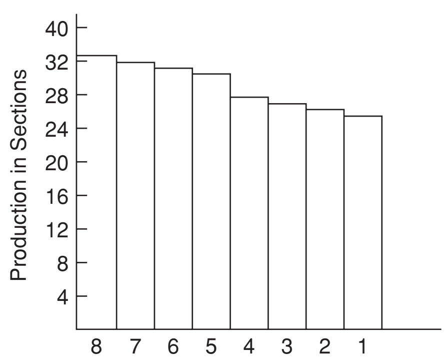


Figure 8.17 Line of balance for week 5.

REVIEW QUESTIONS AND EXERCISES

8.1 **(a)** Using PERT, calculate the expected project duration and determine the critical path in the network defined by the data below.

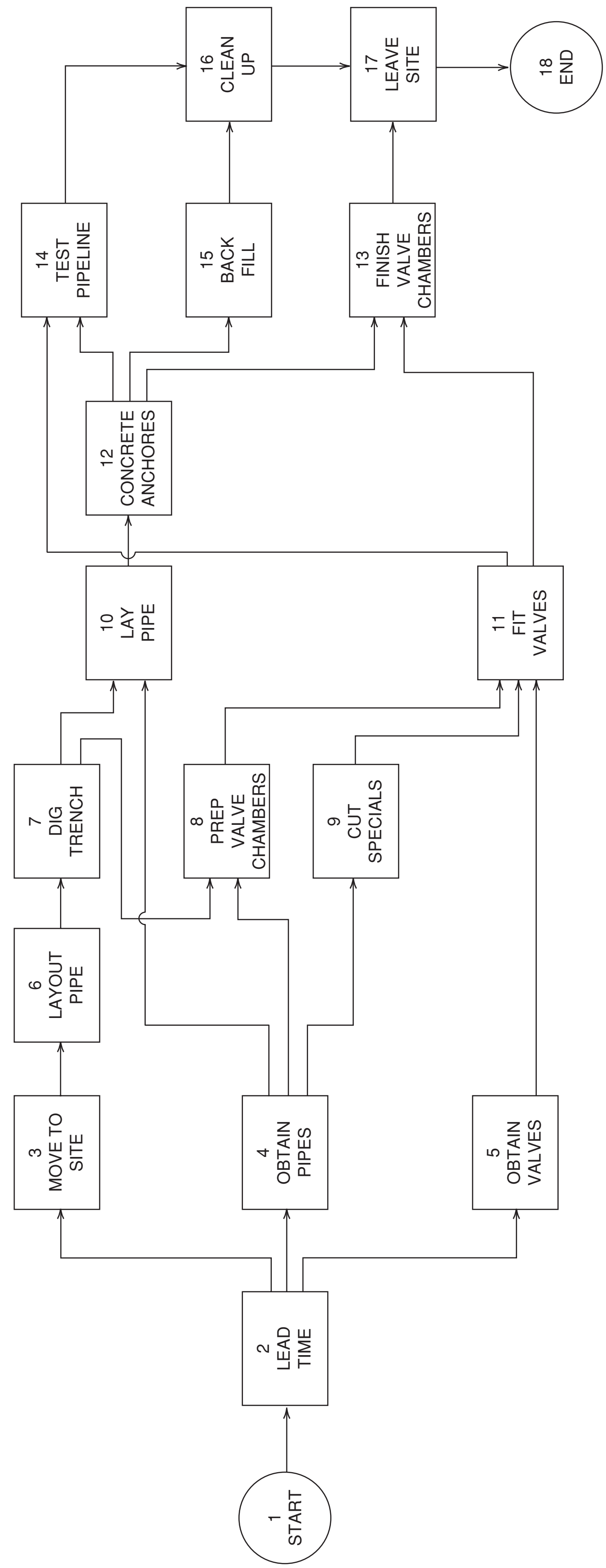
(b) What is the probability of completing this project in 32 weeks?

Activity #	Activity	Type	Duration (Weeks)	Followed by Act #
10	Prefab Wall Forms	constant	2	40
20	Excavate Cols and Walls	constant	3	50, 60, 70
30	Let Elec and Mech Subcontract	t_a, t_m, t_b	3, 4, 8	60, 70
40	Deliver wall Forms	constant	4	80, 90, 100
50	Forms, Pour & Cure Wall & Col Fig	t_a, t_m, t_b	6, 7, 8	80, 90, 100
60	Rough-in Plumbing	t_a, t_m, t_b	5, 7, 10	110
70	Install Conduit	t_a, t_m t_b	9, 11, 15	110
80	Erect Wall Forms & Steel	constant	9	110
90	Fabricate & Set Interior Column Forms	constant	6	120
100	Erect Temporary Roof	t_a, t_m, t_b	12, 16, 18	140
110	Pour, Cure & Strip Walls	constant	10	130
120	Pour, Cure & Strip Int. Walls	constant	6	140
130	Backfill for Slab on Grade	constant	1	140
140	Grade & Pour Floor Slab	constant	5	END

8.2 **(a)** Given the data below for a small pipeline project, based on a PERT analysis what is the expected project duration?

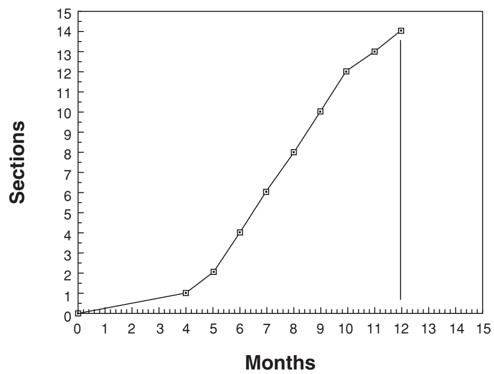
(b) What is the probability of completing this project in 120 days?

Activity	Description	t_a	t_m	t_b	Followed by Activity
1	Start	0	0	0	2
2	Lead Time	10	10	10	3, 4, 5
3	Move to Site	18	20	22	6
4	Obtain Pipes	20	30	100	8, 9, 10
5	Obtain Valves	18	20	70	11
6	Lay Out Pipeline	6	7	14	7
7	Dig Trench	20	25	60	8, 10
8	Prepare Valve Chambers	17	18	31	11
9	Cut Specials	7	9	17	11
10	Lay Pipes	18	20	46	12
11	Fit Valves	8	10	12	13, 14
12	Concrete Anchors	11	12	13	13, 14, 15
13	Finish Valve Chambers	8	8	8	17
14	Test Pipeline	5	6	7	16
15	Backfill	8	10	20	16
16	Clean Up	2	3	10	17
17	Leave Site	3	4	5	18
18	End				



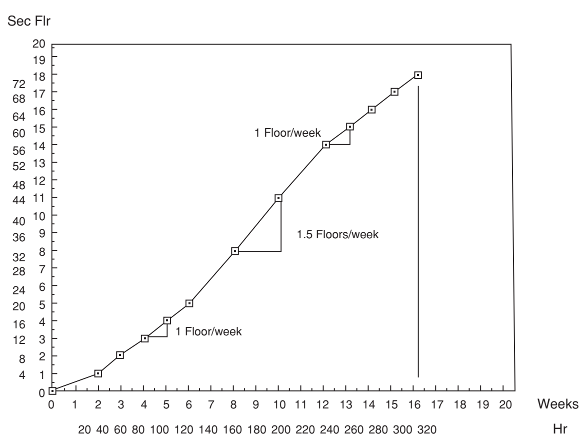
Network For Problem 8.2

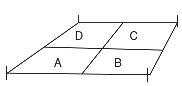
8.3 Consider the road job described in Figure 8.5, which consists of 14 road sections to be completed. The objective chart for this job is given below. Assume that each month consists of 20 working days on the average. The program chart for this process is also shown below. Calculate the line of balance for the study representing the beginning of month 9 (i.e., day to right of number 8).



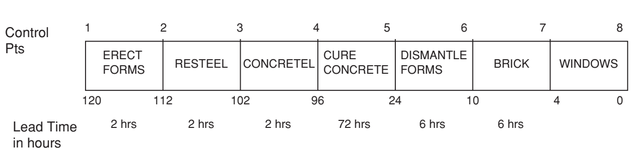
Program Chart

8.4 The objective chart for a 10-story building is show below. Each floor is divided into four sections (A, B, C, D). The production for a typical section is shown below the objective chart, Calculate the LOB values for control points 1–8 for week 5 (200 hr). Determine the LOB values in numbers of floor sections.

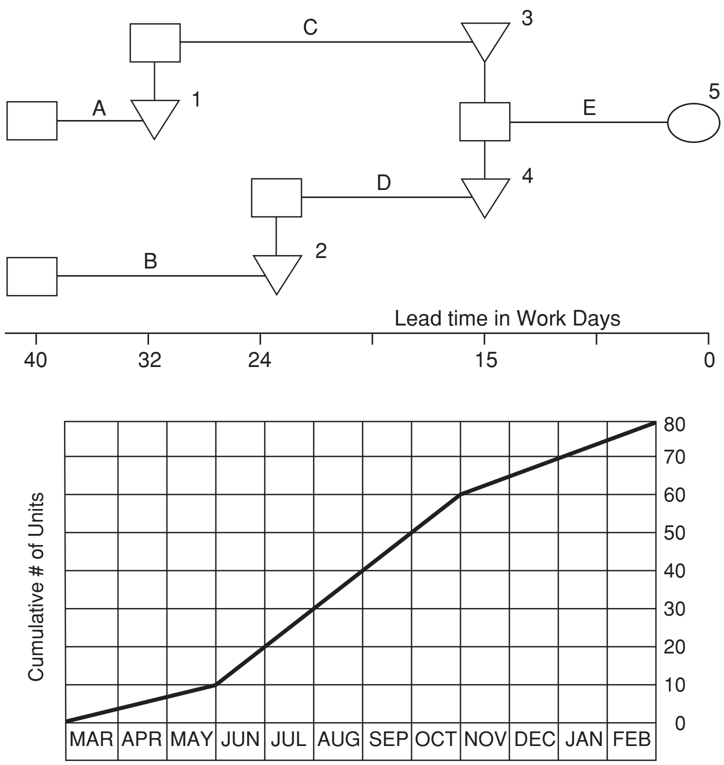




Typical floor w/ 4 sections

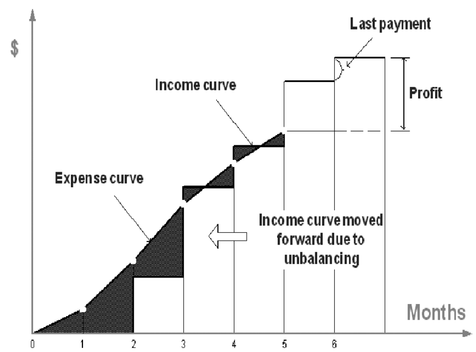


8.5 Given the following charts, calculate the LOB quantities for July 1. What are these charts called?



Chapter 9

Project Cash Flow



Cash Flow Diagram

Scenario Testing

The Need

Construction company operations are project based. Cash flows can be estimated by attempting to assess flows from (1) projects in progress, (2) projects under contract but not yet begun, and (3) potential projects which will start during the coming financial accounting period. These sources of income can be viewed as (1) Birds in the hand, (2) Birds in the bush, and (3) Birds flying in the sky. In other words, cash flows can be projected from projects in progress and projects which may, with some probability, start in the coming period for which forecasts are being made. The advent of spreadsheet analysis and high speed computing has led to "scenario testing" of future cash flow expectations.

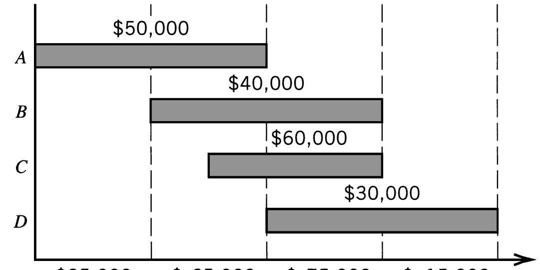
The Technology

Spreadsheets allow managers to run probabilistic cash flow projections that take into account the factors noted above. More advanced analysis can also factor in historical evidence of payment trends and the potential impact of macroeconomic factors. These techniques go beyond the typical best-, expected-, and worst-case scenario modeling and may rely on Monte Carlo simulation, Markov modeling, or the use of "fuzzy" data sets to build up statistically valid outcomes. At the most advanced level, when future cash flows are tied to a multitude of unknowns, probabilistic techniques may be employed in combination with real-options theory to gain an improved view of the impact of a financial decision (e.g., accepting or declining a project or changing market strategy) on value creation for a company. This level of analysis used to be in the economist's realm, but is now commonplace in the finance and business development groups of corporations.

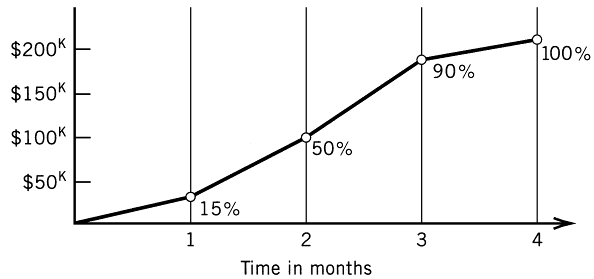
9.1 CASH FLOW PROJECTION

The projection of income and expense during the life of a project can be developed from several time-scheduling aids used by the contractor. The sophistication of the method adopted usually depends on the complexity of the project. In many contracts (e.g., public contracts such as those used by state agencies), the owner requires the contractor to provide an S-curve of estimated progress and costs across the life of the project. The contractor develops this by constructing a simple bar chart of the project, assigning costs to the bars, and smoothly connecting the projected amounts of expenditures over time.

Consider the highly simplified project (Fig. 9.1) in which four major activities are scheduled across a four-month time span. Bars representing the activities are positioned along a time scale indicating start and finish times. The direct costs associated with each activity are shown above each bar. It is assumed that the monthly cost of indirect charges (i.e., site office costs, telephone, heat, light, and supervisory salaries, which cannot be



Monthly direct costs	$25,000	$ 65,000	$ 75,000	$ 15,000
Monthly indirect costs	$ 5,000	$ 5,000	$ 5,000	$ 5,000
Total monthly costs	$30,000	$ 70,000	$ 80,000	$ 20,000
Cumulative monthly costs	$30,000	$100,000	$180,000	$200,000



The letter "K" is used to indicate thousands of dollars.

Figure 9.1 Development of the S-curve.

charged directly to an activity) is $5,000. Assuming for simplicity that the direct costs are evenly distributed across the duration of the activity, the monthly direct costs can be readily calculated and are shown below the time line. The direct charges in the second month, for example, derive from activities A, B, and C, all of which have a portion in the period. The direct charge is simply calculated based on the portion of the activity scheduled in the second month as:

$$\begin{aligned}
\text{Activity } A\!: \frac{1}{2} \times 50{,}000 &= \$25{,}000\\
\text{Activity } B\!: \frac{1}{2} \times 40{,}000 &= \$20{,}000\\
\text{Activity } C\!: \frac{1}{3} \times 60{,}000 &= \underline{\$20{,}000}\\
&\ \$65{,}000
\end{aligned}$$

The figure shows the total monthly and cumulative monthly expenditures across the life of the project. The S-curve is nothing more than a graphical presentation of the cumulative expenditures over time. A curve is plotted below the time-scaled bars through the points of cumulative expenditure. As activities come on-line, the level of expenditures increases and the curve has a steeper middle section. Toward the end of a project, activities are winding down and expenditures flatten again. The points are connected by a smooth curve since the assumption is that the expenditures are relatively evenly distributed over each time period. This curve is essentially a graphical portrayal of the outflow of monies (i.e., expense flow) for both direct and indirect costs.

9.2 CASH FLOW TO THE CONTRACTOR

The flow of money from the owner to the contractor is in the form of progress payments. As already noted, estimates of work completed are made by the contractor periodically

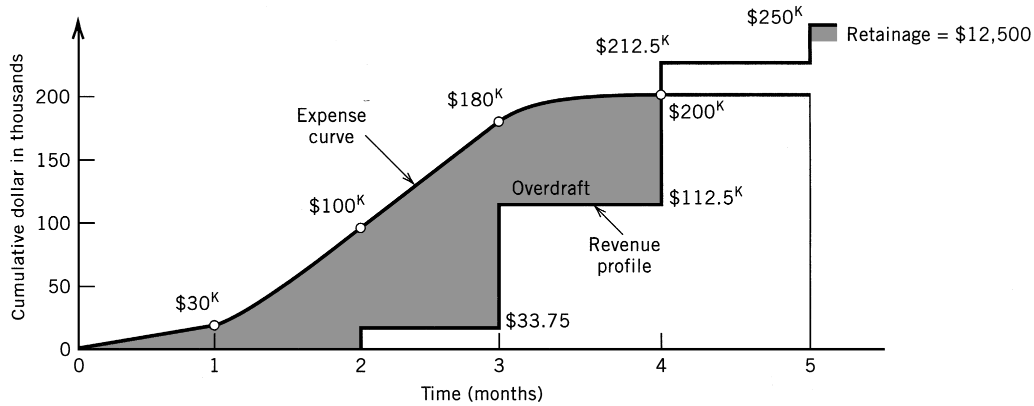


Figure 9.2 Expenses and income profiles.

(usually monthly) and are verified by the owner's representative. Depending on the type of contract (e.g., lump sum, unit price, etc.), the estimates are based on evaluations of the percentage of total contract completion or actual field measurements of quantities placed. This process is best demonstrated by further consideration of the four-activity example just described. Assume that the, contractor originally included a profit or markup in his bid of $50,000 (i.e., 25%) so that the total bid price was $250,000. The owner retains 10% of all validated progress payment claims until one-half of the contract value (i.e., $125,000) has been built and approved as an incentive for the contractor to complete the contract. The retainage will be deducted from the progress payments on the first $125,000 and eventually paid to the contractor on satisfactory completion of the contract. The progress payments will be billed at the end of the month, and the owner will transfer the billed amount minus any retainage to the contractor's account 30 days later. The amount of each progress payment can be calculated as:

$$\begin{aligned}\text{Pay} = {} & 1.25(\text{indirect expense} + \text{direct expense}) \\ & -0.10[1.25(\text{indirect expense} + \text{direct expense})]\end{aligned}$$

The minus term for retainage drops out of the equation when 50% of the contract has been completed. Because of the delay in payment of billings by the owner and the retainage withheld, the revenue profile lags behind the expense S-curve as shown in Figure 9.2.

The revenue profile has a stair-step appearance since the progress payments are transferred in discrete amounts based on the preceding equation. The shaded area in Figure 9.2 between the revenue and expense profiles indicates the need on the part of the contractor to finance part of the construction until such time as he is reimbursed by the owner. This difference between revenue and expense makes it necessary for the contractor to obtain temporary financing. Usually, a bank extends a line of credit against which the contractor can draw to buy materials, make payments, and pay other expenses while waiting for reimbursement. This is similar to the procedure used by major credit card companies in which they allow credit card holders to charge expenses and carry an outstanding balance for payment. Interest is charged by the bank (or credit card company) on the amount of the outstanding balance or overdraft[1]. It is, of course, good policy to try to minimize the amount of the overdraft and, therefore, the interest payments. The amount of the overdraft is

[1] Similar examples of this type of inventory financing can be found in many cyclic commercial undertakings. Automobile dealers, for instance, typically borrow money to finance the purchase of inventories of new car models and then repay the lender as cars are sold. Clothing stores buy large inventories of spring or fall fashions with borrowed money and then repay the lender as sales are made.

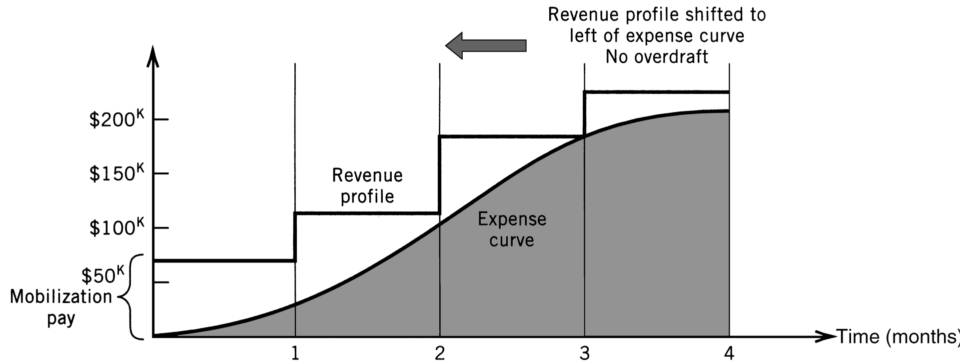


Figure 9.3 Influence of front, or mobilization, payment on expense and income profiles.

influenced by a number of factors, including the amount of markup or profit the contractor has in his bid, the amount of retainage withheld by the owner, and the delay between billing and payment by the owner.

Interest on this type of financing is usually quoted in relationship to the prime rate. The *prime rate* is the interest rate charged preferred customers who are rated as very reliable and who represent an extremely small risk of default (e.g., General Motors, Exxon, etc.). The amount of interest is quoted in the number of points (i.e., the number of percentage points) above the prime rate. The higher-risk customers must pay more points than more risky borrowers. Construction contractors are normally considered high-risk borrowers; if they default, the loan is secured only by some materials inventories and partially completed construction. In the event that a manufacturer of household appliances defaults, the inventory of appliances is available to cover part of the loss to the lender. Additionally, since construction contractors have a historically high rate of bankruptcy, they are more liable to be charged higher interest rates in most of their financial borrowings.

Some contractors offset the overdraft borrowing requirement by requesting front, or mobilization, money from the owner. This shifts the position of the revenue profile so that a reduced, or zero, overdraft occurs (Fig. 9.3). Since the owner is normally considered less of a risk than the contractor, he can borrow short-term money at a lower interest rate. If the owner agrees to this approach, he essentially takes on the interim financing requirement normally carried by the contractor. This can occur on cost-reimbursable contracts where the owner has great confidence in the contractor's ability to complete the project. In such cases it represents an overall cost savings to the owner, since otherwise he will ultimately be back-billed for the contractor's higher financing rate if the contractor must carry the overdraft.

9.3 OVERDRAFT REQUIREMENTS

In order to know how much credit must be made available at the bank, the contractor needs to know what the maximum overdraft will be during the life of the project. With the information given regarding the four-activity project, the overdraft profile can be calculated and plotted. For purposes of illustration, the interest rate applied to the overdraft will be assumed to be one percent per month. That is, the contractor must pay the bank 1% per month for the amount of the overdraft at the end of the month. More commonly, daily interest factors may be employed for the purpose of calculating this interest service charge. Month-end balances might otherwise be manipulated by profitable short-term borrowings at the end of the month. The calculations required to define the overdraft profile are summarized in Table 9.1.

Table 9.1 Overdraft Calculations

	Month									
	1	2		3		4			5	6
Direct cost	$25,000	$65,000		$75,000		$15,000				
Indirect cost	5,000	5,000		5,000		5,000				
Subtotal	30,000	70,000		80,000		20,000				
Markup (25%)	7,500	17,500		20,000		5,000				
Total billed	37,500	87,500		100,000		25,000				
Retainage withheld (10%)	3,750	8,750		0		0				
Payment received			$33,750		$78,750		$100,000		$37,500	
Total cost to date	30,000	100,000		180,000		200,000		200,000		
Total amount billed to date	37,500	125,000		225,000		250,000		250,000		
Total paid to date			$33,750		112,000		212,500		250,000	
Overdraft end of month	30,000	100,300		147,553		90,279		(8,818)[b]		(46,318)[b]
Interest on overdraft balance[a]	300	1,003		1,476		903		0		0
Total amount financed	30,300	101,303		149,029		91,182		(8,818)		

[a] A simple illustration only. Most lenders would calculate interest charges more precisely on the amount/time involved employing daily interest factors.
[b] Parentheses indicate a positive balance in this case.

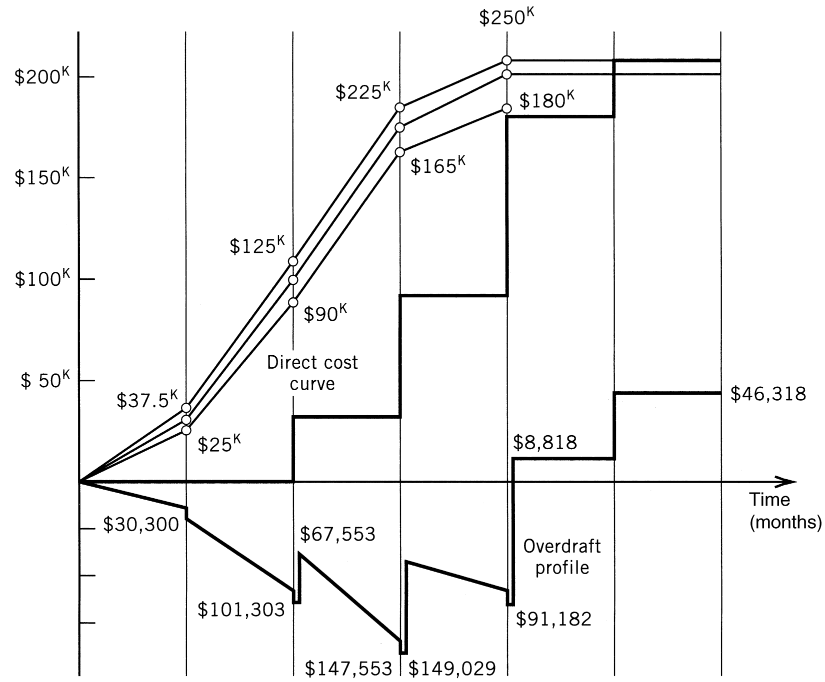


Figure 9.4 Plot of maximum overdraft.

The table indicates that the payment by the owner occurs at the end of a month based on the billing at the end of the previous month. It is assumed that the interest is calculated on the overdraft and added to obtain the amount financed. This amount is then reduced by the amount received from the owner for previous billings. To illustrate: The overdraft at the bank at the end of the second month is $100,300. The interest on this amount is $1,003 and is added to the overdraft to obtain the total amount financed ($101,303). To obtain the overdraft at the end of the third month, the progress payment of $33,750 is applied to reduce the overdraft at the beginning of the third month to $67,553. The overdraft at the end of the period is, then, $67,553 plus the costs for the period. Therefore, the overdraft is $67,553 plus $80,000, or $147,553. The information in the table is plotted in Figure 9.4. The overdraft profile appears as a sawtooth curve plotted below the baseline. This profile shows that the maximum required is $149,029. Therefore, for this project the contractor must have a line of credit that will provide at least $150,000 at the bank plus a margin for safety, say $175,000 overall to cover expenses.

Requirements for other projects are added to the overdraft for this project to get a total overdraft or cash commitment profile. The timing of all projects presently under construction by the contractor leads to overlapping overdraft profiles that must be considered to find the maximum overdraft envelope for a given period of time. Bids submitted that may be accepted must also be considered in the projection of total overdraft requirement. The plot of total overdraft requirements for a set of projects is shown in Figure 9.5.

Cash flow management involves all of the techniques described in this chapter—and very much more. It is fairly true to say, for example, that you cannot budget the other fellow's payments! That is, cash flows are affected by a significant degree of uncertainty. A cash flow management model of a relatively simple kind involves making provision for a set of at least 50 variables and requires a computer program to secure sufficient, timely, and usable cash management decision-making information.

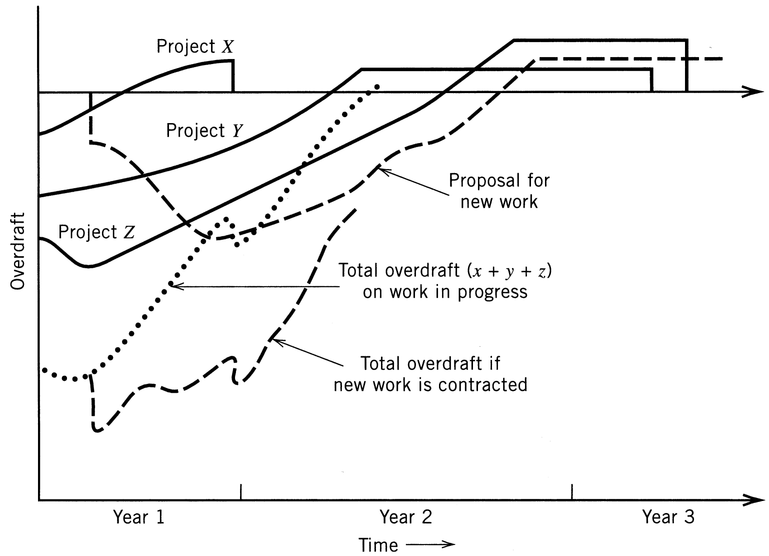


Figure 9.5 Composite overdraft profiles.

9.4 COMPARISON OF PAYMENT SCHEMES

Rate-of-return (ROR) analysis is helpful in comparing the economic value to a contractor of varying payment schemes. This technique utilizes engineering economy to evaluate the value of economic plans and strategies based on the time value of money. It is assumed in this section that the reader is familiar with the concepts of engineering economy. This subject is discussed in a number of textbooks (e.g., Collier and Ledbetter, *Engineering Economics and Cost Analysis*, 1988). It provides a vehicle for examining the economic impact of (1) varying retainage policies, (2) delay in payment strategies, and (3) the payment of a mobilization item to the contractor.

Consider the small four-activity project of Figure 9.1. The owner will consider the payment of a mobilization item at the end of the first period. This will be deducted from the final payment to the contractor. The amount of the payment will be $20,000. To determine the impact of this payment, the rate of return on the original payment sequence will be compared with the rate of return given the mobilization payment. Figure 9.6 shows a diagram of the original payment and expenditure sequence. Expenditures as taken from Table 9.1 are shown above the baseline in the figure. Revenues are shown below the line.

In order to determine the rate of return for a given sequence of payments and expenditures, a value for the interest rate must be found which satisfies the following relationship.

$$\sum^{all\ \mathrm{I}} PW[REV(I)] - \sum^{all\ \mathrm{I}} PW[EXP(I)] = 0$$

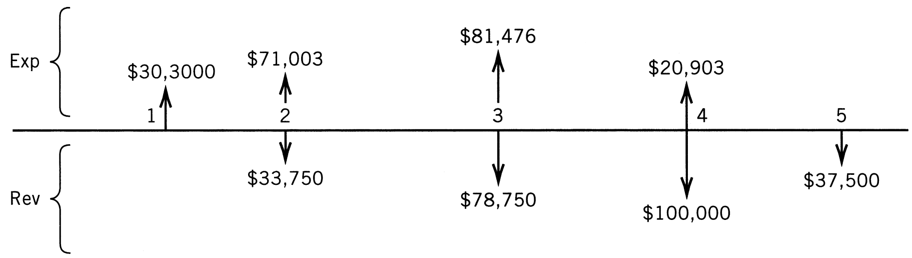
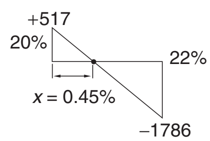


Figure 9.6 ROR for small bar chart problem.

Table 9.2 ROR Calculations for Small Project

N	NET[a]	PWF[b] @ 20%	Total @ 20%	PWF @ 25%	Total @ 25%	PWF @ 22%	Total @ 22%
1	−30300	.8333	−25249	.8000	−24240	.8196	−24834
2	−37253	.6944	−25868	.6400	−23842	.6719	−25030
3	−2726	.5787	−1577	.5120	−1396	.5507	−1501
4	79097	.4822	38140	.4096	32398	.4514	35704
5	37500	.4019	15071	.3277	12289	.3700	13875
			$\sum = +517$		$\sum = -4971$		$\sum = -1786$



$$\frac{X}{2\%} = \frac{517}{(1786 + 517)}$$
$$X = 0.45\%$$

$$\text{ROR} = 20\% + 0.45\%$$
$$= 20.45\%$$

[a] A negative net value indicates expenses exceed revenue for this period.
[b] PWF = Present Worth Factor.

where REV(I) = revenue for period I
EXP(I) = expenditure for period I
PW = present worth of these values

Since the difference between revenues and expenditures for a given period is REV(I) − EXP(I) = NET(I), the equation can be reduced to $\sum$PW[NET(I)] = 0. In other words, the sum of the present worth values for all period NET values must equal to zero. This assumes that all expenditures and all revenues are recognized at the end of each period, I. The effective ROR will be the value of interest that satisfies this equation or, in effect, causes the present value of all expenditures (recognized at the end of each month) to equal the present value of all revenues (again recognized at the end of the month). Since this method does not consider a company's cost of capital, it is often referred to as the Internal Rate of Return (IRR).

We do not have a closed-form mathematical expression that allows for the determination of the correct interest value i. Therefore, an iterative approach must be used to bracket the proper value of i. Values for the present value of revenues and expenditures or net values in each period are calculated using an assumed value of interest, i. The summation of the net values at present worth must equal zero. If the value of the summation of NET(I) changes sign (from minus to plus) between two different values of i, then the value of i that satisfies the equation is contained between those two values. Table 9.2 summarizes the calculations required to determine the rate of return for the original payment scheme given in Table 9.1. The net values [NET(I)] for the five periods are shown in the first column. A value of i of 20% is selected. The summation of the net values is calculated to be +517. The i value [present worth factor (PWF)] is increased from 20 to 22%, and the summation of net values

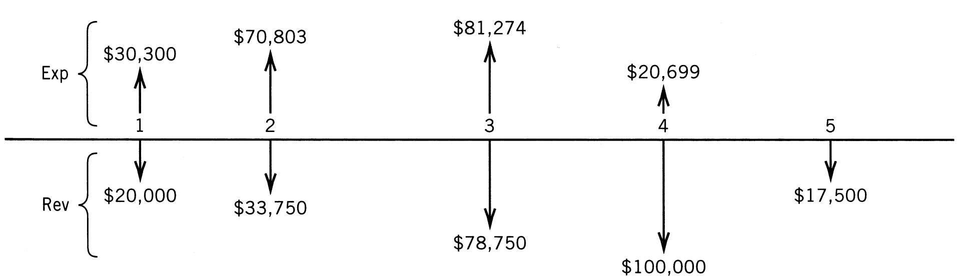


Figure 9.7 ROR for small bar chart problem with mobilization payment.

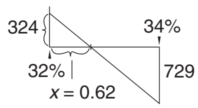
Table 9.3 Overdraft Calculations with Mobilization Payment

	Month										
	1		2		3		4		5		6
Direct cost	$25,000		$65,000		$75,000		$15,000				
Indirect cost	5,000		5,000		5,000		5,000				
Subtotal	30,000		70,000		80,000		20,000				
Markup (25%)	7,500		17,500		20,000		5,000				
Total billed	37,500		87,500		100,000		25,000				
Retainage withheld (10%)	3,750		8,750		0		0				
Payment received		$20,000		$33,750		$78,750		$100,000		$17,500	
Total cost to date	30,000		100,000		180,000		200,000		200,000		
Total amount billed to date	37,500		125,000		225,000		250,000		250,000		
Total paid to date		$20,000		$53,750		$132,000		$232,500		$250,000	
Overdraft end of month	30,000		80,300		127,353		69,877		(29,424)[a]		(46,924)[a]
Interest on overdraft balance	300		803		1,274		699		0		0
Total amount financed	$30,300		$81,103		$128,627		$70,576		(29,424)		

[a]Parentheses indicate a positive balance.

Table 9.4 ROR Calculations to Include Mobilization Payment

N	Net[a]	PWF[b] 30%	Total @ 30%	PWF 32%	Total @ 32%	PWF 34%	Total @ 34%
1	−10300	.7692	−7923	.7575	−7802	.7463	−7687
2	−37053	.5917	−21925	.5739	−21265	.5569	−20635
3	−2524	.4552	−1149	.4348	−1097	.4156	−1049
4	79301	.3501	27765	.3294	26122	.3101	24591
5	17500	.2693	4713	.2495	4366	.2315	4051
			$\sum = 1482$		$\sum = 324$		$\sum = -729$



$$\frac{X}{2\%} = \frac{324}{(324 + 729)}$$
$$X = 0.62$$

$$\text{ROR} = [32 + .62]\%$$
$$= 32.62\%$$

[a]A negative net value indicates expenses exceed revenue for this period.
[b]PWF = Present Worth Factor

becomes –1786. The value of i that satisfies the equality of $\text{PW}\sum[\text{NET}(I)] = 0$ must be between 20 and 22%. The correct ROR value is found by interpolation to be 20.45%.

The alternative sequence of payment including the $20,000 mobilization payment is shown in Figure 9.7. This sequence pays the contractor $20,000 at the end of the first work period and deducts the prepayment from the final payment. The final payment is reduced from $37,500 to $17,500. The cash flow calculations for this sequence are shown in Table 9.3. It can be seen that the mobilization payment causes the revenue profile to move closer to the expense curve, thus reducing the area between the two. This also reduces the overdraft and peak financial requirement.

The calculations to determine the ROR of this payment sequence are given in Table 9.4. The correct value is bracketed between 32 and 34%. The final ROR is 32.6%. This indicates that payment of the mobilization payment at the end of the first period increases the rate of return on this project to the contractor in the amount of approximately 12%. This is due in part to the reduction in the amount of inventory financing that must be carried by the contractor. What would be the impact of paying a $30,000 mobilization payment immediately upon commencement of the job? This is left as an exercise for the reader to determine the change in the rate of return.

REVIEW QUESTIONS AND EXERCISES

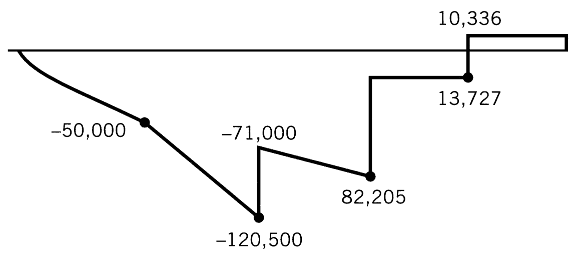
9.1 Given the following cost expenditures for a small warehouse project (to include direct and indirect charges), calculate the peak financial requirement, the average overdraft, and the rate of return on invested money. Sketch a diagram of the overdraft profile.

Assume 12% markup
Retainage 10% throughout project
Finance charge = 1.5% month
Payments are billed at end of month and received one month later

Month	1	2	3	4
Indirect + Direct Cost ($)	$69,000	$21,800	$17,800	$40,900

9.2 The table and graph on page 157 represent a contractor's overdraft requirements for a project. Complete the table shown for costs, markup, total worth, retainage, and pay received. Retainage is 10%, markup is 10%, and interest is 1% per month. The client is billed at the end of the month. Payment is received the end of the next month, to be deposited in the bank the first of the following month.

Overdraft	−50,000	−120,500	−82,205	−13,727	+10,336
Interest	−500	−1,205	−822	−137	—
Cumulative	−50,500	−121,705	−83,027	−13,864	+10,336



	1	2	3	4	5
Direct cost					
Indirect cost	10,000	10,000	5,000		
Total cost					
Markup					
Total worth					
Retainage					
Pay received					

9.3 Given the bar chart in Figure 9.1 with the direct costs for each activity as shown, calculate the rate of return of the contractor. Assume that (a) the markup is 15%; (b) retainage is 5% on the first 50% of worth, and 0% thereafter; (c) payment requests are submitted at the end of each month, and payments are received one month later; and (d) the finance charge is 1% per month of the amount of the overdraft at the end of the month.

Timing and allocation	$25,000	$65,000	$75,000	$15,000	
			Total direct costs		$180,000
Indirect costs $5000/month	5,000	5,000	5,000	5,000	
			Total indirect costs		$20,000
	$30,000	$70,000	$80,000	$20,000	$200,000

9.4 A contractor is preparing to bid for a project. He has made his cost estimate together with the schedule of work. His expected expenses and their time occurrence are as shown in the following table. For simplicity of analysis he assumed that all expenses are recognized at the end of the month in which they occur.

Month	Mobilization Demobilization	Subcontractors	Materials	Payroll	Equipment	Field Overhead
0	$40,000	$0	$0	$0	$0	$0
1	0	10,000	10,000	10,000	20,000	1,000
2	0	30,000	20,000	15,000	10,000	5,000
3	0	30,000	30,000	20,000	20,000	6,000
4	0	40,000	30,000	20,000	30,000	6,000
5	0	50,000	40,000	40,000	20,000	6,000
6	0	50,000	40,000	40,000	15,000	6,000
7	0	40,000	30,000	40,000	10,000	6,000
8	0	40,000	10,000	20,000	10,000	6,000
9	0	70,000	10,000	10,000	10,000	6,000
10	0	30,000	5,000	5,000	10,000	6,000
11	0	30,000	5,000	5,000	5,000	6,000
12	20,000	50,000	0	5,000	5,000	5,000
Total	$60,000	$470,000	$230,000	$230,000	$165,000	$65,000

Total cost = \$60,000 + \$470,000 + \$230,000 + \$230,000 + \$165,000 + \$65,000 = \$1,220,000
Profits + overhead @ 10% = \$122,000
Bid price = \$1,342,000

(a) The contractor is planning to add 10% to his estimated expenses to cover profits and office expenses. The total will be his bid price. He is also planning to submit for this progress payment at the end of each month. Upon approval, the owner will subtract 5% for retainage and pay the contractor one month later. The accumulated retainage will be paid to the contractor with the last payment (i.e., end of month 13).

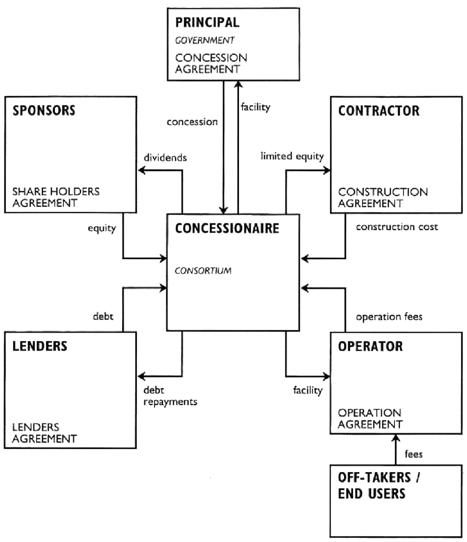
(i) Develop the cash flow diagram.

(ii) What is the peak financial requirement and when does it occur?

(b) Assume the same as in part (a), except that the owner will retain 10% instead of 5%. Plot the cash flow diagram and calculate the peak financial requirement.

Chapter 10

Project Funding



Stake Holders in BOT Funding

Build Operate and Transfer (BOT)

Concept

Pollalis (1996) defines Build Operation and Transfer as follows:

"In the BOT approach, a private party or concessionaire retains a concession for a fixed period from a public party, called principal (client), for the development and operation of a public facility. The development consists of the financing, design, and construction of the facility, managing and maintaining the facility adequately, and making it sufficiently profitable. The concessionaire secures return of investment by operating the facility and, during the concession period, the concessionaire acts as owner. At the end of the concession period, the concessionaire transfers the ownership of the facility free of liens to the principals at no cost."

The modern implementation of BOT concepts is generally accredited to the Turkish government under the leadership of Prime Minister Ozal.

This method of funding and constructing a large infrastructure program was initiated in Turkey starting in 1984. In fact, the financing and construction of the Suez Canal by the French in the nineteenth century was done using a system which would be considered BOT by today's standards (Levy 1996).

Confederation Bridge Crossing – Prince Edwards Island – Canada

Advantages

Traditionally, highways, dams, public buildings (e.g., jails), tunnels, etc. have been constructed using funds which were generated from taxes levied by public entities (e.g., federal, state, municipal government). In many cases, tax payers have rebelled and failed to support the issuance of bonds and similar borrowing instruments to allow construction of critically needed public facilities. In developing countries with relatively weak economies, modest tax revenues have led to a delay in developing infrastructure to support national development.

The concept of privatization as defined by the BOT approach became popular in the early 1980s. Privatization addresses the problems of developing infrastructure projects by utilizing private funds to finance and construct public projects. For instance, if a bridge is needed to connect two political entities separated by a river or a strait, a private consortium can raise the funds and construct the bridge recovering the cost and effort involved by charging tolls to users of the bridge. The Confederation Bridge linking New Brunswick with Prince Edwards Island in Canada is an example of a BOT infrastructure project.

10.1 MONEY: A BASIC RESOURCE

The essential resource ingredients that must be considered in the construction of a project are usually referred to as the four Ms. These basic construction resources are (1) money, (2) machines, (3) manpower, and (4) materials. They are presented in this order since this is the sequence in which they will be examined in the next few chapters. Here, the first of these resources to be encountered in the construction process, money, is considered. Money (i.e., actual cash or its equivalent in monetary or financial transactions) is a cascading resource that is encountered at various levels within the project structure. The owner or developer must have money available to initiate construction. The contractor must have cash reserves available to maintain continuity of operations during the time he is awaiting payment from the owner. The major agents involved in the flow of cash in the construction process are shown in simple schematic format in Figure 10.1.

Rising construction costs have increased the pressure on the construction industry to carefully monitor and control the flow of money at all levels. As a result, more emphasis is being placed on cash flow and cost control functions in construction management than ever before. In the planning phases, more thorough investigations and more accurate cost estimates are being required for those seeking financial backing. To remain competitive, contractors are being forced to monitor their cost accounts more closely and to know where losses are occurring. In this chapter, the methods by which the owner/entrepreneur acquires project funding will be considered. The relationship between the flow of money from owner to contractor and its impact on the contractor's project financing has been discussed in Chapter 9.

10.2 CONSTRUCTION FINANCING PROCESS

The owner's financing of any significant undertaking typically requires two types of funding: *short-term* (construction) funding and *long-term* (mortgage) funding. The short-term funding is usually in the form of a construction loan, whereas the long-term financing involves a mortgage loan over a term ranging from 10 to 30 years.

The short-term loans may provide funds for items such as facility construction, land purchases, or land development. Typically these short-term loans extend over the construction period of the project. For large and complex projects, this can be a period of 6 to 8 years as in the case of utility power plants. A short-term loan is provided by a lending

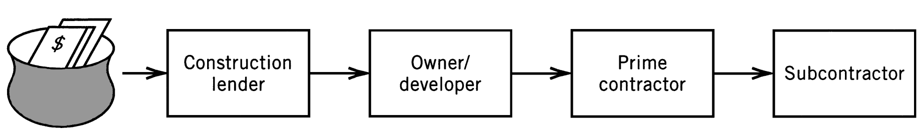


Figure 10.1 Project money flow.

institution, based on the assurance that it will be repaid with interest, by some other loan. This subsequent mortgage loan constitutes the long-term financing. Therefore, the first objective of any entrepreneur is to seek a commitment for long-term, or permanent, financing from a mortgage lender. Regardless of the type of project, this commitment will permit the construction loan, and any other funding required, to be obtained with relative ease or, at least, more easily.

Unless he is in a position to raise the funds required directly by the issue of his own securities, the entrepreneur will seek to obtain a commitment from one of several alternate sources, including real estate investment trusts (REITs), investment or merchant banks, commercial banks, savings and loan associations, insurance companies, governmental agencies (VA, FHA), or, in special cases, from one of the international development banks. Public institutions often raise project construction funds by the sale of bonds. The choice of lender depends on the type and size of project. The choice of the form of security employed depends on a number of factors such as relative cost, the time period for which the funds will be available, and the degree of flexibility involved (the freedom to pay out or refinance) as to whether there are any restrictions involved and whether there is any sacrifice of control to the lender. The funding of some larger projects may be handled by a consortium of international bankers (e.g., the Channel Tunnel).

Lending institutions are cautious; they are not interested in financing failures or in owning partially completed projects. Therefore, they will undertake a great deal of research and evaluation prior to providing a commitment for funding. At a minimum, an entrepreneur will be expected to provide the following as part of the loan application:

1. A set of financial statements for the firm
2. Personal financial statements from the principals of the firm
3. Proof of clear title to the land for the project and that it has an appropriate zoning
4. Preliminary floor plans and elevations for the project
5. Preliminary cost estimates
6. A market research study to verify expected income
7. A detailed pro forma indicating projected income and expense throughout the life of the mortgage loan

EXAMPLE

An example of a long-term finance pro forma for a venture involving the construction and leasing of a 75-unit apartment complex is shown in Figure 10.2a. This document indicates that the annual income from the proposed apartment complex project will be $306,830. The requested loan is $2,422,000, and the annual debt service (i.e., interest) on this amount is $236,145, realizing an income after debt service of approximately $70,000. The ratio between income and debt service is 1.3. Lenders normally wish this ratio to be below 1.3. The basis for the loan amount is given in Figure 10.2b. Items 1 to 34 are construction-related items and are developed from standard references [e.g., R. S. Means, Co., *Building Construction Cost Data* (published annually)] based on unit measures such as square footage. The lender normally has a unit-price guide for use in verifying these figures. Items 35 to 46 in Figure 10.2b cover nonconstruction costs that are incurred by the entrepreneur. It should be noticed that the interest for the construction loan is included in the costs carried forward to the long-term financing.

The method used to calculate the actual dollar amount of the loan is of great interest to the entrepreneur. The interest the developer pays for the use of the borrowed money is an expense, and it is generally considered prudent business policy to minimize expenses. One way to minimize the interest expense would be to borrow as little as possible. This is not, however, the way the developer moves toward his objective. The developer seeks primarily to protect his own personal assets (or those of his company) in his efforts to complete the project. The more he invests, the more he stands to lose if the project fails. With this consideration in mind, the developer may seek to minimize his own investments. That is, the developer tries to expand his own small initial asset input into a large amount of usable money. This is called *leverage*. He takes a small amount and levers, or amplifies, it into a large amount.

The amount of the mortgage loan should be a happy medium between too much and too little. If the mortgage is too small, there will not be enough to cover the project. On the other hand, if the mortgage is too large, the developer will find that the individual mortgage payments will exceed his available revenue, and he may be unable to meet all of his obligations.

The amount the lender is willing to lend as long-term funding is derived from two concepts: the economic value of the project and the capitalization rate (cap rate). The economic value of the project is a measure of the project's ability to earn money. One method of predicting the economic value is called the *income approach* to value and is the method shown in Figure 10.2a. Simply stated, it is the result of an estimated income statement of the project in operation. Like any income statement, it shows the various types of revenue and their sum. These are matched against the predicted sums of the different expenses. Although the predicted net income is a function of many estimated numbers, commonly a fairly reasonable degree of accuracy is achieved. The expected net income divided by the cap rate produces the economic value of the project. The cap rate used in Figure 10.2a is 9.5%. The capitalized economic value of the project is obtained by dividing the net income ($306,830) by the cap rate factor (0.095). This yields an economic value of $3,229,789.

How is the cap rate obtained? First, a lender generally provides a mortgage that is about 75% of the estimated economic value of the project. This is done because 25% of the value, or thereabouts, must be invested by the developer and will serve as an incentive for his making the project a success. That is, the lender furnishes 75% and the developer furnishes 25%. The lender must then decide what the interest rate will be and takes up the developer's rate of return. The sum of these numbers, times their respective portions, gives the cap rate.

As an example, suppose that the lender decides that the interest rate will be 8.5% and that the developer's planned rate of return will be 12%. Then, the cap rate is obtained as 8.5% times 75% plus 12% times 25%, which gives 9.375% or 0.09375 as the cap rate factor. Obviously, the value of the cap rate can be adjusted by the values that the lender places on his interest rate and the developer's rate of return. These numbers are a function of the existing

Market rent for subject property (unfurnished) 55 two-bedroom A, B, or C units—1167 sq ft @ 41.0 cents/sq ft = $478.47/mo or $480 × 55	$	26,400.00
20 three-bedroom A, B units—1555 sq ft @ 37.3 cents/sq ft = $580.00/mo $580 × 20		11,600.00
Total estimated monthly income	$	38,000.00
Other income: Coin laundry, vending machine		150.00
	$	38,150.00
× 12 = annual total		457,800.00
Less vacancy factor of 5% (based on historical data)		−22,890.00
Adjusted gross annual income		434,910.00
Less estimated expenses @ 29.45%		−128,080.00
Net income before debt service	$	306,830.00
Capitalized value @ 9.5% = $3,229,789.00 =		$\frac{306{,}830.00}{(0.095)}$

Requested loan value	= $2,422,000.00
Loan/value ratio	= 75% (high) governed by law
Long-term debt service @ 9.75% constant	= $236,145.00
Debt service coverage ratio	= 1.3
Loan per unit	= $32293.33
Loan per square foot	= $25.42

Figure 10.2a Pro forma for 75 apartment units.

Construction Related Costs	1. Excavation and grading	$ 67,500
	2. Storm sewers	48,000
	3. Sanitary sewers	84,030
	4. Water lines	28,000
	5. Electric lines	14,000
	6. Foundations	31,000
	7. Slabs	96,000
	8. Lumber and sheathing	185,000
	9. Rough carpentry	185,000
	10. Finish carpentry	81,362
	11. Roofing and labor	20,035
	12. Drywall and plaster	70,000
	13. Insulation	28,888
	14. Millwork	140,556
	15. Hardware	8,813
	16. Plumbing	165,000
	17. Heating and air conditioning	95,025
	18. Electrical	90,350
	19. Linoleum and tile	17,752
	20. Carpeting	101,881
	21. Kitchen cabinets	62,075
	22. Painting and decorating	107,000
	23. Masonry, block	20,680
	24. Masonry, brick	100,200
	25. Ranges and hoods	29,638
	26. Disposals	3,139
	27. Exhaust fans	1,022
	28. Refrigerator	35,040
	29. Paving	20,915
	30. Walks and curbs	20,792
	31. Landscaping	30,000
	32. Fence and walls	36,792
	33. Fireplace	51,100
	34. Cleanup	29,200
Non-Construction Costs	35. Lender's fee	32,000
	36. Surveyor's fee	1,000
	37. Architect's fee	12,500
	38. Land cost	80,000
	39. Attorney's fee	7,500
	40. Title insurance premium	5,762
	41. Other closing costs	150
	42. Hazard insurance premium	4,780
	43. Construction loan interest	120,000
	44. Appraisal	750
	45. Building permit	1,500
	46. Tax	50,000
	Total	$2,422,000

Figure 10.2b Construction cost breakdown for 75 apartment units.

economic conditions and thus fluctuate with the state of the economy. The lender, therefore, cannot exert as much influence on their values as might at first be expected. In addition, the lender is in business to lend and wisely will not price himself out of the competition. He will attempt to establish a rate that is conservative but attractive. The expected income divided by the cap rate yields the economic value. The mortgage value may then be on the order of 75% of the calculated economic value. Not every lender will follow this type of formula approach; some, for example, may have a policy of lending a fixed proportion of their own assessed valuation, which may not be based on the economic value but instead on their estimate of the market value of the property.

The mortgage loan may be the critical financial foundation of the entire project and may also involve protracted and complex negotiations. For this reason, the project developing company may exercise its right to hire a professional mortgage broker whose business it is to find a source of funds and service mortgage loan dealings. The broker's reputation is based on his ability to obtain the correct size mortgage at the best rate that is also fair to his client. The broker acts as an advisor to his client, keeping him apprised of all details of the proposal financing in advance of actually entering into the commitment. For this service, the mortgage broker receives a fee of about 2% of the mortgage loan, although the rate and amount will vary with the size of the loan.

10.3 MORTGAGE LOAN COMMITMENT

Once the lending institution has reviewed the venture and the loan committee of the lender has approved the loan, a preliminary commitment is issued. Most institutions reserve their final commitment approval until they have reviewed and approved the final construction plans and specifications.

The commitment issued is later embodied in a formal contract between the lender and borrower, with the borrower pledging to construct the project following the approved plans, and the lender agreeing that upon construction completion, and the achievement of target occupancy, he will provide the funds agreed upon at the stated interest rate for the stated period of time. As noted earlier, the actual amount of funds provided generally is less than the entire amount needed for the venture. This difference, called *owner's equity*, must be furnished from the entrepreneur's own funds or from some other source. The formal commitment will define the floor and ceiling amounts of the long-term loan.

During the construction period, no money flows from the long-term lender to the borrower. Funds necessary for construction must be provided by the entrepreneur or obtained from a short-term construction lender. Typically the lender of the long-term financing will pay off the short-term loan in full, at the time of construction completion, thereby canceling the construction loan and leaving the borrower with a long-term debt to the mortgage lender.

10.4 CONSTRUCTION LOAN

Once the long-term financing commitment has been obtained, the negotiation of a construction loan is possible. Very often commercial banks make construction loans because they have some guarantee in knowing the loan will be repaid from the long-term financing. However, even in these situations, there are definite risks involved for the short-term lender. These risks relate to the possibility that the entrepreneur or contractor may, during construction, find themselves in financial difficulties. If this occurs, it may not be possible for the entrepreneur/contractor to complete the project, in which case the construction leader may have to take over the job and initiate action for its completion. This risk is offset by a discount (1–2%), which is deducted from the loan before any money is disbursed. For example, if the amount of construction money desired is $1,000,000, the borrower signs a note that he will pay back $1,020,000. The borrower, in effect, pays immediately an interest of $20,000. This is referred to as a discount and may be viewed as an additional interest rate for the construction loan. The current trend to minimize these risks is to require the borrower to designate his intended contractor and design architect. The lender may also require that all contactors involved in the construction be bonded as well. Some commercial banks evaluate and seek to approve the owner's intended contractor, his prime subcontractors, and the owner's architect, as a prerequisite to approving the construction loan. This evaluation extends to an evaluation of their financial positions, technical capabilities, and current workloads.

To minimize the risks involved, the banks will also base their construction loans on the floor of the mortgage loan, and only 75 to 80% of this floor will be lent. Of course, the developer may need additional funds to cover construction costs. One way to ensure this is to finance the gap between the floor and ceiling of the long-term mortgage loan. The entrepreneur goes to a lender specializing in this type of financing and obtains a standby commitment to cover the difference or gap between what the long-term lender provides and the ceiling of the long-term mortgage. Then, if the entrepreneur fails to achieve the breakeven rent roll, he still is ensured of the ceiling amount. In this situation, the construction lender will provide 75 to 80% of the ceiling rather than the floor. If the floor of the loan is $2,700,000 and the ceiling is $3,000,000, the financing of the gap can lead to an additional $240,000 for construction (i.e., 80% of $300,000). Financing of the gap is usually expensive, requiring a prepaid amount of as much as 5% to the gap lender. In the above example, this would be $15,000 paid for money that may not be required if the rent roll is achieved. Nevertheless, the additional $240,000 of construction funding may be critical to completion of the project and, therefore, the $15,000 is well spent in ensuring that the construction loan will include this gap funding.

Once the construction loan has been approved, the lender sets up a draw schedule for the builder or contractor. This draw schedule allows the release of funds in a defined pattern, depending on the site and length of the project. Smaller projects, such as single-unit residential housing, will be set up for partial payments based on completion of various stages of construction (i.e., foundation, framing, roofing, and interior), corresponding to the work of the various subcontractors who must be paid (see Fig. 10.3). For larger projects, the draw schedule is based on monthly payments. The contractor will invoice the owner each month for the work he has put in place that month. This request for funds is usually sent to the owner's representative or architect who certifies the quantities and value of work in place. Once approved by the architect and representative, the bank will issue payment for the invoice, less an owner's retainage (see Chapter 3).

The owner's retainage is a provision written into the contract as an incentive for the contractor to continue his efforts, as well as a reserve fund to cover defective work that must be made good by the contractor before the retainage is released. Typically this retainage is 10%, although various decreasing formulas are also used. When the project is completed, approved, cleared, and taken over by the owner, these retainages are released to the builder.

In addition to the funds mentioned, the developer should be aware that some front money is usually required. These funds are needed to make a good-faith deposit on the loan to cover architectural, legal, and surveying fees and for the typical closing costs.

10.5 OWNER FINANCING USING BONDS

Large corporations and public institutions commonly use the procedure of issuing bonds[1] to raise money for construction projects. A bond is a kind of formal IOU issued by the borrower promising to pay back a sum of money at a future point in time. Sometimes this proviso is supported by the pledging of some form of property by way of security in case of default by the borrower. A *series* of bonds or debentures, issued on the basis of a prospectus, are the general type of security issued by corporations, cities, or other institutions, but not by individual owner-borrowers. In this discussion, owner financing means financing arrangements made by those corporations or institutions that are the owners

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[1] In this case, bonds refer to financial borrowing instruments.

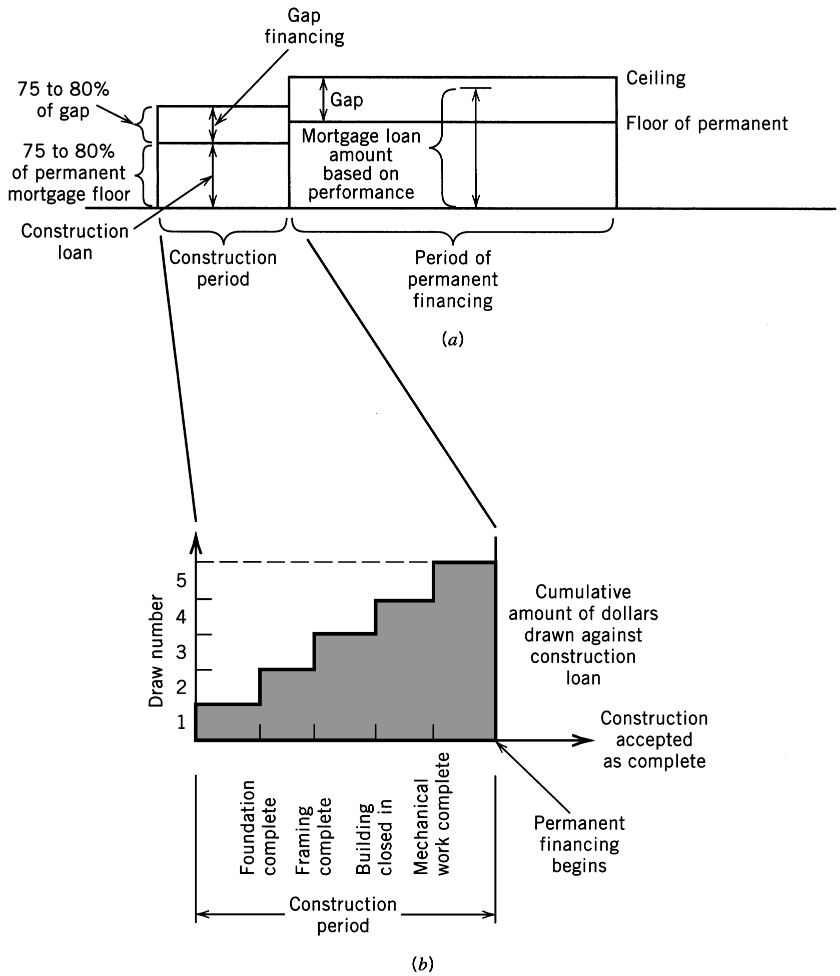

Figure 10.3 (*a*) Profile of project financing by the entrepreneur and (*b*) draw schedule.

of the project property. In the illustrative material that follows, "Joe" stands as a surrogate for "any borrower" ("Joan" would have served as well!). During the period in which he has use of the money, the borrower promises to pay an amount of interest at regular intervals. For instance, Joe borrows $1000 and agrees to pay back the $1,000 (referred to as the principal) in full at the end of 10 years. He pays an annual interest of 8% (at the end of each year). That is, he, in effect, pays a rent of $80.00 per year on the principal sum of $1000 for 10 years and then pays back the amount borrowed. The rent is payable at the end of each year. The sequence of payments for this situation would be as appears in Figure 10.4. When a series of bonds is issued, there may be a commitment to pay the interest due in quarterly installments rather than in one amount at the end of the year. A bond, as a long-term promissory note, may take any one of a variety of forms depending on the circumstances; mortgage bonds involve the pledging of real property, such as land and buildings; debentures do not involve the pledging of specific property. Apart from the security offered, there is the question of interest rates and the arrangements to be made for the repayment of the principal sum. Sometimes a sinking fund may be set up to provide for the separate investment, at interest, of capital installments that will provide for the orderly retirement of the bond issue. Investors find this type of arrangement an attractive condition in a bond issue.

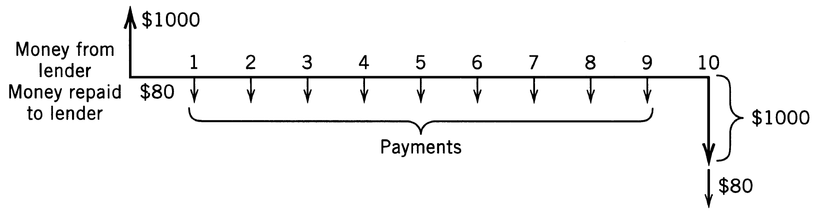

Figure 10.4 Sequence of payments for a bond.

In preparing for a bond or debenture issue, financial statements must be drawn up and sometimes a special audit may be required. A prospectus for the issue may need to be drawn up, and this will involve settling the terms of issue and of repayment, the interest rates payable, and the series of promises or conditions related to the issue, such as its relative status in terms of priority of repayment, limitations on borrowing, the relative value of the security, and the nomination of a trustee to watch the interests of bond or debenture holders. These details are usually settled with the aid of specialists such as a CPA firm or the mortgage broker.

Public bodies may need the approval of some local regulatory authority, and corporations may have to file and have approved a prospectus for the proposed bond issue. Charters or other constitutional documents must, of course, confer on the public body or corporation the power to borrow money in this way; this power is exercised by the council or by the board of directors or governors. For public offerings that are particularly attractive, banks bid for the opportunity to handle the placement of the bonds. The banks recover their expense and profit by offering to provide a sum of money slightly less than the amount to be repaid. As noted above, this is called *discounting the loan*. The fact that more will be repaid by the borrower than is lent by the lender leads to a change in the actual interest rate. This is established through competitive bidding by the banks wishing to provide the amount of the bond issue. The bank that offers the lowest effective rate is normally selected; this represents the basic cost incurred for the use of the money.

Consider the following situation in which a city that has just received a baseball franchise decides to build a multipurpose sports stadium. The design has been completed, and the architect's estimate of cost is $40.5 million. The stadium building authority has been authorized to issue $42 million in bonds to fund the construction and ancillary costs. The bonds will be redeemable at the end of 50 years with annual interest paid at 5% of the bond principal. Neither the term nor its rate purport to be representative of current market conditions. At this time the term for any bond issue would tend to be shorter and its rate higher. In some commercial dealings "index number" escalation clauses are also occasionally seen. The banks bid the amounts for which they are willing to secure payment support. Suppose the highest bid received is $41 million.

In order to determine the effective rate of interest, a rate-of-return analysis may be used. The profile of income and expense is shown in Figure 10.5. The effective rate of interest is that rate for which the present worth of the expenses is equal to the present worth (PW) of

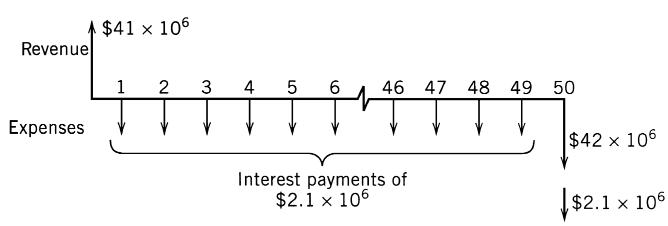

Figure 10.5 Profile of revenue-expense for a bond issue.

the revenue (in this case, $41 $\times$ 10). That is,

$$\text{PW (revenue)} = \text{PW (expenses)}$$

Utilizing the information above, this expression for the bond issue problem becomes

$$\$41 \times 106 = \$2{,}100{,}000\,(\text{PWUS}, i, 50)^2 + \$42{,}000{,}000\,(\text{PWSP}, i, 50)^3$$

The annual interest is \$2.1 million, and this is a uniform series of payments for 50 years. The \$42 million must be repaid as a single payment at the end of 50 years. The notation used in the equation is consistent with that used in a number of standard engineering economy textbooks.

In making this approach to a solution, a trial-and-error method (similar to that used in Section 9.4) must be employed to solve the equation. That is, values of i must be assumed and the equation solved to see if the relationship [e.g., PW(revenue) − PW(expenses) = 0] is satisfied. In this case, two initial candidates for consideration are $i = 0.05$ and $i = 0.06$. Consulting appropriate tables for the present worth factors, the right side of the equation becomes

$$\begin{aligned}
i = 0.05 \quad \text{PW} &= \$2.1 \times 10^6\,(18.256) + \$42 \times 10^6\,(0.0872) \\
&= \$42 \times 10^6 \quad \text{difference} = +1.0 \times 10^6 \\
i = 0.06 \quad \text{PW} &= \$2.1 \times 10^6\,(15.762) + \$42 \times 10^6\,(0.0543) \\
&= \$35.38 \times 10^6 6 \quad \text{difference} = -\$5.62 \times 10^6
\end{aligned}$$

Since the equation balance goes from plus to minus, the value satisfying the relationship is between 5 and 6%. Using linear interpolation, the effective interest rate is found to be

$$i = 0.05 + (0.06 - 0.05) \times \frac{1.0 \times 10^6}{(1.0 + 5.62) \times 10^6} = 0.515$$

or 5.15% as an approximation.

REVIEW QUESTIONS AND EXERCISES

10.1 What is the present level of the prime rate? How does this rate relate to the current financing and overdraft charges for new building construction in your locality? (How many points above the prime is this rate?) Does this overdraft rate vary with the magnitude of the monies involved?

10.2 Referring to the example in Figure 10.2aA, suppose the market rent for a two-bedroom unit is \$550 per month and for a three-bedroom unit is \$650 per month. If the going cap rate is 10%, rework the pro forma calculations for the apartment project of Figure 8.2. Then determine the lender's interest rate. What is the new breakeven vacancy factor?

10.3 What determines the number of draws a builder can make in completing his facility? What is the existing policy regarding number of draws in your locality?

10.4 Suppose that for the multipurpose sports stadium example considered in the text the bond issue was for 40 years and the annual interest rate is 9% of the bond principal. Using the architect's estimate of cost of \$41 million, determine the effective interest rate.

10.5 Suppose in the preceding problem, that the bonds are financed by a bank that discounts the bond issue to \$40 milion. What is the new effective interest rate?

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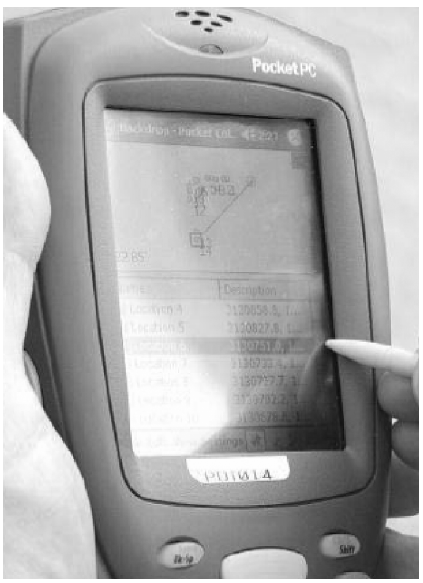
[2](PWUS, i, 50) is the Present Worth Uniform Series Factor for an interest rate, i, over a period of 50 years.

[3](PWSP, i, 50) refers to the Present Worth Single Payment Factor.

Chapter 11

Equipment Ownership

RFID Application in Construction



Hand held RFID device

The Need

For tracing and identifying construction equipment on construction sites, electronic identification tags are becoming widely used. With Radio Frequency Identification (RFID) technology, no line of sight or direct contact is required between the reader and the tag. Since RFID does not rely on optics, it is ideal for dirty, oily, wet, or harsh environments. RFID is an automatic identification technology, similar to bar code technology, with positive identification and automatic data transfer between a tagged object and a reader. Since the RFID tags are read by low wattage radio waves, instead of light waves (as with bar-codes), they will communicate through non-metallic materials such as paint, plastic, grease, and dirt, and are impervious to vibration, light, water, and heat up to 100°C in most cases.

The Technology

A RFID system consists of two major components (reader and the tag) which work together to provide the user with a non-contact solution to uniquely identify people, assets, and locations. The reader performs several functions, one of which is to produce a low-level radio frequency magnetic field. The RF magnetic field serves as a "carrier" of power from the reader to the passive (no battery required) RFID tag. When a tag is brought into the magnetic field produced by the reader, the recovered energy powers the integrated circuit in the tag and the memory contents are transmitted back to the reader. Once the reader has checked for errors and validated the received data, the data are decoded and restructured for transmission to a user in the format required by the host computer system. The RFID tags used are both readable and writable. This capability enables information to be written back to the tag for enhanced asset management. RFID tags do not require a line of sight for identification, and readability is not affected by bright lighting situations.

11.1 GENERAL

Equipment resources play a major role in any construction activity. Decisions regarding equipment type and combination can have a major impact on the profitability of a job. In this respect, the manager's goal is to select the equipment combination that yields the maximum production at the best or most reasonable price. Quite obviously, the manager must have a basic understanding of the costs associated with a particular piece of equipment. He must also be capable of calculating the rate of production of the piece or combination of equipment. The cost and the rate of production combine to yield the cost per unit of production. For example, if it is estimated that the cost of a particular fleet of haulers and loaders is $500 per hour and the production rate is 750 cu yd/hr, the unit price can be easily calculated as $0.66 per cubic yard.

Construction equipment can be divided into two major categories. *Productive equipment* describes units that alone or in combination lead to an end product that is recognized as a unit for payment. *Support equipment* is required for operations related to the placement of construction such as movement of personnel and materials and activities that influence the placement environment. Typical production units are pavers, haulers, loaders, rollers, and entrenchers. Hoists, lighting sets, vibrators, scaffolds, and heaters represent typical classes of support equipment. In most cases, equipment units are involved either in handling construction materials at some point in the process of placing a definable piece of construction (e.g., crane lifting a boiler, pavers spreading concrete or asphalt into lifts on a base course) or in controlling the environment in which a piece of construction is realized (e.g., heaters controlling ambient temperature, prefabricated forms controlling the location of concrete in a frame or floor slab).

In heavy construction, large quantities of fluid or semifluid materials such as earth, concrete, and asphalt are handled and placed, leading to the use of machines. The equipment mix in such cases has a major impact on production, and the labor component controls production rates only in terms of the skill required to operate machines. Therefore, heavy construction operations are referred to as being equipment intensive. Heavy construction contractors normally have a considerable amount of money tied up in fixed equipment assets, since capitalizing a heavy construction firm is a relatively expensive operation.

Building and industrial construction require handwork on the part of skilled labor at the point of placement and are therefore normally not as equipment intensive.

Equipment is required to move materials and manpower to the point of installation and to support the assembly process. Emphasis is on hand tools; and, although heavy equipment pieces are important, the building and industrial contractors tend to have less of their capital tied up in equipment. Also because of the variability of equipment needs from project to project, the building contractor relies heavily on the renting of equipment. The heavy construction contractor, because of the repetitive use of many major equipment units, often finds it more cost effective to own this equipment.

11.2 EQUIPMENT OWNING AND OPERATING COSTS

The costs associated with construction equipment can be broken down into two major categories. Certain costs (e.g., depreciation, insurance, and interest charges) accrue whether the piece of equipment is in a productive state or not. These costs are fixed and directly related to the length of time the equipment is owned. Therefore, these costs are called *fixed*, or *ownership*, costs. The term *fixed* indicates that these costs are time dependent and can be calculated based on a fixed formula or a constant rate basis. On the other hand the operation of a machine leads to operating costs that occur only during the period of operation. Some of these costs accrue because of the consumption of supplies, such as tires, gas, and oil, and the widespread practice of including the operator's wages in the operating costs. Other costs occur as a result of the need to set aside moneys for both routine and unscheduled maintenance. Thus operating costs are *variable costs*.

The total of owning and operating costs for items of equipment such as tractors, shovels, scrapers, dozers, loaders, and backhoes is typically expressed on an hourly basis. These two categories of cost accrue in different ways. *Ownership costs* are usually arrived at by relating the estimated total service life in hours to the total of those costs. If the equipment is idle for some of those hours, the relevant costs would be taken up as part of general operating overhead; when the equipment is in use, the hourly costs are charged to the job or project.

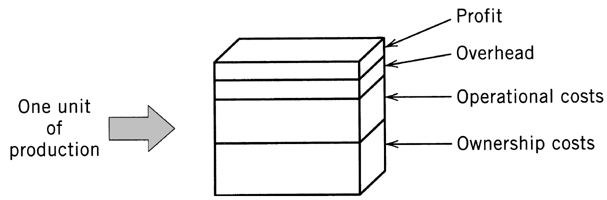


Figure 11.1 Cost components in a production unit.

Operating costs are variable in total amount, being a function of the number of operating hours, but these hourly costs are found to be relatively constant.

The *hourly charge* for a piece of equipment is made up of four elements. An allowance for estimated hourly overhead costs is added to the ownership and operating costs. The fourth element is an amount for income or profit. A schematic illustration of this breakdown of the hourly charge for a piece of equipment is shown in Figure 11.1.

Ownership costs are composed of two elements: first, an estimate for depreciation on the cost of using the equipment itself. Each piece of equipment represents an estimated number of hours of useful service life and the depreciable value, the major part of its original cost, is divided by the total hours to yield a charging rate for this element of equipment costs. The second component of ownership costs consists of estimates of allowance for interest, insurance, and taxes.

Operating costs cover a broader range of items, the principal elements being: fuel, oils and lubricants, hydraulics fluid, grease, filters, and other supplies; maintenance, general overhauls, and repairs; and parts replacement (cutting edges, blades, buckets), tire replacements, and the like. Also included here are the direct labor costs— the operator's wages—including all of the expense loadings for holidays, sick leave, and insurance.

To the direct operating costs just enumerated are added allowances for general overhead expenses and the indirect costs of supervisory labor. This total establishes the total hourly cost of owning and operating a unit of equipment. A percentage markup is added to provide for an income or profit element.

Some of these costs are incurred and paid for concurrently with the operation of the equipment, but the allowances or estimates included for items such as repairs and maintenance are provisions for costs that will have to be paid at some future time.

General administrative costs (e.g., overhead), including items such as telephones, stationery, postage, heat, light and power, and the costs of idle equipment in general are aggregated together as general overhead expense, an allowance that forms part of the hourly charging rate.

11.3 DEPRECIATION OF EQUIPMENT

The method by which depreciation is calculated for tax purposes must conform to standards established by the Internal Revenue Service (IRS). Federal law has introduced the use of fixed percentages as given in published tables to calculate the amount of depreciation for various classes of equipment and depreciable property. The tables have replaced accelerated methods referred to as the declining balance and sum-of-years-digits (SOYD) methods, which were used prior to 1981. Since the methods used under pre-1981 legislation are still relevant in understanding the tables presently used and are still required in some situations, they will be described briefly.

The four most commonly used methods of calculating depreciation on equipment prior to 1981 are:

1. Straight line
2. Declining balance

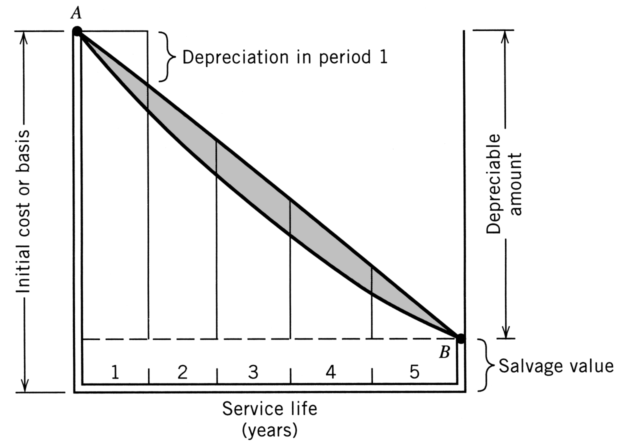


Figure 11.2 Factors in depreciation.

3. Sum of years digits
4. Production

Declining balance and sum of years are referred to as accelerated methods since they allow larger amounts of depreciation to be taken in the early years of the life of the asset. (Only the declining-balance method will be described in this chapter.) The contractor usually selects a method that offsets or reduces the reported profit for tax purposes as much as possible. In effect, for companies paying taxes at the corporate rate (assume 34%), each dollar of depreciation reduces the amount of tax paid by 34 cents (assuming that the depreciation does not reduce revenue below zero).

Most heavy construction contractors assume that each machine in the fleet is a small "profit center" and will attempt to apply any depreciation associated with a piece of equipment to offset the profit generated by that machine. The major factors to be considered in calculating the depreciation of an asset are shown in Figure 11.2. The three major factors form the three sides of the depreciation "box" that are linked by the method of depreciation selected. They are:

1. Initial cost or basis in dollars
2. Service life in years or hours
3. Salvage value in dollars

The amount that can be depreciated or claimed by way of a tax deduction is the difference between the initial net value of the asset and its residual or salvage value. This is referred to as the depreciable amount and establishes the maximum number of depreciation dollars available in the asset during its service life.

The declared initial cost of the asset must be acceptable in terms of the IRS definition of depreciable cost. For instance, suppose a $75,000 scraper is purchased. The tires on the scraper cost $15,000. These tires are considered a current period expense and therefore are not depreciable. That is, they are not part of the capital asset for purpose of depreciation. The tires are considered consumables and have a service life different from that of the asset. In this case, the initial value of the scraper for depreciation purposes is $60,000.

The initial depreciable cost or basis is often referred to as the net first cost. In addition to the purchase price minus major expenses, items such as tires, freight costs, and taxes are included in the net first cost and are part of the amount depreciable. If we have purchased a rubber-tired wheeled tractor, the net first cost for purposes of depreciation would be arrived

Table 11.1 Estimated Service Life Table (Caterpillar Tractor Co.)

Type of equipment	Excellent conditions: hours	Average conditions: hours	Severe conditions: hours
Track-type tractors Traxcavators Wheeled loaders Wheeled tractors Scrapers	12,000	10,000	8,000
Motor graders	15,000	12,000	10,000

To determine the cost per hour due to depreciation, the above information may be used as follows:

$$\text{Depreciation cost per hour} = \frac{\text{Purchase price} - \text{Tire value}}{\text{Estimated service life in hours}}$$

at as follows:

Purchase price	\$84,000 (FOB[1] at factory)
Less tires	\$14,000
	\$80,000
Plus tax at 5%	\$ 4,000
Plus freight	\$ 2,800
Net first cost	\$86,800

The depreciable basis for the calculation of depreciation allowances is this first cost of \$86,800.

The concept of salvage value implies that there is some residual value in the piece of equipment (i.e., scrap value) at the end of its life. Unless this value exceeds 10% of the first cost of the equipment, this value is neglected and the entire first cost is considered to be available for depreciation. In the case cited, if the salvage value is less than \$8,680, the entire first cost will be considered as depreciable and the piece of equipment will yield tax payment reductions in the amount of \$29,512 (i.e., \$86,800 × 0.34) across its service life.

The IRS publishes tables indicating the appropriate service life values. Most construction equipment items fall into the 3-, 5-, or 7-year service life categories. Manufacturers typically publish tables such as that shown in Table 11.1 indicating a variable service life based on operating conditions. Service life is defined by the IRS tables, and the only question has to do with the category or class of property to which an equipment type is to be assigned.

Given the present highly defined system of depreciation based on fixed tabular percentages, decisions regarding depreciation are simplified as to whether an accelerated or linearly prorated system of depreciation is to be used. To better understand the concepts behind the tables and the prorated system, two of the basic methods of calculating depreciation will be discussed in the following sections.

[1]FOB is discussed in Section 16.2 of Chapter 16. In this case it indicates the cost of the equipment at the factory prior to shipment.

11.4 STRAIGHT-LINE METHOD

An accountant (and the IRS) would describe the straight-line method of calculating allowable depreciation as being based on the assumption that the depreciation, or the loss in value through use, is uniform during the useful life of the property. In other words, the net first cost or other basis for the calculation, less the estimated salvage value, is deductible in equal annual amounts over the estimated useful life of the equipment. An engineer would call this a linear method. This simply means that the depreciable amount is linearly prorated or distributed over the service life of the asset. Let us assume that we have a piece of equipment that has an initial cost or base value of $16,000 and a salvage value of $1000. The service life is 5 years and the depreciable amount is $15,000 (initial cost minus salvage value). If we linearly distribute the $15,000 over the 5-year service life (i.e., take equal amounts each year), we are using the straight-line method of depreciation. The amount of depreciation claimed each year is $3000. This is illustrated in Figure 11.3.

The remaining value of the piece of equipment for depreciation purposes can be determined by consulting the stepwise curve of declining value. During the third year of the asset's service life, for example, the remaining base value, or book value, of the asset is $10,000. If we connect the points representing the book value at the end of each year (following subtraction of the depreciation), we have the "straight line."

The concept of the base value, or book value, has further tax implications. For instance, if we sell this asset in the third year for $13,000, we are receiving more from the buyer than the book value of $10,000. We are gaining $3000 more than the depreciated book value of the asset. The $3000 constitutes a *capital gain*. The reasoning is that we have claimed depreciation up to this point of $6000 and we have declared that as part of the cost of doing business. Now the market has allowed us to sell at $3000 over the previously declared value, demonstrating that the depreciation was actually less than was claimed. We have profited and, therefore, have received taxable income. Prior to the 1986 tax law, a capital gain was not taxed at the full rate but at approximately half of the tax rate for normal income. Presently, capital gains are taxed as normal income (i.e., 34%). Business entities have been pressing for the reinstatement of the alternate capital gains tax rate.

The base value for depreciation is affected if we modify substantially the piece of equipment. Assume in the above example, that in the third year we perform a major modification on the engine of the machine at a total cost of $3000. Since this is a capital improvement, the term *basis* is used to refer to the depreciation base. The modification increases the base

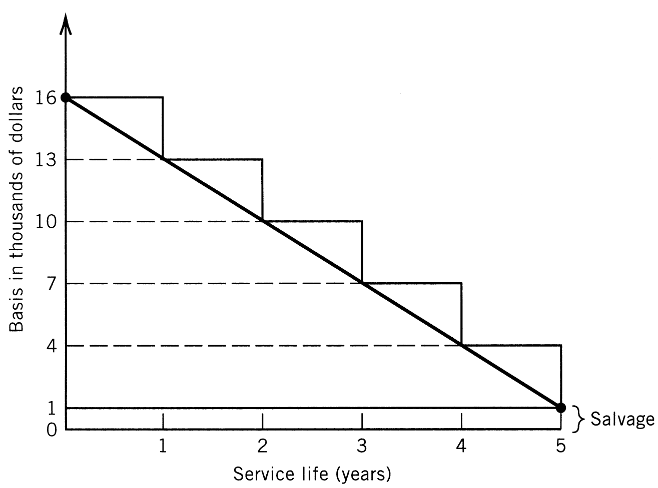


Figure 11.3 Straight-line depreciation.

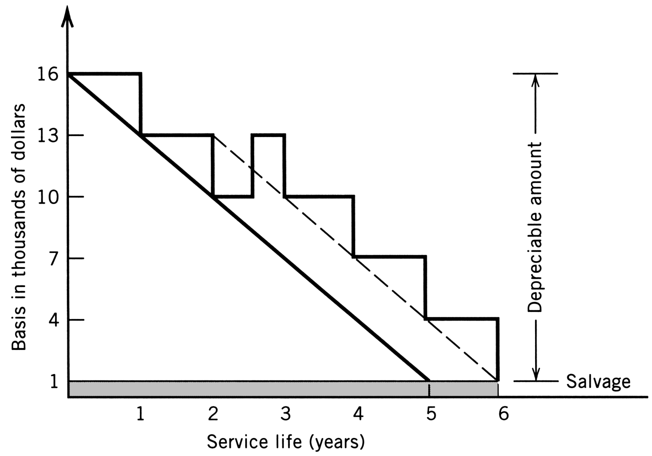


Figure 11.4 Adjustment of basis.

value of the unit by $3000 as shown in Figure 11.4. It also may extend the service life of the asset. Something similar occurs if we make some improvements to a building. The value is increased and this added value can be depreciated.

If we can depreciate real property, can we depreciate the house in which we live? Depreciation represents a cost of doing business. Since in most cases we do not "do business" in our own home, our home is not a depreciable asset. You can, however, think of some instances in which a person conducts some business at home. Special depreciation rules apply to that situation.

11.5 DECLINING BALANCE

One of the accelerated methods previously (prior to 1981) used is the declining balance method. When applied to new equipment with a useful life of at least 3 years, the effective rate at which the balance is reduced may be twice the straight-line rate. For this reason, the expression double-declining balance (DDB) is used when this IRS option is applied to new assets. For assets that are not purchased new but are secondhand, the optional rate is 150% of the straight-line rate. In this method, it is the rate that is important since it remains constant throughout the calculations. Formally stated, in the declining-balance method, the amount of depreciation claimed in the previous year is subtracted from the book value (base value) at the beginning of the previous year before computing the next year's depreciation. That is, a constant rate is applied to a balance which is declined each year by the amount claimed in the previous year. For new equipment the rate is calculated by dividing 200% by the number of service life years (SLY) (i.e., 200/SLY). For used equipment the rate is 150% divided by the service life years.

To illustrate, consider the $16,000 piece of equipment used in discussing the straight-line method. We will assume the piece is purchased new at this price. Since the service life of the unit is 5 years, the constant rate to be applied will be $200\%/5 = 40\%$. The calculations for this example are summarized in Table 11.2.

A repetitive process of calculation can be detected. The constant rate of 40% (column 2) is applied to the book value at the end of the previous year (column 3) to obtain the depreciation (column 4). The reduced value of the property is column 3 minus column 4, as shown in column 5. The "*Book Value End of This Year*" for year N is the "*Book Value End of Previous* Year" for year N + 1. It follows that the value in column 3 for year 2 will be the same as the value in column 5 for year l.

Another interesting fact is noted. The amount of depreciation taken over the 5-year service life is less than the depreciable amount. The book value at the end of 5 years is

Table 11.2 Double-Declining-Balance Method

SLY	Rate applied to balance (%)	Book value end of previous year ($)	Depreciation for this year ($)	Book value end of this year ($)
1	40	16,000.00	6,400.00	9,600.00
2	40	9,600.00	3,840.00	5,760.00
3	40	5,760.00	2,304.00	3,456.00
4	40	3,456.00	1,382.40	2,073.60
5	40	2,073.60	829.44	1,244.16
			TOTAL $14,755.84	

$1244.16 and the salvage is $1000. Therefore, $244.16 has not been recovered. Typically, the method is changed to the straight-line approach in the fourth or fifth year to ensure closure on the salvage value. This underlines the fact that the only role played by the depreciable value in the declining-balance method is to set an upper limit on the amount of depreciation that can be recovered. That is, an asset may not be depreciated below a reasonable salvage value. A common mistake is to apply the rate to the *depreciable value* in the first year. The rate is always applied to the *total* remaining book value, which in this example during the first year is $16,000.

If the piece of equipment had been purchased used, for $16,000, the procedure would be the same but the rate would be reduced. In this case, the rate would be 150%/5 or 30%. The 150% calculations are summarized in Table 11.3. In this situation, since $1689.12 in unclaimed depreciation would remain at the end of year 5, the method could be changed to the straight-line approach in the fourth or fifth year with some advantage. A comparison of the double-declining-balance methods and the straight-line method is shown in Figure 11.5.

The proportionately higher rate of recovery in the early service life years is revealed by this figure. More depreciation is available in the first year using the double-declining-balance method ($6400) than in the first 2 years using the straight-line method ($6000). Equipment rental firms that intend to sell the equipment after the first 2 years of ownership are in a good position to capitalize on this feature of the accelerated methods. Of course, if they sell at a price well above the book value, they must consider the impact of the capital gains tax.

11.6 PRODUCTION METHOD

It was stated earlier that the contractor tries to claim depreciation on a given unit of equipment at the same time the equipment is generating profit in order to reduce the tax that might otherwise be payable. The production method allows this since the depreciation is taken based on the number of hours the unit was in production or use for a given year. The asset's

Table 11.3 150 Declining-Balance Method

SLY	Rate (%)	Book value end of previous year ($)	Depreciation for this year ($)	Book value end of this year ($)
1	30	16,000.00	4,800.00	11,200.00
2	30	11,200.00	3,360.00	7,840.00
3	30	7,840.00	2,352.00	5,488.00
4	30	5,488.00	1,646.40	3,841.60
5	30	3,841.60	1,152.48	2,689.12
			TOTAL $13,310.88	

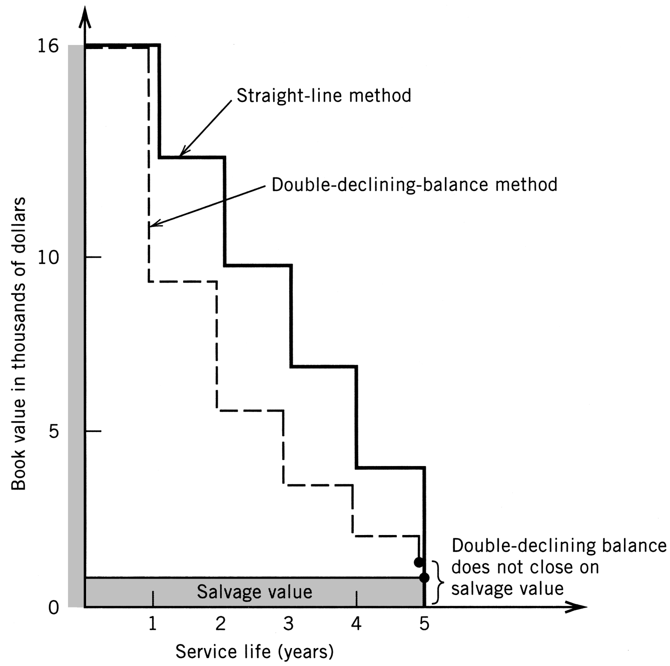


Figure 11.5 Comparison of double-declining-balance and straight-line methods.

cost is prorated and recovered on a per-unit-of-output basis. If the $16,000 equipment unit we have been discussing has a 10,000-hour operation time, the $15,000 depreciable amount is prorated over 10,000 hours of productive service life. This method is popular with smaller contractors since it is easy to calculate and ensures that the depreciation available from the asset will be recovered at the same time the unit is generating profit. A reasonable estimate of the total operating hours for a piece of equipment may be obtained by referring to the odometer on the unit together with the logbook or job cards.

In some cases, unless this method is used, the units may be depreciated during a period when they are not generating income and, consequently, the full benefit of the depreciation deduction may be lost. The objective of the contractor is to have a depreciation deduction available in years in which it can be more effectively applied to reduce taxable income. It may not be possible to defer depreciation and to take it in years in which it can be applied with more advantage. Therefore, the strategy should be to have it available in the years in which profits are likely to be high. The production method ensures that depreciation deduction is available when the machine is productive and theoretically profitable or income producing.

At the time of construction of the Alaska pipeline, contractors with contracts for the access road to parallel the pipeline purchased large equipment fleets in anticipation of project start-up. Then, environmental groups delayed the project several years during which time the contractors were forced to put their equipment fleets in storage. Since these units were not in use and were not productive and profitable during this delay, the contractors claimed no depreciation. Nevertheless, the production method allowed them to apply the depreciation at the proper time when the job mobilized and the units were put into production.

In some situations, the production method might be less desirable. If we own an entrenching machine (service life of 10,000 hours) but only operate it 500 hours per year. using the production method would stretch the period of recovery out over 20 years. If the machine is sold after 5 years, we would have claimed only one-quarter of the available depreciation. One advantage offsetting this apparent disadvantage is that we might have a smaller adjustment to make by way of capital gain on the sale. In such a case, clearly a method other than the production method would be more appropriate and a more balanced way of dealing with the matter.

11.7 DEPRECIATION BASED ON CURRENT LAW

For equipment placed in service prior to 1981, depreciation was calculated using methods such as the straight-line or declining-balance methods described above. For equipment placed in service during the period 1981 to 1986, contractors were required to depreciate using either the Accelerated Cost Recovery System (ACRS) method or the alternate ACRS system. which is equivalent to a straight line prorating of the cost across the life of the asset (e.g., the straight-line or production method). With the ACRS method, equipment is depreciated according to 3-year, 5-year, 10-year and 15-year property classes. For example, light trucks (less than 6.5 tons) are considered to be 3-year property. Most average-weight construction equipment is considered to be 5-year equipment. Some heavy construction equipment such as dredging barges are depreciated over a 10-year, life.

A set of tables defines accelerated depreciation amounts for equipment placed in service after 1986. In contrast to the ACRS method, these tables are referred to as the Modified ACRS or MACRS. Changes to the ACRS system include:

1. 7- and 20-year property life categories have been added.
2. The amount depreciated is calculated using prescribed depreciation methods for each class of equipment. For example, 3-, 5-, 7-, and 10-year property are depreciated using the 200% declining-balance method with a switch to the straight-line method at a time that maximizes the deduction. In addition, the "half-year convention" is used to calculate the first-year depreciation.
3. Certain assets have been reclassified to different property classes. In particular, cars and light general-purpose trucks have been reclassified as 5-year property. Most medium-weight, off-highway construction equipment is now considered 7-year property, while heavy equipment remains 10-year property.

The alternate MACRS method remains the straight-line method and can be used for depreciation as before. The accelerated MACRS values are given in Table 11.4. To better understand the basis of the values in the table, consider the following situation. A $100,000 piece of equipment is to be depreciated using the accelerated MACRS method. It is assumed that the equipment has a 5-year property life. The MACRS table is based on using the 200% declining-balance (DB) method. The rate of depreciation will be 40% (200% divided by 5 years). However, due to the half-year convention, only half of the 200-DB depreciation is taken in the first year. Therefore, the effective percent is 20 and $20,000 can be depreciated in the first year. The remaining value is $80,000. The second-year depreciation is 40% of $80.000, or $32,000. This amounts to 32% of the original $100,000 basis. The balance is now declined to $80,000 − $32,000, or $48,000. Again for the third-year depreciation the 200-DB method yields 40% of $48,000, or $19,200. The depreciation table for this equipment is as follows:

Year	Depreciation	Book Value
1	$20,000	$80,000
2	$32,000	$48,000
3	$19,200	$28,000
4	$11,520	$17,280
5	$11,520	$ 5,760
6	$ 5,760	$0

Table 11.4 MACRS Table for Accelerated Depreciation

Recovery year	Annual recovery (Percent of original depreciable basis)					
	3-year class (200% d.b.)	5-year class (200% d.b.)	7-year class (200% d.b.)	10-year class (200% d.b.)	15-year class (150% d.b.)	20-year class (150% d.b.)
1	33.00	20.00	14.28	10.00	5.00	3.75
2	45.00	32.00	24.49	18.00	9.50	7.22
3	15.00	19.20	17.49	14.40	8.55	6.68
4	7.00	11.52	12.49	11.52	7.69	6.18
5		11.52	8.93	9.22	6.93	5.71
6		5.76	8.93	7.37	6.23	5.28
7			8.93	6.55	5.90	4.89
8			4.46	6.55	5.90	4.52
9				6.55	5.90	4.46
10				6.55	5.90	4.46
11				3.29	5.90	4.46
12					5.90	4.46
13					5.90	4.46
14					5.90	4.46
15					5.90	4.46
16					3.00	4.46
17						4.46
18						4.46
19						4.46
20						4.46
21						2.25

It will be noted that although this is a 5-year property class equipment, it is depreciated out across a 6-year period. Also, following the third year, a switch from 200-DB to straight-line method is made to close on a residual or salvage value of zero. By dividing the depreciation amounts for each year by the original basis of $100.000, it will be seen that the percentage of depreciation in each year is the same as the values given in Table 11.4. To confirm that this method is used to determine the percentages in Table 11.4, the reader should try to calculate the annual depreciation amounts for a $100,000 piece of equipment with a 10-year service life.

11.8 DEPRECIATION VERSUS AMORTIZATION

Depreciation is a legitimate cost of business that recognizes the loss in value of equipment over time. As such, it is an expense and can be deducted from revenues, resulting in a lowering of taxes (e.g., 34 cents per dollar of depreciation as noted earlier). This yields the contractor a tax savings that can be used to replace the equipment. However, this savings would represent only 34% of the original value of the equipment. To provide for the replacement of the equipment at some point in the future, contractors charge the client an amount that provides a fund to purchase new equipment. This practice of charging clients an amount to be used to purchase replacement equipment is referred to as amortizing the equipment. This is a protocol throughout the industry and allows the contractor to accumulate (i.e., escrow) funds for renewing the equipment fleet over time.

For instance, the contractor will charge clients an annual amount of $20,000 for a $100,000 equipment with a service life of 5 years. This provides $100,000 at the end of 5 years to purchase replacement equipment. Of course, due to inflation and escalating prices, a replacement equipment may cost $120,000. This would indicate that the contractor should recover \$24,000 per year to escrow the needed \$120,000 for a new machine. Part of this amount will be recovered through depreciation due to reduced taxes: \$34,000 will be available through the reduction of taxes. The contractor may consider this in calculating the amount of back charge to the client.

Since the amortization charge leads to larger revenue and the possibility of incurring income, the contractor may end up paying some tax on the amount charged to the client to amortize equipment. There is a complex interaction between depreciation and amortization, and this must be studied in the context of each equipment piece and the tax structure of each company.

11.9 INTEREST, INSURANCE, AND TAX (IIT) COSTS

In addition to the amortization/depreciation component, the ownership costs include a charge for other fixed costs that must be recovered by the equipment owner. Throughout the life of the unit, the owner must pay for insurance, applicable taxes, and either pay interest on the note used to purchase the equipment or lose interest on the money invested in equipment if the unit was paid for in cash. These costs are considered together as what can be called the IIT costs. Recovery of these charges is based on percentages developed from accounting records that indicate the proper levels that must be provided during the year to offset these costs. The percentages for each cost are applied to the average *annual value* of the machine to determine the amount to be recovered each hour or year with respect of these cost items.

The average annual value is defined as:

$$\text{AAV} = \frac{C(n+1)}{2n}$$

where AAV is the average annual value, C is the initial new value of the asset, and n is the number of service life years. This expression assumes that the salvage value is zero. What the formula does is level the declining value of the asset over its service life so that a constant average value on an annual basis is achieved. This is indicated graphically in Figure 11.6.

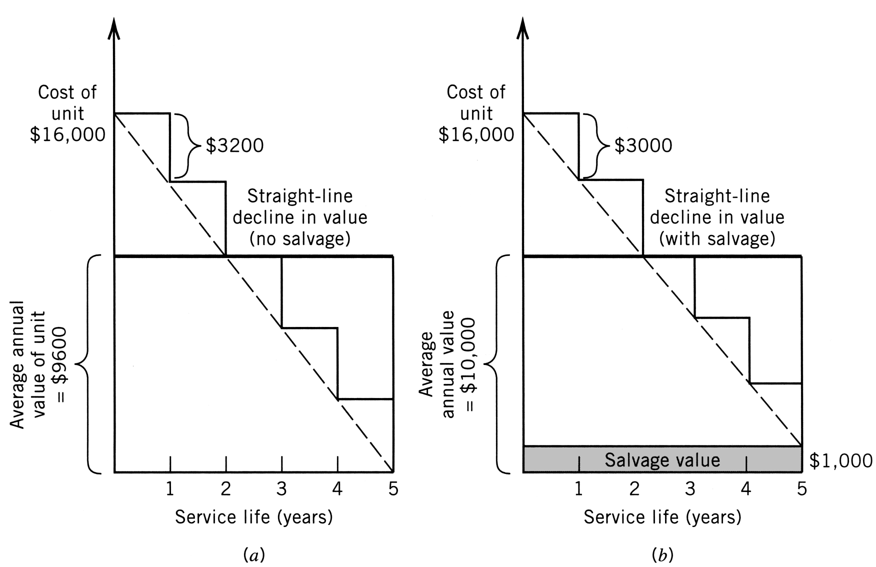


Figure 11.6 Interpretation of average annual value: (*a*) average annual value without salvage value included and (*b*) average annual value considering salvage value.

Applying this formula to a machine with initial capital value of \$16,000 and a salvage value of \$1000, the average annual value is calculated as:

$$\text{AAV} = \frac{\$16{,}000\ \times\ (6)}{10} = \$9{,}600$$

The area under the rectangle in Figure 11.6 representing the average annual value equals the area under the plot representing the straight-line decline in value. Using this fact, the formula can be derived. If we consider the salvage value, the area under the stepped curve is increased by the area of the shaded segment in Figure 11.6b. Therefore, the AAV is increased somewhat. The appropriate expression for AAV including the salvage value is:

$$\text{AAV} = \frac{C(n+1) + S(n-1)}{2n}$$

For the \$16,000 piece of equipment considered, this yields

$$\text{AAV} = \frac{\$16{,}000\ (6) + \$1{,}000\ (4)}{10} = \$10,\ 000$$

Verification of this expression is left as an exercise for the reader.

Assume that the proper levels of the annual provision to cover IIT costs for the unit are as follows:

$$\begin{aligned} \text{Interest} &= 8\%\ \text{of AAV} \\ \text{Insurance} &= 3\%\ \text{of AAV} \\ \text{Taxes} &= \underline{2\%\ \text{of AAV}} \\ \text{Total} &= 13\%\ \text{of AAV} \end{aligned}$$

The amount to cover these ownership costs must be recovered on an hourly basis by backcharging the owner. Therefore, an estimate of the number of hours the unit will be operational each year must be made. Assume the number of hours of operation for the unit is 2000 hours/year. Then, the IIT cost per hour would be:

$$\text{IIT} = \frac{0.13(\text{AAV})}{2000} = \frac{0.13(9600)}{2000} = \$0.624 \quad \text{or} \quad \$0.62 \text{ per hour}$$

Manufacturers provide charts that simplify this calculation.

The interest component may be a nominal rate or an actual rate or, again, it may reflect some value of the cost of capital to the company. Some contractors also include here a charge for the protective housing or storage of the unit when it is not in use. These adjustments may raise the annual provision to cover IIT costs by from 1 to 5% with the following effect (in this case, each 1% charge may represent a 5 cents per hour increase in the charging rate).

Percentage of AAV(%)	**General Provision for IIT Costs** (\$)	**Hourly Rate** (**Base 2000 hours**) (\$)
13	1248	0.62
14	1344	0.67
15	1440	0.72
16	1536	0.77
17	1632	0.82
18	1728	0.87

Ultimately it is the competitive situation that sets practical limits to what may be recovered. That is why the tax limitation strategies discussed earlier are of such importance.

Figure 11.7 shows a chart for calculating the hourly cost of IIT. To use the chart the total percent of AAV and the estimated number of annual operating hours are required. Entering the y axis with the percent (use 13% from above) and reading down from the intersection of

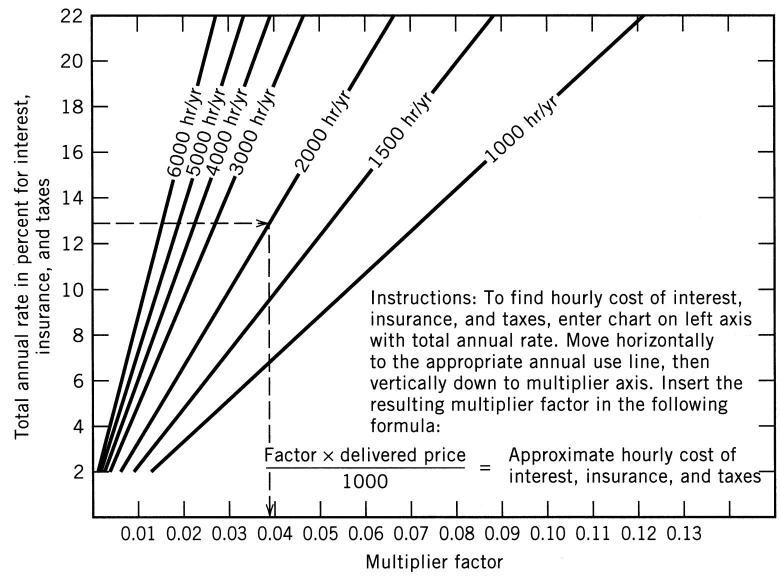


Figure 11.7 Guide for estimating hourly cost of interest, insurance, and taxes (Caterpillar Tractor Co.).

the 13% line with the 2000-hour slant line, the multiplier factor is 0.039. The hourly charge for IIT is calculated as:

$$\text{IIT/hour} = \frac{\text{factor} \times \text{delivery price}}{1000}$$

In the example discussed,

$$\text{IIT/hour} = \frac{0.039 \times 16{,}000}{1000} = \$0.624 \quad \text{or} \quad \$0.62 \text{ per hour}$$

If the amortization/depreciation costs using the straight-line method for the \$16,000 unit in the example is \$l.50 per hour, the owner must recover \$1.50 plus \$0.62 or \$2.12 per hour for fixed costs.

11.10 OPERATING COSTS

The major components contributing to the operating or variable costs are fuel, oil, grease (FOG), tire replacement (on rubber-wheeled vehicles), and normal repairs. Normally, historical records (purchase vouchers, etc.) are available that help in establishing the rate of use of consumables such as fuel, oil, and tires. Maintenance records indicate the frequency of repair. The function that best represents the repair costs to be anticipated on a unit starts low and increases over the life of the equipment. Since repairs come in discrete amounts, the function has a stepwise appearance (see Fig. 11.8).

The following guidelines for establishing the amount to set aside for repairs are taken from Caterpillar Tractor material.

Guide for Estimating Hourly Repair Reserve. (See Caterpillar Performance Handbook)

To estimate hourly repair costs, select the appropriate multiplier factor from the table below and apply it in the following formula:

$$\frac{\text{Repair factor} \times (\text{delivered price} - \text{tires})}{1000} = \text{estimated hourly repair reserve}$$

	Operating Conditions		
	Excellent	Average	Severe
Track-type tractors	0.07	0.09	0.13
Wheel tractor scrapers	0.07	0.09	0.13
Off-highway trucks	0.06	0.08	0.11
Wheel-type tractors	0.04	0.06	0.09
Track-type loaders	0.07	0.09	0.13
Wheel loaders	0.04	0.06	0.09
Motor graders	0.03	0.05	0.07

The cost of tires on rubber-wheeled vehicles is prorated over a service life expressed in years or hours. Therefore, if a set of tires has an initial cost of $15.000 and a service life of 5000 hours, the hourly cost of tires set aside for replacements is:

$$\text{Hourly cost of tires} = \frac{\$15,000}{5000} = \$3.00$$

11.11 OVERHEAD AND MARKUP

In addition to the direct costs of ownership and operation, general overhead costs must be considered in recovering costs associated with equipment ownership and operation. Overhead charges include items such as the costs of operating the maintenance force and facility including: (1) wages of the mechanics and supervisory personnel, (2) clerical and records support, and (3) rental or amortization of the maintenance facility (i.e., maintenance bays, lifts, machinery, and instruments). The industry practice is to prorate the total charge to each unit in the equipment fleet based on the number of hours it operates as a fraction of the total number of hours logged by the fleet. For instance, if the total number of hours logged by all units in the fleet was 20,000 and a particular unit operated 500 hours, its proportion of the total overhead would be 500/20,000 × 100, or 2.5%. If the total cost of overhead for the year is $100,000, the unit above must recover $2500 in backcharge to the client to cover its portion of the overhead. Overhead rates are updated annually from

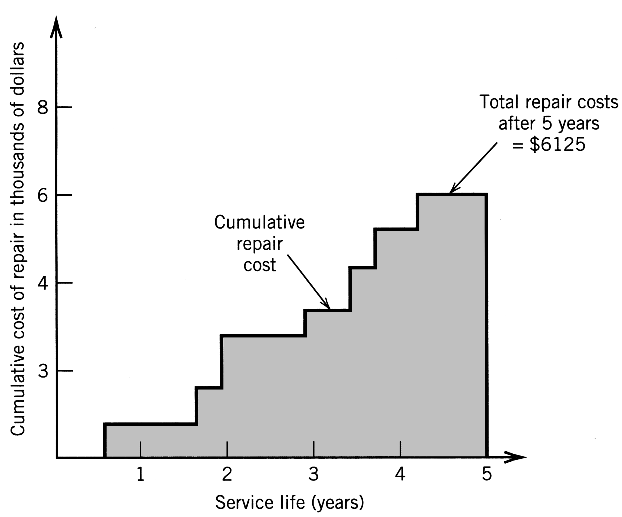


Figure 11.8 Repair cost profile.

operating records to ensure adequate coverage. If overhead costs overrun projections, the coverage will be inadequate and the overrun will reduce profits.

The last component of the total charge associated with a unit of production is the profit expressed as a percentage of total hourly operating costs, which, in turn, may be expressed in cubic yards of material moved or in some other bid-relevant measure. The amount of profit per cubic yard, square foot, or linear foot is a judgment that contractors must make based on their desire to win the contract and the nature of the competition. In a "tight" market where competition is strong, the allowable margin of profit that still allows the bidder to be competitive may be only 1 or 2%. In a "fat" market, where a lot of jobs are available, the demand is greater and the client is ready to pay a higher markup to get the work under way. Competition is bidding higher profit so the amount of profit can be adjusted upward.

Bidding strategy will include attention to the concept of marginal costs, which may permit the acceptance of jobs yielding less than the desired rate of return. In general, bidding, based on margins as low as l or 2% is uncomfortably close to what one might call the disaster area; the area of operating *losses*.

REVIEW QUESTIONS AND EXERCISES

11.1 What are the major cost components that must be considered when pricing out a piece of equipment? How can a contractor manipulate amortization for a piece of equipment in order to increase or reduce direct costs charged per unit of production? Why are tires on a rubber-tired vehicle not considered for depreciation?

11.2 You have just bought a new pusher dozer for your equipment fleet. Its cost is $100,000. It has an estimated service life of 4 years. Its salvage value is $12,000.

(a) Calculate the depreciation for the first and second year using the straight-line and double-declining methods.

(b) The tax, interest, and insurance components of ownership cost based on average annual value are:

Tax:	2%
Insurance:	2%
Interest:	7%

What cost per hour of operation would you charge to cover interest, tax, and insurance?

11.3 You have just bought a used track-type tractor to add to your production fleet. The initial capitalized value of the tractor is $110,000. The estimated service life remaining on the tractor is 10,000 hours, and the anticipated operating conditions across the remainder of its life are normal. The salvage value of the tractor is $12,000. The tractor was purchased on July 1, 1997.

(a) What amount of depreciation will you claim for each calendar year between 2007 and 2010?

(b) What percent of the total depreciable amount is taken in the first year?

(c) The tax, interest, and insurance components of ownership cost based on average annual value are:

Tax:	3%
Insurance:	2%
Interest:	8%

What cost per hour of operation would you charge to cover interest, tax, and insurance?

(d) If the total average operating cost for the tractor is $23.50 per hour and the amount of overhead cost prorated to this tractor for the year is $4000, what would be your total hourly cost for the operation of the tractor (during the first year of its service life)?

11.4 Verify the 5- and 7-year property class percentage given in Table 12.4 by applying the 200% d.b. approach to a piece of equipment with a nominal value of $1000. For the 7-year property class, in what year is the switch from 200% d.b. to straight line made based on the percentages given in the table?

Chapter 12

Equipment Productivity

Laser Based Machine Control

Grader with TopCon 3D-MC

The Need

Construction equipment using laser control technology can achieve higher levels of productivity. The guiding of road construction equipment in curving contours requires references such as hubs, staking, or elevated string lines. These benchmarks limit productivity, because their installation is slow, subject to human errors, and requires skilled operators to accurately steer the machine using rudimentary control methods. Attempts to guide equipment in curves using radio communication have been tried but this solution is still slow and unreliable.

Computer and Total-station

The Technology

New systems use three modules to control the piece of equipment:

- Survey plans are uploaded in a total station using a computer notebook. The total station converts the digital information into an infrared laser beam.
- A receiver, mounted on the blade of the equipment, intercepts the laser beam emitted by the total station and continuously determines (20 upgrades per second) the blade's current position and grade with respect the theoretical ones defined by the designer plans.
- The interface between the positioning information and the actual steering of the equipment is performed through the use of a control system device, which converts the digital data into machine hydraulic valve pulses.

Receiver

The main benefit of these systems is the obvious gain of productivity generated by this innovation. According to some research carried out by manufacturers of such guide systems, the laser devices can triple the productivity of equipment on highway projects as well as drastically increase their levels of precision and performance. Laser based systems represent the next generation of equipment controlling devices bringing an alternative to the existing slower and unreliable manual systems.

12.1 PRODUCTIVITY CONCEPTS

Now that a basis for charging each unit of production has been established, the rate of production, or the number of productive units, that can be generated per hour, per day, or other period of time must be considered. Our discussions here will be limited primarily to heavy construction units such as haulers, graders, and dozers. The concepts developed, however, are applicable to all types of construction equipment performing basically repetitive or cyclic operations. The cycle of an equipment piece is the sequence of tasks, which is repeated to produce a unit of output (e.g., a cubic yard, a trip load, etc.).

There are two characteristics of the machine and the cycle that dictate the rate of output. The first of these is the cyclic capacity of the machine or equipment, which establishes the number of units produced per cycle. The second is the cyclic rate or speed of an equipment piece. A truck, for instance, with a capacity of 16 cu yd, can be viewed as producing 16 yd each time it hauls. The question of capacity is a function of the size of the machine, the state of the material that is to be processed, and the unit to be used in measurement. A hauler such as a scraper pan usually has a rated capacity, "struck," versus its "heaped" capacity. The bowl of the scraper can be filled level (struck), yielding one capacity, or can be filled above the top to a heaped capacity. In both cases, the earth hauled tends to take on air voids and bulks, yielding a different weight per unit volume than it had in the ground when excavated (i.e., its in situ location). The material has a different weight-to-volume ratio when it is placed in its construction location (e.g., a road fill, an airport runway) and is compacted to its final density. This leads to three types of measure: (1) bank cubic yards [cu yd (bank)] (in situ volume), (2) loose cubic yards [cu yd (loose)], and (3) compacted cubic yards. Payment in the contract is usually based on the placed earth construction, so that the "pay" unit is the final compacted cubic yard. The relationship between these three measures is shown in Figure 12.1.

The relationship between the bulk or loose volume and the bank volume is defined by the percent swell. In Figure 12.1, the percent swell is 30%. Percent swell is given as:

$$\text{Percent swell} = \left[\left(\frac{1}{\text{load factor}}\right) - 1\right] \times 100$$

where

$$\text{Load factor} = \frac{\text{pounds per cubic yard} - \text{loose}}{\text{pounds per cubic yard} - \text{bank}}$$

Tables such as Table 12.1 give the load factor for various types of materials indicating their propensity for taking on air voids in the loose state. The higher the load factor, the smaller tendency the material has to "bulk up." Therefore, with a high load factor the loose volume and the in situ volume tend to be closer to one another. Each material has its own characteristic load factor. In the example above, the material has a load factor of 0.77.

$$\text{Percent swell} = \left[\left(\frac{1}{0.77}\right) - 1\right] \times 100 = 30\%$$

Therefore, we would expect 10 yd of bank material to expand to 13 yd during transport. The shrinkage factor relates the volume of the compacted material to the volume of the bank material. In the example, the shrinkage factor is 10% since the bank cubic yard is reduced by 10% in volume in the compacted state.

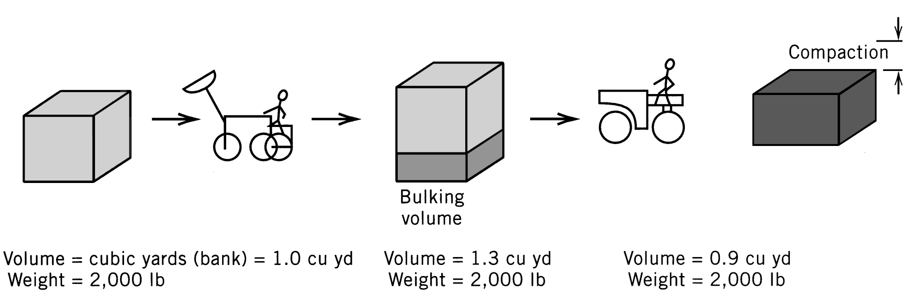


Figure 12.1 Volume relationships.

Table 12.1 Approximate Material Characteristics[a]

Material	Pounds per Cubic Yard—Bank	Percent of Swell	Load Factor	Pounds per Cubic Yard—Loose
Clay, natural bed	2,960	40	0.72	2,130
Clay and gravel				
Dry	2,960	40	0.72	2,130
Wet	2,620	40	0.72	2,220
Clay, natural bed				
Anthracite	2,700	35	0.74	2,000
Bituminous	2,160	35	0.74	1,600
Earth, loam				
Dry	2,620	25	0.80	2,100
Wet	3,380	25	0.80	2,700
Gravel, $\frac{1}{4}$–2 in.				
Dry	3,180	12	0.89	2,840
Wet	3,790	12	0.89	3,380
Gypsum	4,720	74	0.57	2,700
Iron ore				
Magnetite	5,520	33	0.75	4,680
Pyrite	5,120	33	0.75	4,340
Hematite	4,900	33	0.75	4,150
Limestone	4,400	67	0.60	2,620
Sand				
Dry, loose	2,690	12	0.89	2,400
Wet, packed	3,490	12	0.89	3,120
Sandstone	4,300	54	0.65	2,550
Trap rock	4,420	65	0.61	2,590

[a]The weight and load factor will vary with factors such as grain size, moisture content, and degree of compaction. A test must be made to determine an *exact* material characteristic.

In order to understand the importance of capacity, consider the following situation. A front-end loader has an output of 200 bank cu yd of common earth per hour. It loads a fleet of four trucks (capacity 18 loose cu yd each), which haul the earth to a fill where it is compacted with a shrinkage factor of 10%. Each truck has a total cycle time of 15 min, assuming it does not have to wait in line to be loaded. The earth has a percent swell of 20%. The job requires a volume of 18,000 compacted cu yd. How many hours will be required to excavate and haul the material to the fill? Two types of productive machines are involved: four trucks and a front-end loader. We must see which unit or set of units is most productive. Reference all calculations to the loose cubic yard production per hour. Then the loader productivity (given 20% swell) is

$$200 \text{ cu yd (bank)/hr} = 1.2(200) \text{ or } 240 \text{ cu yd (loose)/hr}$$

The truck fleet production is

$$\begin{aligned} 4 \text{ trucks} \times \frac{60 \text{ min/hr}}{15 \text{ min/cycle}} &\times 18 \text{ cu yd (loose) truck} \\ &= 72 \text{ cu yd (loose)} \times 4 \text{ cycle/hr} \\ &= 288 \text{ cu yd (loose)/hr for 4 trucks} \end{aligned}$$

Because the loader production is lower, it constrains the system to a maximum output of 240 cu yd (loose)/hr. We must now determine how many loose cubic yards are represented by 18,000 cu yd (compacted).

$$18{,}000 \text{ cu yd compacted} = \frac{18{,}000}{0.9} \quad \text{or} \quad 20{,}000 \text{ cu yd (bank)}$$
$$20{,}000 \text{ cu yd (bank)} = 24{,}000 \text{ cu yd (loose) required}$$

Therefore, the number of hours required is

$$\text{Hours} = \frac{24{,}000 \text{ cu yd (loose)}}{240 \text{ cu yd (loose)/hr}} = 100$$

This problem illustrates the interplay between volumes and the fact that machines that interact with other machine cycles may be constrained or constraining.

Table 12.2 Typical Rolling Resistance Factors (Caterpillar Tractor Co.)

A hard, smooth, stabilized roadway without penetration under load (concrete or blacktop)	40 lb/ton
A firm, smooth-rolling roadway flexing slightly under load (macadam or gravel-topped road)	65 lb/ton
Snow-packed	50 lb/ton
Loose	90 lb/ton
A rutted dirt roadway, flexing considerably under load; little maintenance, no water (hard clay road, 1 in. or more tire penetration)	100 lb/ton
Rutted dirt roadway, no stabilization, somewhat soft under travel (4–6 in. tire penetration)	150 lb/ton
Soft, muddy, rutted roadway, or in sand	200–400 lb/ton

12.2 CYCLE TIME AND POWER REQUIREMENTS

The second factor affecting the rate of output of a machine or machine combination is the time required to complete a cycle, which determines the cyclic rate. This is a function of the speed of the machine and, in the case of heavy equipment, is governed by (1) the power required, (2) the power available, and (3) the usable portion of the power available that can be developed to propel the equipment unit.

The power required is related to the rolling resistance inherent in the machine due to internal friction and friction developed between the wheels or tracks and the traveled surface. The power required is also a function of the grade resistance inherent in the slope of the traveled way. Rolling resistance in tracked vehicles is considered to be zero, since the track acts as its own roadbed, being laid in place as the unit advances. The friction between track and support idlers is too small to be considered. Rolling resistance for rubber-wheeled vehicles is a function of the road surface and the total weight on the wheels. Tables such as Table 12.2 are available in equipment handbooks giving the rolling resistance in pounds per tons of weight. Figure 12.2 indicates visually the factors influencing rolling resistance and therefore contributing to the required power that must be developed to move the machine.

If tables are not available, a rule of thumb can be used. The rule states that the rolling resistance (RR) is approximately 40 lb/ton plus 30 lb/ton for each inch of penetration of the surface under wheeled traffic. If the estimated deflection is 2 in. and the weight on the wheels of a hauler is 70 tons, we can calculate the approximate rolling resistance as:

$$\text{RR} = [40 + 2(30)] \text{ lb/ton} \times 70 \text{ tons} = 7{,}000 \text{ lb}$$

The second factor involved in establishing the power required is the grade resistance. In some cases, the haul road across which a hauler must operate will be level and, therefore, the slope of the road will not be a consideration. In most cases, however, slopes (both uphill

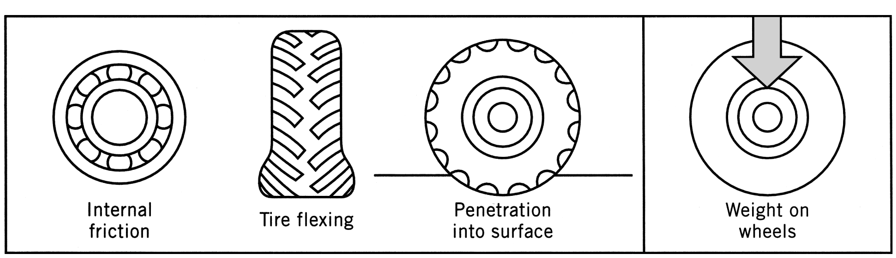


Figure 12.2 Factors influencing rolling resistance.

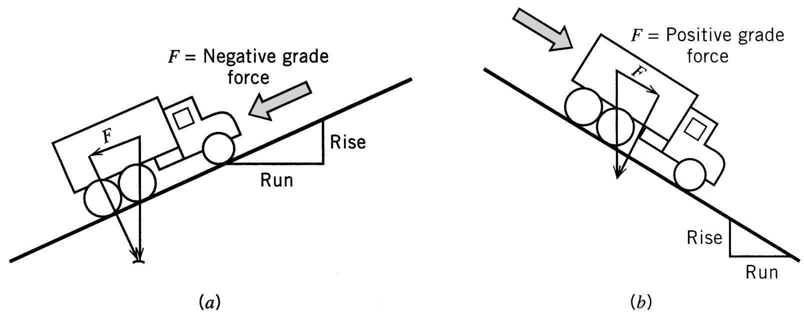


Figure 12.3 Grade resistance: (*a*) negative (resisting) force and (*b*) positive (aiding) force.

and downhill) will be encountered and lead to higher or reduced power requirements based on whether gravity is aiding or resisting movement (see Fig. 12.3).

The percent grade is calculated by the ratio of rise over run, as depicted in Figure 12.3. If, for instance, a slope rises 6 ft in 100 ft of horizontal distance, the percent grade is 6. Similarly, a slope that increases 1.5 ft in 25 ft also has a percent grade of 6. Percent grade is used to calculate the grade resistance (GR) using the following relationship:

$$\text{GR} = \text{percent grade} \times 20\ \text{lb/ton/\% grade} \times \text{weight on wheels (tons)}$$

If the 70-ton piece of equipment referred to previously is ascending a 6% grade, the grade resistance is

$$\text{GR} = 6\%\ \text{grade} \times 20\ \text{lb/ton/\% grade} \times 70\ \text{tons} = 8{,}400\ \text{lb}$$

Assuming the rolling resistance calculated above holds for the road surface of the slope and assuming the equipment is wheeled, the total power required to climb the slope will be

$$\text{Power required} = \text{RR} + \text{GR} = 7{,}000\ \text{lb} + 8{,}400\ \text{lb} = 15{,}400\ \text{lb}$$

If the slope is downward, an aiding force is developed, and the total power required becomes

$$\text{Power required} = \text{RR} - \text{GR} = 7{,}000\ \text{lb} - 8{,}400\ \text{lb} = -1{,}400\ \text{lb}$$

The sign of the grade resistance becomes negative since it is now aiding and helping to overcome the rolling resistance. Since a negative rolling resistance has no meaning, the power required on a downward 6% grade is zero. In fact, the 1,400 lb represents a downhill thrust that will accelerate the machine, and lead to a braking requirement.

Traveled ways or haul roads normally consist of a combination of uphill, downhill, and level sections. Therefore, the power requirement varies and must be calculated for each section. Knowing the power required for each haul road section, a gear range that will

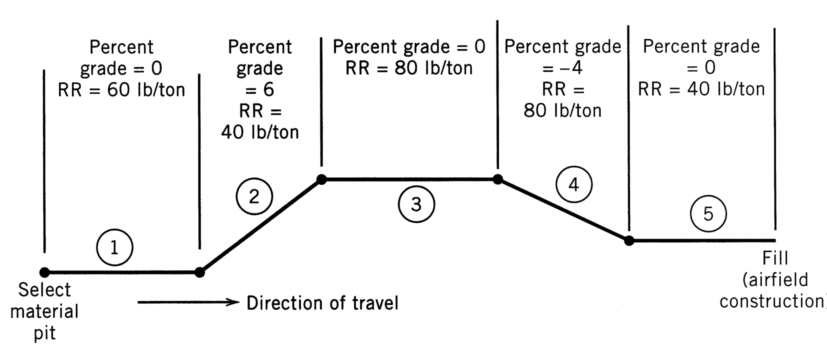


Figure 12.4 Typical haul road profile.

Table 12.3 Calculations for Haul Road Sections[a]

Section	Percent Grade (%)	Grade Resistance (lb)	Rolling Resistance (lb)	Power Required (lb)
1	0	0	4,200	4,200
2	6	8,400	2,800	11,200
3	0	0	5,600	5,600
4	−4	−5,600	5,600	0
5	0	0	2,800	2,800

[a] All calculations assume travel from pit to fill.

provide the required power can be selected. The gear range allows a speed to be developed and, given the speed, we can develop the time required to transit each section and the total time required for a cycle.

Consider the haul road profile shown in Figure 12.4 with rolling resistance and percent grade values as shown. The calculation of power required for each section of the road based on a 70-ton machine is shown in Table 12.3. Given the power requirements, the next section indicates how a gear range is selected. As noted above, this allows determination of the speed across each section and the time required.

12.3 POWER AVAILABLE

The power available is controlled by the engine size of the equipment and the drive train, which allows transfer of power to the driving wheels or power take-off point. The amount of power transferred is a function of the gear being used. Most automobile drivers realize that lower gears transfer more power to overcome hills and rough surfaces. Lower gears sacrifice speed in order to provide more power. Higher gears deliver less power, but allow higher speeds. Manufacturers publish figures regarding the power available in each gear for individual equipment pieces in equipment handbooks that are updated annually. This information can be presented in a tabular format such as that shown in Table 12.4 or in graphical format such as the nomograph shown in Figure 12.5.

For tracked vehicles, the power available is quoted in drawbar pull. This is the force that can be delivered at the pulling point (i.e., pulling hitch) in a given gear for a given tractor type. Power available for a wheeled vehicle is stated in pounds of rimpull. This is the force that can be developed by the wheel at its point of contact with the road surface. Manufacturers also provide information regarding rated power and maximum power. Rated power is the

Table 12.4 Speed and Drawbar Pull (270 hp) (Track-Type Tractor)

					Drawbar Pull Forward[a]			
	Forward		Reverse		At Rated rpm		Maximum at Lug	
Gear	mph	km/h	mph	km/h	lb	kg	lb	kg
1	1.6	(2–6)	1.6	(2.6)	52,410	(23,790)	63,860	(28,990)
2	2.1	(3–4)	2.1	(3.4)	39,130	(17,760)	47,930	(21,760)
3	2.9	(4.7)	2.9	(4.7)	26,870	(12,200)	33,210	(15,080)
4	3.7	(6.0)	3.8	(6.1)	19,490	(8,850)	24,360	(11,060)
5	4.9	(7.9)	4.9	(7.9)	13,840	(6,280)	17,580	(7,980)
6	6.7	(10.8)	6.8	(10.9)	8,660	(3,930)	11,360	(5,160)

[a] Usable pull will depend on traction and weight of equipped tractor.

level of power that is developed in a given gear under normal load and over extended work periods. It is the base or reference level of power that is available for continuous operation. The maximum power is just what it indicates. It is the peak power that can be developed in a gear for a short period of time to meet extraordinary power requirements. For instance, if a bulldozer is used to pull a truck out of a ditch, a quick surge of power would be used to dislodge the truck. This short-term peak power could be developed in a gear using the maximum power available.

Most calculations are carried out using rated power. If, for example, the power required for a particular haul road section is 25,000 lb based on the procedures described in Section 12.2, the proper gear for the 270-hp track-type tractor is third gear. This is determined by entering Table 12.4 and comparing power required with rated power. Consider the example shown in the shaded area below.

Nomographs are designed to allow quick determination of required gear ranges as well as the maximum speed attainable in each gear. The nomograph shown in Figure 12.5 is for a 35-ton, off-highway truck. To illustrate the use of this figure, consider the following problem. On a particular road construction job, the operator has to choose between two available routes linking the select material pit with a road site fill. One route is 4.6 miles (one-way) on a firm, smooth road with a RR = 50 lb/ton. The other route is 2.8 miles (one-way) on a rutted dirt road with RR = 90 lb/ton. The haul road profile in both cases is level so that grade resistance is not a factor. Using the nomograph of Figure 12.5, we are to determine the pounds pull to overcome rolling resistance for a loaded 35-ton, off-highway truck. The same chart allows determination of the maximum speed.

In order to use the chart, consider the information in the chart regarding gross weight. The weight in pounds ranges from 0 to 280,000 (140 tons). The weights of the truck empty and with a 70,000-1b load (i.e., 35-ton capacity) are indicated by vertical dashed lines intersecting the gross weight axis (top of chart) at approximately 56,000 lb (empty) and 126,000 lb (loaded). For this problem, the loaded line is relevant since the truck hauls loads from pit to fill.

Next consider the slant lines sloping from lower left to upper right. These lines indicate the total resistance (i.e., RR + GR) in increments from 0 to 25% grade. In this problem, there is no grade resistance. In dealing with rolling resistance, it is common to convert it to an equivalent percent grade. Then, the total resistance can be stated in percent grade by

The sum of the rolling resistance and grade resistance that a particular wheel-type tractor and scraper must overcome on a specific job has been estimated to be 10,000 lb. If the "pounds pull-speed" combinations listed below are for this particular machine, what is the maximum reasonable speed of the unit?

		Pounds Rimpull	
Gear	Speed	Rated	Maximum
1	2.6	38,670	49,100
2	5.0	20,000	25,390
3	8.1	12,190	15,465
4	13.8	7,185	9,115
5	22.6	4,375	5,550

Third gear would be selected since the rated rimpull is 12,190 lb. (If the total power required had been in excess of 12,190 lb. we would select second gear because you recall that rated pounds pull should always be used for gear selection. The reserve rimpull of the maximum rating is always available-at reduced speed-to pull the unit out of small holes or bad spots.)

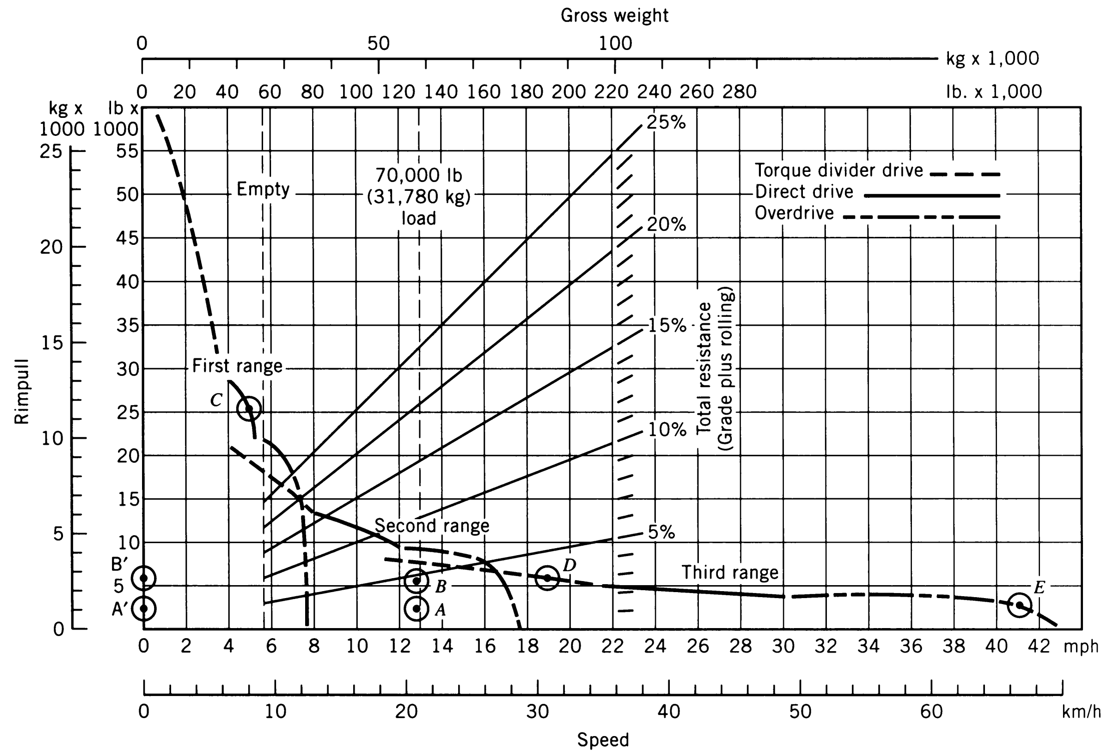


Figure 12.5 Gear requirements chart-35-ton, off-highway truck (Caterpillar Tractor Co.).

adding the equivalent percent grade for rolling resistance to the slope percent grade. To convert rolling resistance to equivalent percent grade, the following expression is used:

$$\text{Equivalent precent grade} = \frac{\text{RR}}{20\ \text{1b/ton/\% grade}}$$

For the rolling resistance values given in the problem, the equivalent percent grades become as follows:

Route	Distance	RR	Equivalent Percent Grade
1	4.6 miles	50 1b/ton	2.5
2	2.8 miles	90 1b/ton	4.5

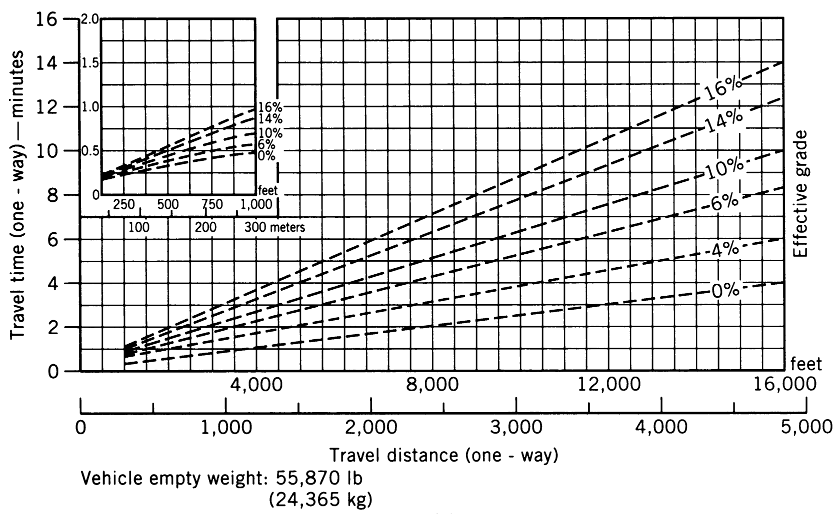
In order to determine the required pounds pull, the intersection of the slant line representing the equivalent percent grade with the load vertical line is located. This intersection for route 1 is designated point *A* in Figure 12.5. The corresponding point for route two is labeled *B*.

The pounds required value is found using these points by reading horizontally across to the *y* axis, which gives the rimpull in pounds. For route 1, the approximate power requirement is 2,500 lb. The requirement for route 2 is 5,500 lb. Points *A* and *B* are also used to determine the maximum speed along each route.

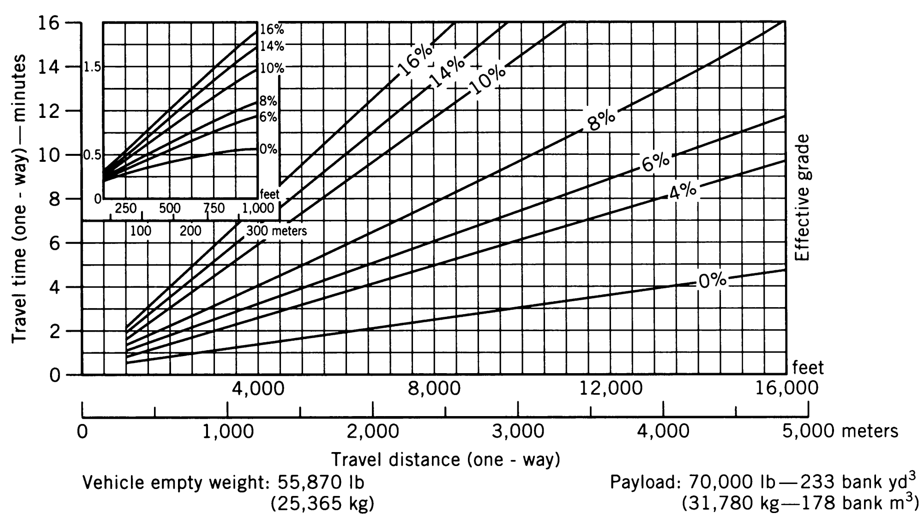
Consider the curves descending from the upper left-hand corner of the chart to the lower right side. As labeled, these curves indicate the deliverable power available in first, second, and third ranges as well as the speed that can be developed. At 25,000 lb of rimpull, for example, on the *y* axis, reading horizontally to the right the only range delivering this much power is first range (see point *C*). Reading vertically down to the x axis, the speed that can be achieved at this power level is approximately 5 mi/hr.

Proceeding in a similar manner, it can be determined that two ranges, second and third, will provide the power necessary for route 2 (i.e., 5,500 lb). Reading horizontally to the right from point B, the maximum speed is developed in third range at point *D*. Referencing this point to the *x* axis, the maximum speed on route 2 is found to be approximately 19 mi/hr. Route 1 requires considerably less power. Again reading to the right, this time from point *A*, the third range provides a maximum speed of approximately 41 mi/hr (see point *E*).

Now, having established the maximum speeds along each route and knowing the distances involved, it should be simple to determine the travel times required. Knowledge of the speeds, however, is not sufficient to determine the travel times since the requirements to accelerate and decelerate lower the effective speed between pit and fill. Knowing the mass of the truck and the horsepower of the engine, the classic equation, force = mass × acceleration (F = *ma*), would allow determination of the time required to accelerate to and decelerate from maximum speed. This is not necessary, however, since the equipment handbooks provide time charts that allow direct readout of the travel time for a route and piece of equipment, given the equivalent percent grade and the distance. These charts for loaded and empty 35-ton trucks are given in Figure 12.6. Inspection of the chart for the



(*a*)



(*b*)

Figure 12.6 Travel time: (*a*) empty and (b) loaded (Caterpillar Tractor Co.).

loaded truck indicates that the distance to be traveled in feet is shown along the *x* axis. The equivalent percent grade is again shown as slant lines sloped from lower left to upper right. Converting the mileages given to feet yields the values 24,344 ft for route 1 and 14,784 ft for route 2. Entering the chart, with an equivalent percent grade of 4.5 for route 2, the travel time can be read (on the *y* axis), as 9.5 min.

A problem develops in reading the travel time for route 1 since the maximum distance shown on the chart is 16,000. One way of reconciling this problem is to break the 24,344 into two segments: (1) 16,000 ft as shown and (2) the 8,344 ft remaining. The assumption is made that the 8,344 ft is traveled at the maximum speed determined previously to be 41 mi/hr. At this speed, the travel time for this segment is

$$T_2 = \frac{8{,}344 \text{ ft } (60 \text{ min/hr})}{(41 \text{ mi/hr})(5{,}280 \text{ ft/mi})} = 2.31 \text{ min}$$

The time for the remaining 16.000 ft is read from the chart as 7.2 min. It is assumed that acceleration and deceleration effects are included in this time. Therefore, the required time for route 1 is also 9.5 min ($T_1 + T_2 = 7.2 + 2.31$). Therefore, the decision as to which route to use is based on wear and tear on the machines, driver skill, and other considerations. This problem illustrates the development of time, given information affecting power required and power available. Using the same procedure, the travel time empty returning to the pit from the fill can be determined and total cycle time can be determined.

12.4 USABLE POWER

To this point, it has been assumed that all of the available power is usable and can be developed. Environmental conditions play a major role in determining whether the power available can be utilized under operating conditions. The two primary constraints in using the available power are the road surface traction characteristics (for wheeled vehicles) and the altitude at which operations are conducted. Most people have watched the tires of a powerful car spin on a wet or slippery pavement. Although the engine and gears are delivering a certain horsepower, the traction available is not sufficient to develop this power into the ground as a driving force. Combustion engines operating at high altitudes experience a reduction in oxygen available within the engine cylinders. This also leads to reduced power.

Consider first the problem of traction. The factors that influence the usable power that can be developed through the tires of wheeled vehicles are the coefficient of traction of the surface being traveled and the weight of the vehicle on the driving wheels.

The coefficient of traction is a measure of the ability of a particular surface to receive and develop the power being delivered to the driving wheels and has been determined by experiment. The coefficient of traction obviously varies based on the surface being traversed and the delivery mechanism (i.e., wheels, track, etc.). Table 12.5 gives typical values for rubber-tired and tracked vehicles on an assortment of surface materials.

The power that can be developed on a given surface is given by the expression:

$$\text{Usable pounds pull} = (\text{coefficient of traction}) \times (\text{weight on drivers})$$

In the consideration of rolling resistance and grade resistance, the entire weight of the vehicle or combination was used. In calculating the usable power, *only the weight on the driving wheels* is used, since it is the weight pressing the driving mechanism (e.g., wheels) and surface together. Equipment handbooks specify the distribution of load to all wheels for both empty and loaded vehicles and combinations. The weight to be considered in the calculation of usable power for several types of combinations is shown in Figure 12.7. To illustrate the constraint imposed by usable power, consider the following situation. A 30-yd-capacity, two-wheel tractor-scraper is operating in sand and carrying 26-ton loads.

Table 12.5 Coefficients of Traction

Materials	Rubber Tires	Tracks
Concrete	.90	.45
Clay loam, dry	.55	.90
Clay loam, wet	.45	.70
Rutted clay loam	.40	.70
Dry sand	.20	.30
Wet sand	.40	.50
Quarry pit	.65	.55
Gravel road (loose, not hard)	.36	.50
Packed snow	.20	.25
Ice	.12	.12
Firm earth	.55	.90
Loose earth	.45	.60
Coal, stockpiled	.45	.60

The job superintendent is concerned about the high rolling resistance of the sand (RR = 400 lb/ton) and the low traction available in sand. The question is: Will the tractors have a problem with 26-ton loads under these conditions? The weight distribution characteristics of the 30-yd tractor-scraper are as follows:

	Empty Weight (lb)	**Percent**	**Loaded Weight (lb)**	**Percent**
Drive wheels	50,800	67	76,900	52
Scraper wheels	25,000	33	70,900	48
Total weight	75,800	100	147,800	100

The difference between the total weight empty and loaded is 72,000 lb, or 36 tons. The loaded weight with 26-ton loads would be 127,800 lb. Assuming the same weight distribution given above for fully loaded vehicles, the wheel loads would be as follows:

	Percent	**Weight in Pounds**
Drive wheels	52	66,456
Scraper wheels	48	61,344
Total	100	127,800

The resisting force (assuming a level haul site) would be

$$\text{Pounds required} = 400\text{lb/ton} \times 63.9 \text{ tons} = 25{,}560\text{lb}$$

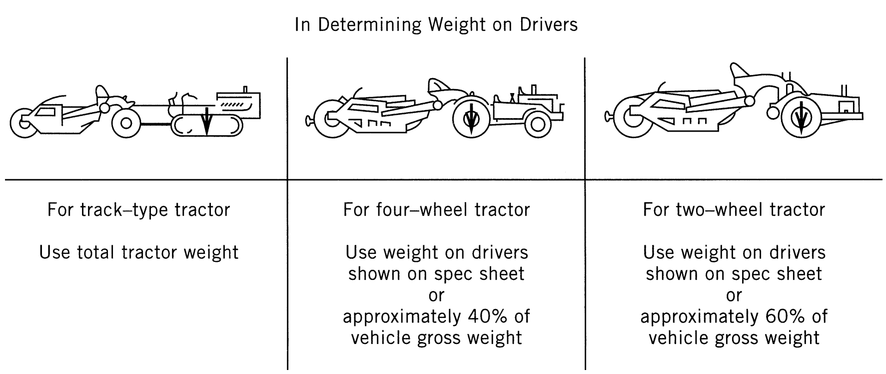


Figure 12.7 Determination of driver weights.

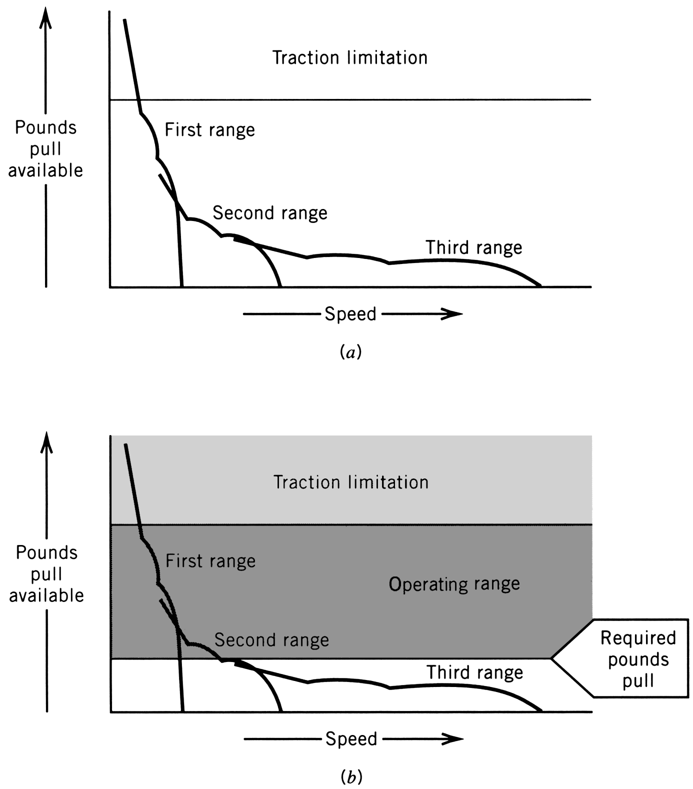


Figure 12.8 Impact of usable power constraints.

The deliverable or usable power is

$$\text{Usable power} = 0.20 \times 66{,}4561\text{b} = 13{,}291.201\text{b}$$

Quite obviously, there will be a problem with traction since the required power is almost twice the power that can be developed. The "underfoot" condition must be improved. A temporary surface (e.g., wood or steel planking) could be installed to improve traction. One simple solution would be to simply wet the sand. This yields an increased usable power:

$$\text{Usable power} = 0.40 \times 66{,}4561\text{b} = 26{,}582.41\text{b} > 25{,}5601\text{b}$$

The impact of usable power constraints can be shown graphically (see Fig. 12.8). Now, if the total resistance of the unit (rolling resistance plus grade resistance) is 10,000 lb, then an operating range for the machine is indicated in Figure 12.8b.

The altitude at which a piece of equipment operates also imposes a constraint on the usable power. As noted previously, the oxygen content decreases as elevation increases, so that a tractor operating in Bogotá, Colombia (elevation 8,600 ft), cannot develop the same power as one operating in Atlanta, Georgia (elevation 1,050 ft). A good rule of thumb to correct this effect is as follows: Decrease pounds pull 3% for each 1,000 ft (above 3,000 ft). Therefore, if a tractor is operating at 5,000 ft above sea level, its power will be decreased by 6%.

12.5 EQUIPMENT BALANCE

In situations where two types of equipment work together to accomplish a task, it is important that a balance in the productivity of the units be achieved. This is desirable so that one unit is not continually idle waiting for the other unit to "catch up." Consider the problem of

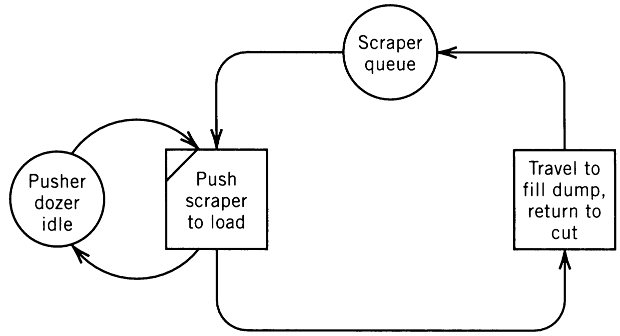


Figure 12.9 Scraper-pusher dual-cycle model.

balancing productivity within the context of a pusher dozer loading a tractor scraper. A simple model of this process is shown in Figure 12.9. The circles represent delay or waiting states, while the squares designate active work activities with associated times that can be estimated. The haul unit is a 30 cu-yd scraper, and it is loaded in the cut area with the aid of a 385-hp pusher dozer. The system consists of two interacting cycles.

Assume that in this case the 30-cu-yd tractor scraper is carrying rated capacity and operating on a 3,000-ft level haul where the rolling resistance (RR) developed by the road surface is 40 lb/ton. Using the standard formula, this converts to

$$\text{Effective grade} = \frac{\text{RR}}{20\ \text{lb/ton/\% grade}} = \frac{40\ \text{lb/ton}}{20\ \text{lb/ton/\% grade}} = 2\%\ \text{grade}$$

By consulting the charts given in Figure 12.10, the following travel times can be established:

1. Time loaded to fill: 1.4 min
2. Time empty to return: 1.2 min

Assume further that the dump time for the scraper is 0.5 min and the push time using a track-type pusher tractor is 1.23 min, developed as follows:

$$\begin{aligned}\text{Load time} &= 0.70\\ \text{Boost time} &= 0.15\\ \text{Transfer time} &= 0.10\\ \text{Return time} &= \underline{0.28}\\ \text{Total} &= 1.23\ \text{min}\end{aligned}$$

Using these deterministic times for the two types of flow units in this system (i.e., the pusher and the scrapers), the scraper and pusher cycle times can be developed, as shown in Figure 12.11.

$$\begin{aligned}\text{Pusher cycle} &= 1.23\ \text{min}\\ \text{Scraper cycle} &= 0.95 + 1.2 + 1.4 + 0.5 = 4.05\ \text{min}\end{aligned}$$

These figures can be used to develop the maximum hourly production for the pusher unit and for each scraper unit as follows.

Maximum System Productivity (Assuming a 60-min Working Hour)

1. Per scraper

$$\begin{aligned}\text{Prod (scraper)} &= \frac{60\ \text{min/hr}}{4.05\ \text{min}} \times 30\ \text{cu yd (loose)}\\ &= 444.4\ \text{cu yd (loose)/hr}\end{aligned}$$

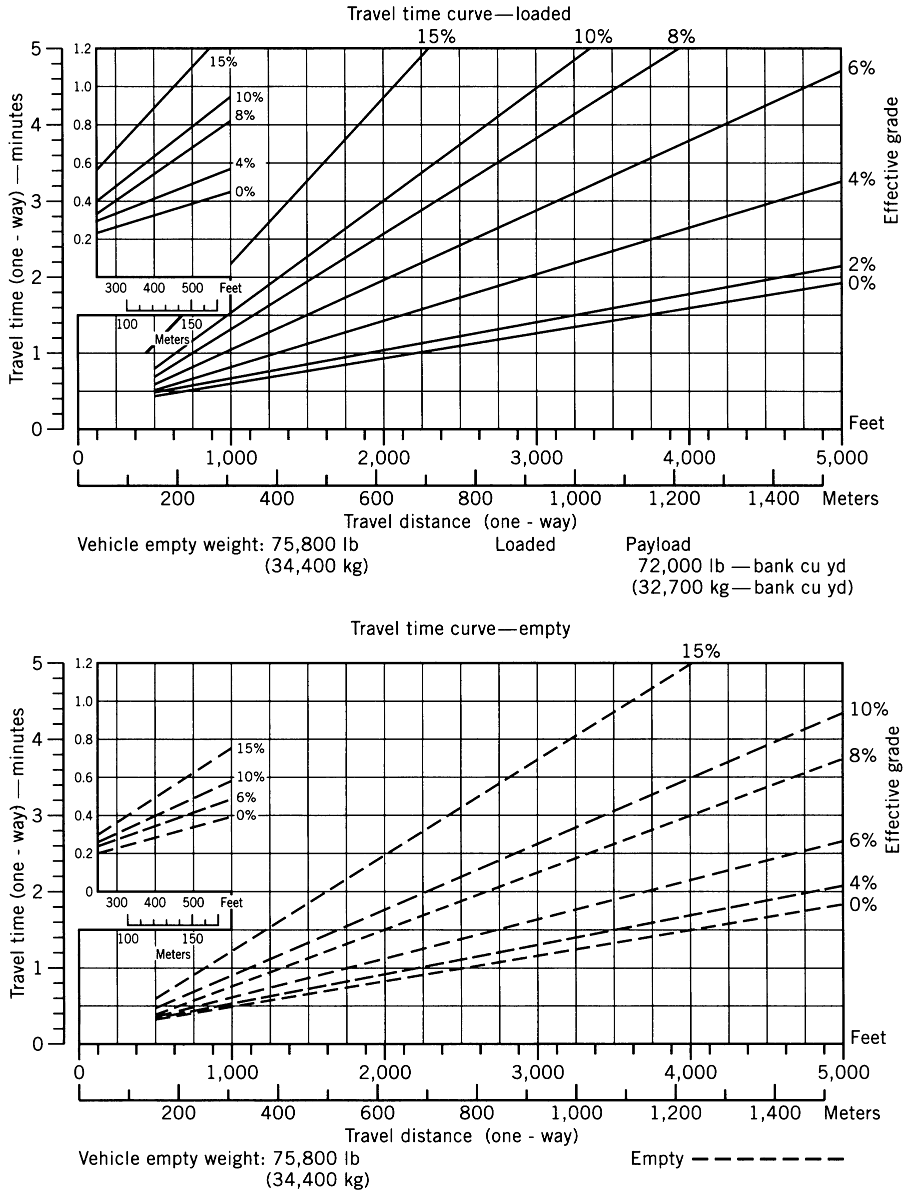


Figure 12.10 Travel time nomographs (Caterpillar Tractor Co.).

2. Based on single pusher

$$\text{Prod (pusher)} = \frac{60}{1.23} \times 30 \text{ cu yd (loose)}$$
$$= 1{,}463.4 \text{ cu yd (loose)/hr}$$

Using these productivities based on a 60-min working hour, it can be seen that the pusher is much more productive than a single scraper and would be idle most of the time if matched to only one scraper. By using a graphical plot, the number of scrapers that are needed to keep the pusher busy at all times can be determined.

The linear plot of Figure 12.12 shows the increasing productivity of the system as the number of scrapers is increased. The productivity of the single pusher constrains the total productivity of the system to 1,463.4 cu yd. This is shown by the dotted horizontal line

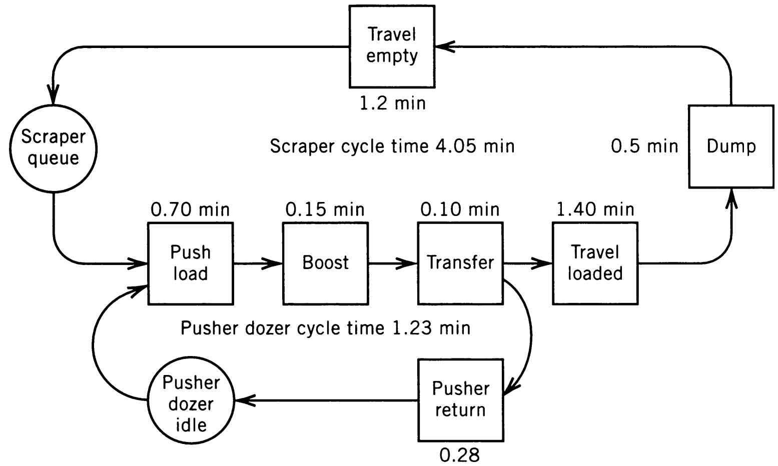


Figure 12.11 Scraper-pusher cycle times.

parallel to the x axis of the plot. The point at which the horizontal line and the linear plot of scraper productivity intersect is called the balance point. The balance point is the point at which the number of haul units (i.e., scrapers) is sufficient to keep the pusher unit busy 100% of the time. To the left of the balance point, there is an imbalance in system productivity between the two interacting cycles; this leaves the pusher idle. This idleness results in lost productivity. The amount of lost productivity is indicated by the difference between the horizontal line and the scraper productivity line. For example, with two scrapers operating in the system, the ordinate *AB* of Figure 12.12 indicates that 574.6 cu yd, or a little less than

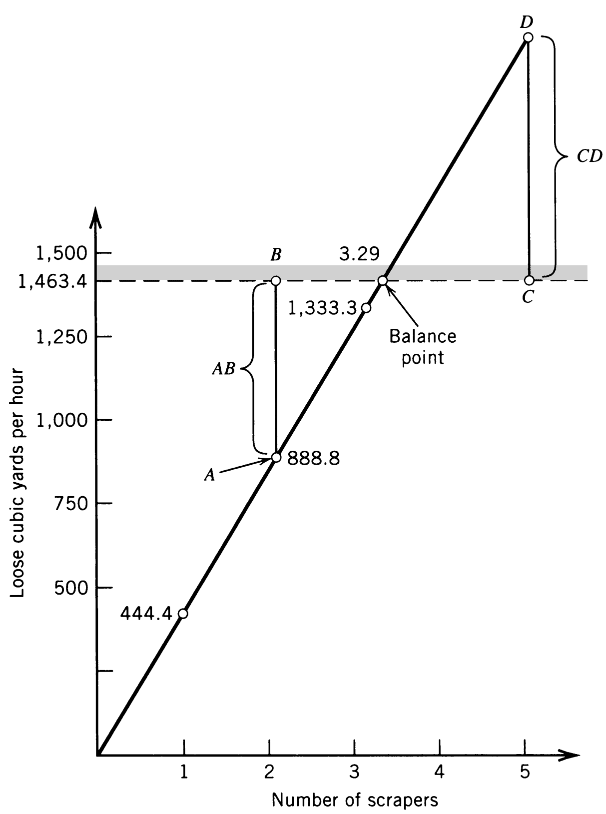


Figure 12.12 Productivity plot.

half of the pusher productivity, is lost because of the mismatch between pusher and scraper productivities. As scrapers are added, this mismatch is reduced until, with four scrapers in the system, the pusher is fully utilized. Now the mismatch results in a slight loss of productivity caused by idleness of the scrapers. This results because, in certain instances, a scraper will have to wait to be loaded until the pusher is free from loading a preceding unit. If five scraper units operate in the system, the ordinate *CD* indicates that the loss in the productive capacity of the scraper because of delay in being push loaded is

$$\text{Productive loss} = 5(444.4) - 1{,}463.4 = 758.6 \text{ cu yd}$$

This results because the greater number of scrapers causes delays in the scraper queue of Figures 12.9 and 12.11 for longer periods of time. The imbalance or mismatch between units in dual-cycle systems resulting from deterministic times associated with unit activities is called *interference*. It is due only to the time imbalance between the interacting cycles. It does not consider idleness or loss of productivity because of random variations in the system activity durations. In most cases, only a deterministic analysis of system productivity is undertaken because it is sufficiently accurate for the purpose of the analyst.

12.6 RANDOM WORK TASK DURATIONS

The influence of mismatches in equipment fleets and crew mixes on system productivity was discussed in the last section in terms of deterministic work task durations and cycle times. In systems where the randomness of cycle times is considered, system productivity is reduced further. The influence of random durations on the movement of resources causes various units to become bunched together and thus to arrive at and overload work tasks. Resulting delays impact the productivity of cycles by increasing the time that resource units spend in idle states pending release to productive work tasks.

Consider the scraper-pusher problem and assume that the effect of random variation in cycle activity duration is to be included in the analysis.

In simple cases such as the two-cycle system model of Figure 12.9, mathematical techniques based on *queuing theory* can be used to develop solutions for situations where the random arrival of scrapers to the dozer can be postulated. In order to make the system amenable to mathematical solution, however, it is necessary to make certain assumptions about the characteristics of the system that are not typical of field construction operations.

Figure 12.13 indicates the influence of random durations on the scraper fleet production. The curved line of Figure 12.13 slightly below the linear plot of production based on

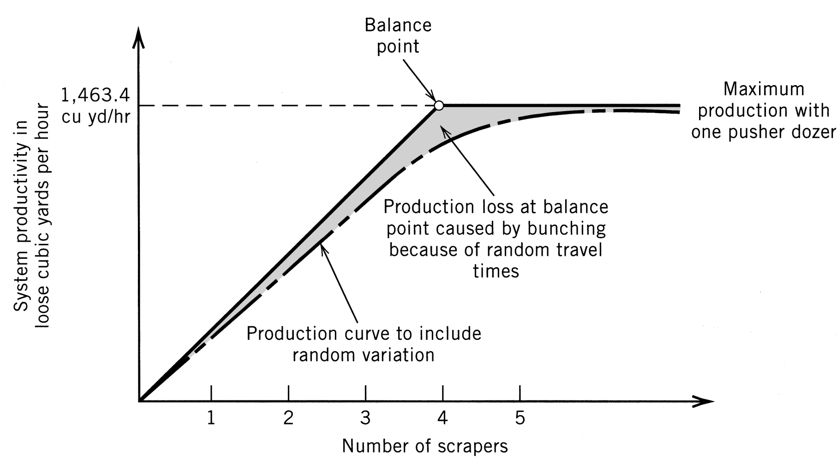


Figure 12.13 Productivity curve to include effect of random cycle times.

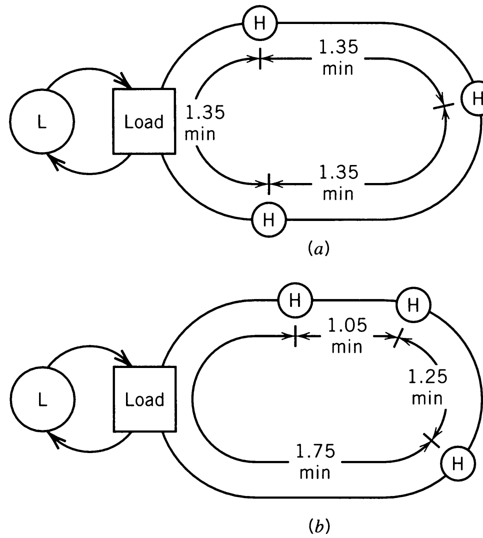


Figure 12.14 Comparison of haul unit cycles.

deterministic work task times shows the reduction in production caused by the addition of random variation of cycle activity times. This randomness leads to bunching of the haulers on their cycle. With deterministic work task times, the haul units are assumed to be equidistant in time from one another within their cycle

In deterministic calculations, all three of the haul units shown in Figure 12.14a are assumed to be exactly 1.35 min apart. In this system, there are three units, and the hauler cycle time is taken as a deterministic value of 4.05 min. In systems that include the effect of random variation of cycle times, "bunching" eventually occurs between the units on the haul cycle. That is, the units do not stay equidistant from one another but are continuously varying the distances between one another. Therefore, as shown in Figure 12.14b, a situation often occurs in which the units on the haul are unequally spaced apart in time from one another. This bunching effect leads to increased idleness and reduced productivity. It is intuitively clear that the three units that are bunched as shown in Figure 12.14b will be delayed for a longer period at the scraper queue since the first unit will arrive to load only 1.05 min instead of 1.35 min in advance of the second unit. The bunching causes units to "get into each other's way." The reduction in productivity caused by bunching is shown as the shaded area in Figure 12.13 and occurs in addition to the reduction in productivity caused by mismatched equipment capacities.

This bunching effect is most detrimental to the production of dual-cycle systems such as the scraper-pusher process at the balance point. Several studies have been conducted to determine the magnitude of the productivity reduction at the balance point because of bunching. Simulation studies conducted by the Caterpillar Tractor Company indicate that the impact of random time variation is the standard deviation of the cycle time distribution divided by the average cycle time. Figure 12.15 illustrates this relationship graphically.

As shown in the figure, the loss in deterministic productivity at the balance point is approximately 10% due to the bunching; this results in a system with a cycle coefficient of variation equal to 0.10. The probability distribution used in this analysis was lognormal. Other distributions would yield slightly different results. The loss in productivity in equipment-heavy operations such as earthmoving is well documented and recognized in the field, mainly because of the capital-intensive nature of the operation and the use of scrapers in both single-unit operations and fleet operations. To some extent, field policies have emerged to counteract this effect by occasionally breaking the queue discipline of

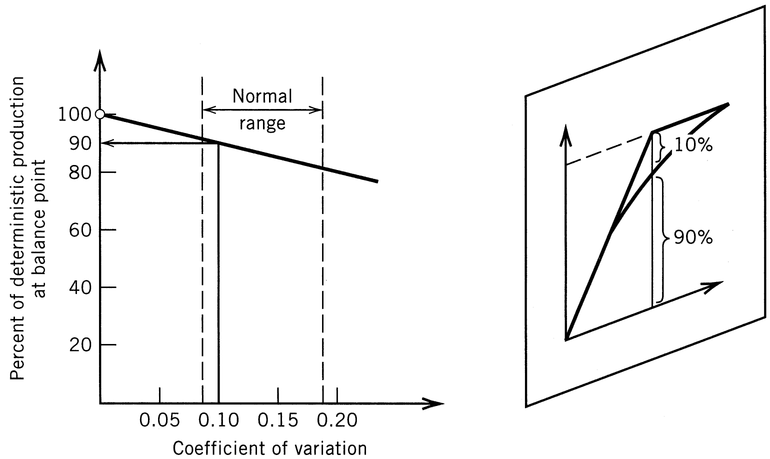


Figure 12.15 Plot of cycle time coefficient of variation.

the scrapers so that they self-load when bunching effects become severe. The resulting increased load and boost time for the scraper add little to the system productivity, but it does break down the bunching of the scrapers.

REVIEW QUESTIONS AND EXERCISES

12.1 A customer estimates that he is getting 30 cu yd (loose) of gypsum in his scraper. Determine the percent overload if the load estimate is correct. The maximum load capacity of the scraper is 84,000 lb.

12.2 Stripping overburden in the Illinois coal belt, the Dusty Coal Company uses 270-hp, track-type tractors (with direct-drive transmissions) and drawn scrapers. The overburden is a very soft loam that weighs 2,800 lb/yd (loose). Estimated rolling resistance factor for the haul road is 300 lb/ton. If the scraper weighs 35,000 lb (empty) and carries 25 loose cubic yards per trip, what is the rolling resistance of the loaded unit? What operating gear and speed do you estimate for the loaded machines on level ground? (See Table 12.4.)

12.3 The ABC Company is planning to start a new operation hauling sand to a ready-mix concrete plant. The equipment superintendent estimates that the company-owned 30-yd wheel tractor scrapers can obtain 26-ton loads. He is concerned about the high rolling resistance of the units in the sand (RR factor 250 lb/ton) and the low tractive ability of the tractors on this job. Will traction be a problem? If so, what do you suggest to help?

12.4 Estimate the cycle time and production of a 30-cu-yd wheel tractor scraper carrying rated capacity, operating on a 4,500-ft level haul. The road flexes under load, has little maintenance, and is rutted. Material is 3000 lb/BCY. The scrapers are push-loaded by one 385-hp, track-type pusher tractor. How many scrapers can be served by this one pusher?

12.5 How many trips would one rubber-tired Herrywampus have to make to backfill a space with a geometrical volume of 5400 cu yd? The maximum capacity of the machine is 30 cu yd (heaped), or 40 tons. The material is to be compacted with a shrinkage of 25% (relative to bank measure) and has a swell factor of 20% (relative to bank measure). The material weighs 3,000 lb/cu yd (bank). Assume that the machine carries its maximum load on each trip. Check by both weight and volume limitations.

12.6 You own a fleet of 30 cu yd tractor-scrapers and have them hauling between the pit and a road construction job. The haul road is clayey and deflects slightly under the load of the scraper. There is a slight grade (3%) from pit at the fill location. The return road is level. The haul distance to the dump location is 0.5 miles and the return distance is 0.67 miles. Four scrapers are being used.

(a) What is the rimpull required when the scraper is full and on the haul to the fill?

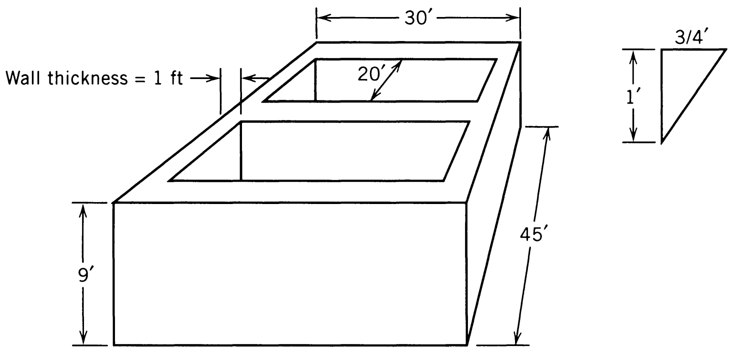
(b) What are the travel times to and from the dump location (see Fig. 12.10)?

(c) The scrapers are push loaded in the pit. The load time is 0.6 min. What is the cycle time of the pusher dozer?

(d) Is the system working at, above, or below the balance point? Explain.

(e) What is the production of the system?

12.7 You are excavating a location for the vault shown below. The top of the walls shown are 1 ft below grade. All slopes of the excavation are $\frac{3}{4}$ to 1 to a toe 1 ft outside the base of the walls. The walls sit on a slab 1 ft in depth. Draw a sketch of the volume to be excavated, break it into components, and calculate the volume. The material from the excavation is to be used in a compacted fill. The front-end loader excavating the vault has an output of 200 bank cubic yards of common earth per hour. It loads a fleet of four trucks (capacity 18 loose cubic yards each) that haul the earth to a fill where it is compacted with a shrinkage factor of 10%. Each truck has a total cycle time of 15 min, assuming it does not have to wait in line to be loaded. The earth has a swell factor of 20%. How many hours will it take to excavate and haul the material to the fill?



12.8 You have four 35-ton, off-highway trucks hauling from a pit to an airfield job. The haul road is maintained by a patrol grader and has a rolling resistance of 80 lb/ton. The road is essentially level and the distance one-way is 2.1 miles. The gross weight of the truck when loaded is 70 tons.

(a) What is the power required on the haul to the fill location?

(b) What is the maximum speed when hauling to the fill?

(c) What are the travel times to and from the fill (i.e, loaded and empty)?
The trucks are being loaded by a shovel with a 5-yd bucket (assume seven load cycles per truck load). The cycle time for the shovel is 0.5 mins.

(d) What is the total truck cycle time?

(e) What is the production of this system in cubic yards per hour, assuming the trucks carry 35 cu yd per load?

(f) Is the system working at, above, or below its balance point?

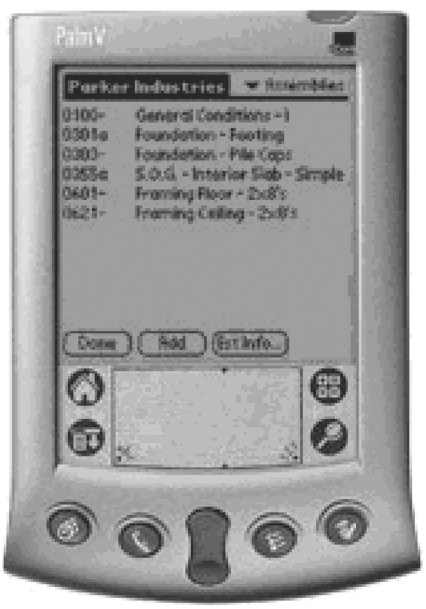
(g) If there is probability of major delay on the travel elements to and from the fill of 7% and the mean value of delay is 5 min, what is the new system production?

(h) Is the new system above or below the balance point?

12.9 You are given the following information about a dry-batch paving operation. You are going to use one mixer that has a service rate of 30 services per hour. The dry-batch trucks you use for bringing concrete to the paver have an arrival rate of 7.5 arrivals per hour. Each truck carries 6 cu yd of concrete. You have a total amount of 13,500 cu yd of concrete to pour. You rent a truck at $15 per hour, and the paver at $60 per hour. If the job takes more than 80 hours, you pay a penalty of $140 per hour owing to delays in job completion. On the basis of least cost, determine the number of trucks you should use. Plot the cost versus the number of trucks used.

Chapter 13

Estimating Process



Hand-Held Estimating Device

Estimating Using Hand-Held Devices

The Need

Estimators need a way to increase efficiency and lessen the chance for error when collecting estimate information in the field. With Hand-Held Devices, users can have access to the same precision estimating data they use in the office. Cover page information, item numbers and descriptions, assembly numbers and descriptions, WBS codes, variables, and variable help can all be stored on a hand-held device. This ensures that estimators have the information they need to collect all project details necessary to deliver an accurate, complete bid.

The Technology

Designed for Hand-Held Devices, estimating programs on personal digital assistants (PDAs) equip estimators with all the tools needed to perform detailed takeoffs remotely. Then, when convenient, data can be transferred to desktop software to instantly generate a detailed estimate or change order. With this type of mobile data acquisition, there's a much better chance of collecting all the necessary dimensional information to create a bid the first time. Specialized programs allow the user to take information from the desktop into the field to use as a checklist for takeoff.

PDA estimating lets users access existing estimate information or create brand new estimates directly in the field. All the project information can be logged in one place, keeping estimators better organized and ready to make additions and changes as needed.

13.1 ESTIMATING CONSTRUCTION COSTS

The key to a good job and successful cost control is the development of a good estimate as the basis for bid submittal. The estimate represents the cost "flight plan" that will be followed by the constructor and that will aid him or her in achieving profit. If the flight plan is unrealistic or contains basic errors, the contractor will lose money on the job. If the estimate is well thought out and correctly reflects the costs that will be encountered in the field, the chances of a profitable job are greatly increased.

Estimating is the process of looking into the future and trying to predict project costs and resource requirements. Studies indicate that one of the major reasons for the failure of construction contracting firms is incorrect and unrealistic estimating and bidding practices. If 20 estimators or contractors were furnished the same set of plans and specifications and told to prepare an estimate of cost and resources, it would be safe to assume there would not be more than 2 estimates prepared on the same basis or from the same units. Therefore, a consistent procedure or set of steps for preparing an estimate is needed to minimize errors and achieve reliable results.

13.2 TYPES OF ESTIMATES

Estimating methods vary in accordance with the level of design detail that is available to the estimator. Prior to the commencement of design, when only conceptual information is available, a comprehensive unit such as a square foot of floor space or a cubic foot of usable space is used to characterize the facility being constructed. The representative unit is multiplied by a price per unit to obtain a gross estimate ($\pm$10% accuracy) of the facility cost. A table of square foot and cubic foot building costs as given in *Building Construction Cost Data* published by the R. S. Means Company is shown in Figure 13.1 Such information is available in standard references and can be used for preliminary cost projections based on minimal design data. This *conceptual estimate* is useful in the schematic or budgetary phase, when design details are not available. The figures developed are of limited use for project control, and their use should be discontinued as soon as design data are available. These estimates are based on documents such as that given in Figure 2.2.

As the level of design detail increases, the designer typically maintains estimates of cost to keep the client informed of the general level of costs to be expected. The production of the plans and specifications usually proceeds in two steps. As noted in Chapter 2, the first step is called *preliminary design* and offers the owner a pause in which to review construction before detail design commences. A common time for this review to take place is at 40% completion of the total design. The preliminary design extends the concept documentation. At this point in the design process, a *preliminary estimate* is prepared by the architect or architect/engineer to reflect expected costs based on more definitive data.

Once the preliminary design has been approved by the owner, final or detail design is accomplished. The detail design phase culminates in the plans and specifications that are given to the constructor for bidding purposes. In addition to these detailed design documents, the architect/engineer produces a final *engineer's estimate* indicating the total job cost minus markup. This estimate should achieve approximately $\pm$3% accuracy since the total design is now available. The owner's estimate is used (1) to ensure that the design produced is within the owner's financial resources to construct (i.e., that the architect/engineer has not designed a gold-plated project) and (2) to establish a reference point in evaluating the bids submitted by the competing contractors.

On the basis of the final drawings and specifications the contractor prepares his estimate of the job's cost to include a markup for profit. This is the *bid estimate*. Both the engineer's and bid estimates require a greater level of effort and a considerable number of estimator hours to prepare. A rough rule of thumb states that the preparation of a bid estimate by the contractor will cost one-fourth of one percent of the total bid price. From the contractor's point of view this cost must be recovered as overhead on jobs that are won. Therefore, a prorate based on the number of successful bids versus total bids must be included in each quotation to cover bid costs on unsuccessful bids.

In building construction, these four levels of estimates are the ones most commonly encountered. To recapitulate, the four types of estimates are:

1. Conceptual estimate
2. Preliminary estimate
3. Engineer's estimate
4. Bid estimate

These four levels of precision reflect the fact that as the project proceeds from concept through preliminary design to final design and the bidding phase, the level of detail increases,

171 | S.F., C.F. and % of Total Costs

17 SQUARE FOOT

	171 000 | S.F. & C.F. Costs			UNIT	UNIT COSTS			% OF TOTAL		
					1/4	MEDIAN	3/4	1/4	MEDIAN	3/4
010	0010	**APARTMENTS** Low Rise (1 to 3 story)	R171 -100	S.F.	40.20	50.65	67.35			
	0020	Total project cost		C.F.	3.61	4.74	5.95			
	0100	Site work		S.F.	3.34	4.81	7.60	6.30%	10.50%	13.90%
	0500	Masonry			.73	1.87	3.18	1.50%	3.90%	6.50%
	1500	Finishes			4.22	5.40	7.15	8.90%	10.70%	12.90%
	1800	Equipment			1.31	1.99	2.96	2.70%	4.10%	6.30%
	2720	Plumbing			3.13	4.03	5.06	6.70%	8.90%	10.10%
	2770	Heating, ventilating, air conditioning			1.99	2.46	3.56	4.20%	5.60%	7.60%
	2900	Electrical			2.32	3.08	4.19	5.20%	6.70%	8.40%
	3100	Total: Mechanical & Electrical			6.95	8.50	10.90	15.90%	18.20%	22%
	9000	Per apartment unit, total cost		Apt.	31,200	46,700	68,900			
	9500	Total: Mechanical & Electrical		"	5,700	8,400	12,100			
020	0010	**APARTMENTS** Mid Rise (4 to 7 story)	R171 -100	S.F.	52.80	63.90	77.90			
	0020	Total project costs		C.F.	4.14	5.65	7.85			
	0100	Site work		S.F.	2.06	4.03	7.50	5.20%	6.70%	9.10%
	0500	Masonry			3.23	4.52	6.70	5.20%	7.30%	10.50%
	1500	Finishes			6.55	8.30	10.85	10.40%	11.90%	16.90%
	1800	Equipment			1.66	2.38	3.12	2.80%	3.50%	4.40%
	2500	Conveying equipment			1.20	1.48	1.77	2%	2.20%	2.60%
	2720	Plumbing			3.12	4.93	5.40	6.20%	7.40%	8.90%
	2900	Electrical			3.59	4.77	5.85	6.60%	7.20%	8.90%
	3100	Total: Mechanical & Electrical			9.80	12.35	15.90	17.90%	20.10%	22.30%
	9000	Per apartment unit, total cost		Apt.	38,400	58,300	67,400			
	9500	Total: Mechanical & Electrical		"	12,200	13,700	21,500			
030	0010	**APARTMENTS** High Rise (8 to 24 story)	R171 -100	S.F.	60.60	73	89.20			
	0020	Total project costs		C.F.	4.98	6.90	8.45			
	0100	Site work		S.F.	1.85	3.55	4.96	2.50%	4.80%	6.10%
	0500	Masonry			3.43	6.20	7.85	4.70%	9.60%	10.70%
	1500	Finishes			6.55	8.40	9.60	9.30%	11.70%	13.50%
	1800	Equipment			1.92	2.37	3.16	2.70%	3.30%	4.30%
	2500	Conveying equipment			1.22	2.02	2.88	2.20%	2.70%	3.30%
	2720	Plumbing			4.54	5.25	6.61	6.90%	9.10%	10.60%
	2900	Electrical			4.15	5.20	7.10	6.40%	7.60%	8.80%
	3100	Total: Mechanical & Electrical			12.25	14.85	18.35	18.20%	21.80%	23.90%
	9000	Per apartment unit, total cost		Apt.	55,700	66,500	73,400			
	9500	Total: Mechanical & Electrical		"	13,500	15,500	16,800			
040	0010	**AUDITORIUMS**	R171 -100	S.F.	61	85.30	110			
	0020	Total project costs		C.F.	4.01	5.60	8			
	2720	Plumbing		S.F.	3.89	5.15	6.70	5.80%	7%	8.60%
	2900	Electrical			4.96	7.05	9	6.70%	8.80%	10.90%
	3100	Total: Mechanical & Electrical			10.10	13.65	23.70	14.40%	18.50%	23.60%
050	0010	**AUTOMOTIVE SALES**	R171 -100	S.F.	42.45	50.80	76.60			
	0020	Total project costs		C.F.	3.12	3.56	4.63			
	2720	Plumbing		S.F.	2.26	3.68	4.09	4.70%	6.40%	7.80%
	2770	Heating, ventilating, air conditioning			3.26	4.99	5.40	6.30%	10%	10.30%
	2900	Electrical			3.74	5.60	6.45	7.40%	9.90%	12.30%
	3100	Total: Mechanical & Electrical			7.90	11.55	15.10	16.60%	19.10%	27%
060	0010	**BANKS**	R171 -100	S.F.	91.05	113	143			
	0020	Total project costs		C.F.	6.60	8.85	11.65			
	0100	Site work		S.F.	9.05	16.60	24.65	7%	13.80%	17.50%
	0500	Masonry			4.60	7.65	16.85	2.90%	5.80%	11.30%
	1500	Finishes			7.75	10.55	13.55	5.50%	7.60%	9.90%
	1800	Equipment			3.63	7.55	16.85	3.20%	8.20%	12.50%
	2720	Plumbing			2.89	4.10	6	2.80%	3.90%	4.90%
	2770	Heating, ventilating, air conditioning			5.65	7.30	9.80	4.90%	7.10%	8.50%

Figure 13.1 Costs based on a representative unit (From *Building Construction Cost Data 1996,* copyright Reed Construction Data, Kingston, MA, 781-585-7880 all rights reserved.).

allowing the development of a more accurate estimate. Estimating continues during the construction phase to establish whether the actual costs agree with the bid estimate. This type of “estimating” is what allows the contractor to project profit or loss on a job after it is in progress.

A listing of estimates commonly developed in conjunction with large and complex industrial projects (e.g., power plants, chemical process plants, and the like) is given in

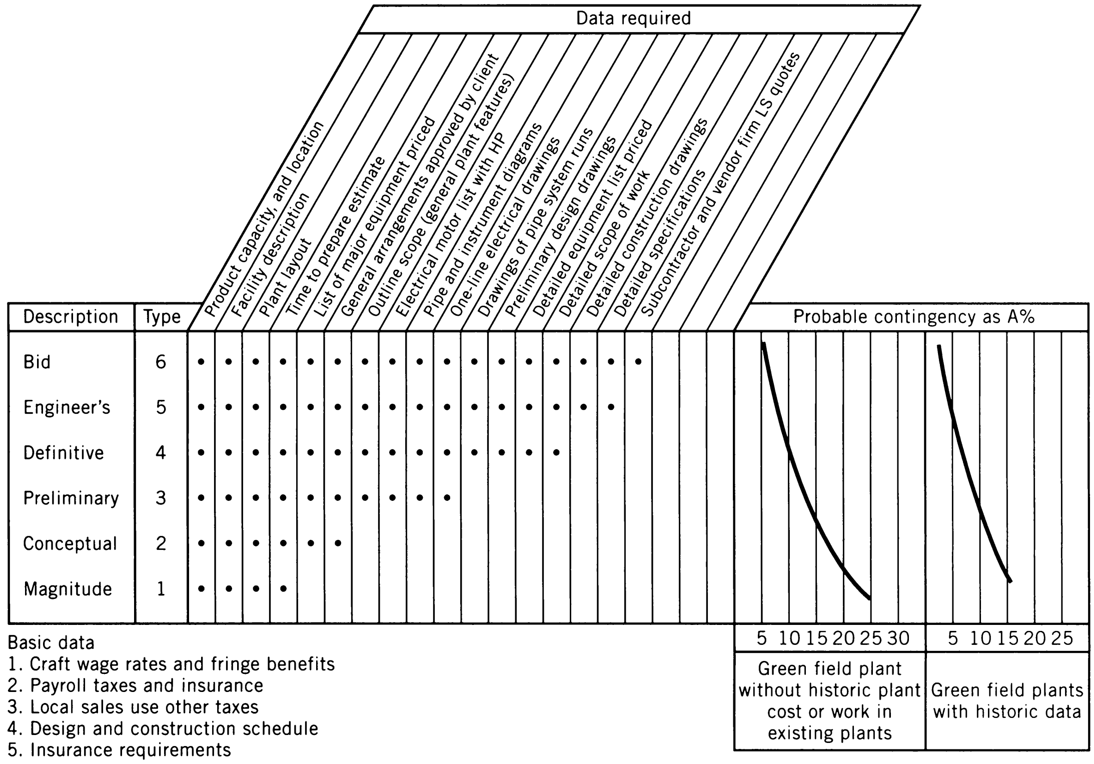


Figure 13.2 Estimate types (*Source:* F. S. Merritt, ed., *Building Construction Handbook*, 3rd ed., New York, McGraw-Hill, 1975).

Figure 13.2. This list includes a magnitude level estimate that is similar in purpose to the conceptual estimate used in building construction. That is, it is used to reflect gross costs for planning and decision purposes before the preliminary and definitive design phases begin. The definitive estimate, as used on complex industrial projects, is a prefinal estimate developed just prior to the production of final drawings and specifications. The definitive estimate can be prepared when all components comprising the project scope definition have been quantitatively determined and priced by using actual anticipated material and labor costs. This estimate is normally prepared when the project scope is defined in terms of firm plot plans, mechanical and process flow diagrams, equipment and material specifications, and engineering and design layouts. The pricing is based on formal vendor quotations for all major items and current predictable market costs for all commodity accounts. The amount of variability inherent in each level of estimate is reflected by the contingency curves shown on the right in Figure 13.2. The variability is, of course, quite high at the magnitude level and decreases to the 3 to 5% range as bid-level documents become available.

13.3 DETAILED ESTIMATE PREPARATION

The preparation of a detailed bid-level estimate requires that the estimator break the project into cost centers or cost subelements. That is, the project is broken down into subcomponents that will generate costs. It is these costs that the estimator must develop on the basis of the characteristic resources required. The word *resource* is used here in the broad sense and applies to the man-hours, materials, subcontracts, equipment-hours, and dollars needed to accomplish the work or meet the requirements associated with the cost center. Typically in construction the cost center relates to some physical subcomponent of the project, such as foundation piles, excavation, steel erection, interior dry wall installation, and the like. Certain non-physical components of the work generate costs, however, and these cost centers must also be considered. Many of the items listed as "indirects" are typical of costs that are not directly connected with physical components or end items in the facility to be constructed. Such items do, however, generate cost that must be recovered. These costs include insurance and bonding premiums, fees for licenses and permits required by contract, expense for special items relating to safety and minority participation programs, and home office overheads projected as allocated to the job. These items are sometimes referred to as *general conditions*, or *general requirements*, although they may or may not be specifically referred to in the contract documents. Accounts relating to these items fall into the categories for conditions of contract and general requirements of the contract. As estimators prepare bids, they have a general framework for cost recovery in mind. In addition, they have a knowledge of the technologies involved in building the project, which allow them to divide projects into individual pieces of work (physical subcomponents, systems, etc.). These work packages consume resources, generating costs that must be recovered from the client. Typically, a chart of cost accounts specific to the company acts as a guide or checklist as the estimator reviews the plans and specifications to highlight what cost centers are present in the contract being estimated.

Although the process of estimating is part art, part science, the estimator generally follows certain steps in developing the estimate:

1. Break the project into cost centers.
2. Estimate the quantities required for cost centers that represent physical end items (e.g., cubic yards of earth, lineal feet of pipe, etc.). For physical systems this procedure is commonly called *quantity takeoff*. For those cost centers that relate to nonphysical items, determine an appropriate parameter for cost calculation (e.g., the level of builder's risk insurance required by the contract or the amounts of the required bonds).
3. Price out the quantities determined in step 2 using historical data, vendor quotations, supplier catalogs, and other pricing information. This pricing may be based on a price per unit (unit cost) basis or a lump-sum (one job) basis. Price development for physical work items may require an analysis of the production rates to be achieved based on resource analysis. If this analysis is used, the estimator must:
   - **a.** Assume work team composition to include number of workers (skilled and unskilled) and equipment required.
   - **b.** On the basis of team composition, estimate an hourly production rate based on the technology being used.
   - **c.** Make an estimate of the efficiency to be achieved on this job, considering site conditions and other factors.
   - **d.** Calculate the effective unit price.
4. Calculate the total price for each cost center by multiplying the required quantity by the unit price. This multiplication is commonly called an *extension*, and this process is called *running the extensions*.

The estimator usually summarizes the values for each cost center on a summary sheet, such as that shown in Figure 13.3.

13.4 DEFINITION OF COST CENTERS

The subdivisions into which the project is divided for detailed cost estimation purposes are variously referred to as:

Jefferson Starship Contractors, Inc.
ESTIMATE SUMMARY
Estimate No. 6692 By: DWH Date: 1 August 2xxx
Owner: NASA Project: Admin Building

Code	Description	MH	Labor	Material	Sub	Owner	Total
01	Site improvements						
02	Demolition						
03	Earthwork						
04	Concrete						
05	Structural steel	1,653	18,768	15,133			33,901
06	Piling						
07	Brick & masonry						
08	Buildings						
09	Major equipment	2,248	26,059	1,794			27,853
10	Piping	2,953	34,518	57,417	1,500	34,541	127,976
11	Instrumentation				33,000		33,000
12	Electrical				126,542		126,542
13	Painting				14,034		14,034
14	Insulation				4,230		4,230
15	Fireproofing			530	1,110		1,640
16	Chemical cleaning						
17	Testing						
18	Const. equipment					35,666	35,666
19	Misc. directs	1,008	10,608	2,050		2,000	14,658
20	Field extra work						
Sub Total Direct Cost		7,862	89,953	76,924	180,416	72,207	419,500
21	Con. tools/sup.			7,361			7,361
22	Field payroll/burden					16,580	16,580
23	Start-up asst.						
24	Ins. & taxes					5,268	5,268
25	Field sprvsn.	480	7,200			2,038	9,238
26	Home off. exp.					2,454	2,454
27	Field emp. ben.					10,395	10,395
Sub Total Indirect Cost		480	7,200	7,361		36,735	51,296
Adjustment Sheets							
Total Field Cost		8,342	97,153	84,285	180,416	108,942	470,796
28	Escalation						
29	Overhead & profit		8,342	5,057	9,021	10,190	32,610
30	Contingency						18,076
31	Total Project Cost						521,482

Figure 13.3 Typical estimate summary.

1. Estimating accounts
2. Line items
3. Cost accounts
4. Work packages

The estimating account is typically defined so as to provide target values for the cost accounts that will be used to collect as-built costs while the job is in progress. Therefore, the end item that is the focus of cost development in the estimating account is linked to a parallel cost account for actual cost information collecting during construction. The cost account expenditures developed from field data are compared with the estimated cost as reflected by the estimating account to determine whether costs are exceeding, underrunning, or coming in on the original estimate values. Therefore, the use of the term *cost account* is not strictly correct during the preparation of bid since this account is not active until the job is in progress and actual cost data are available.

As described in Chapter 6, the term *work package* has become current over the past 20 years and is commonly used to indicate a subdivision of the project that is used both for cost control and scheduling (i.e., time control). When both cost and time control systems are combined into an integrated project management system, work packages are controlled to determine cost versus estimate and time versus schedule.

The subdividing of the project into work packages results in the definition of a work breakdown structure (WBS).

> *A work package is a well-defined scope of work that usually terminates in a deliverable product. Each package may vary in size, but must be a measurable and controllable unit of work to be performed. It also must be identifiable in a numerical accounting system in order to permit capture of both budgeted and actual performance information. A work package is a cost center.*[1]

The breakdown of a project into estimating accounts or work packages (depending on the sophistication of the system) is aided by a comprehensive chart of cost accounts or listing of typical work packages that can be used as a checklist. This checklist or template can be matched to the project being estimated to determine what types of work are present. That is, accounts in the general chart are compared to the project being estimated to determine which ones apply.

13.5 QUANTITY TAKEOFF

The development of the quantities of work to be placed in appropriate units (e.g., square feet, cubic yards, etc.) is referred to as the quantity takeoff (QTO) or quantity surveying.[2] The procedures employed by the estimator to calculate these quantities should incorporate steps to minimize errors. Five of the most common errors experienced during quantity takeoff are:

1. Arithmetic: Errors in addition, subtraction, and multiplication
2. Transposition: Mistakes in copying or transferring figures, dimensions, or quantities
3. Errors of omission: Overlooking items called for or required to accomplish the work
4. Poor reference: Scaling drawings rather than using the dimensions indicated
5. Unrealistic waste or loss factors

The first step in the quantity takeoff procedure is to identify the materials required by each estimating account or work package. Once the types of materials are identified, relevant dimensions are recorded on a spreadsheet so that quantity calculations in the required unit of measure can be made. Calculation of quantities by estimating account or work package has several advantages, not the least of which is the fact that it allows the estimating process to be performed by several estimators, each with a well-defined area of responsibility. No matter how competent an estimator may be in his own field, it is not reasonable to expect him to have an intimate knowledge of all phases of construction. This method enables one estimator to check another estimator's work. It also facilitates computations required to develop the financial "picture" of the job and processing of progress payment requests.

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[1] James N. Neil, *Construction Cost Estimating for Project Control*, Prentice-Hall, Englewood Cliffs, NJ, 1982, p. 73.

[2] This term is commonly used in the United Kingdom and the Commonwealth countries.

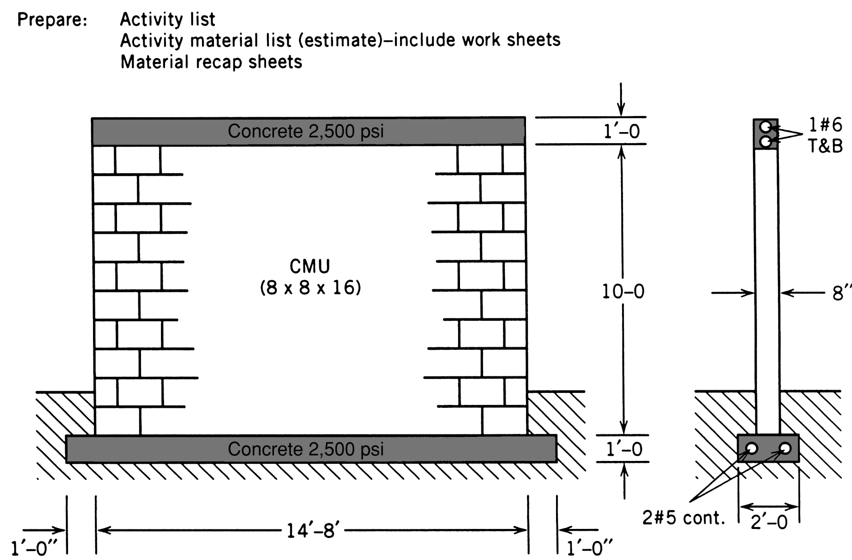


Figure 13.4 Small wall construction (CMU = concrete masonry unit).

When changes occur, only those activities affected must be reacalculated. Other procedures require a completely new takeoff.

Before the calculations for the quantity takeoff are performed, detailed working drawings are sometimes required to clarify the contract drawings and specifications or the chosen construction method (e.g., forming techniques). Such a drawing for a small wall is given in Figure 13.4. During construction these details are of tremendous value to the person in the field who is trying to perform the work within the cost guidelines provided. From these drawings and details a checklist should be developed to indicate all of the materials required for each work package. After this checklist has been made, it should be checked against a standard checklist to identify errors of omission.

The actual calculations should be performed on a standard spread sheets to allow for independent check and self-checks. As the calculations for those items shown on the plans progress, each item taken off should be highlighted by a color marker so that those items remaining to be considered are obvious at a glance. Arithmetic should be performed on a calculator or computer that produces hard copy output. This output should be used by the estimator to identify errors. All supporting documentation should be attached to the estimate to aid in checking by other sources or at a later date. The quantities calculated should be exact. Waste and loss factors will be applied later. A materials takeoff sheet for the small wall (Fig. 13.4) is given in Figure 13.5.

A summary, or "recap sheet," should be made. This recap sheet should consist of a listing, by material type, of all the materials required for the entire work item or package. The listing should include total quantities as well as subquantities identified by activity code. The listing should also include appropriate waste and loss factor calculations. An example of a recap sheet is given in Figure 13.6. This example is simple and is included only to demonstrate the nature of quantity development. In practice, most companies will use computerized data bases and spread sheet programs to prepare final estimates. The basic principles of estimating must be well understood, however, to avoid omissions which could prove disastrous at the time of bid submittal.

13.6 METHODS OF DETAILED COST DETERMINATION

After quantities have been determined for accounts that are relevant to the project at hand, the method by which costs will be assigned can be selected. The two methods of cost

Project ______________________

Activity code	Activity description	Material description	Quantity	Unit	Cost code
1	Layout	Stakes 2 x 4 x 24 8 ea.	10.3	BF	0100
3	Place rebar	#5 st. 2 PCS 16 – 2	32.3	LF	0320
		Tie wire	1	Roll	0320
4	Cost and cure	footing			
		Concrete	1.23	CY	0330
		Curing compound	.25	Gal	0337
5	Erect CMU wall				
		CMU 8 x 8 x 16 stretcher	143	Ea	0412
		CMU 8 x 8 x 16 corner	14	Ea	0412
		CMU 8 x 8 x 16 corner	16	Ea	0412
		Scaffolding 4' x 4' x 6'	2	Sec.	0100
		Mortar	.27	CY	0412
7	Form bond beam				
		2 x 4 (4 – 15' – 0")	43.5	BF	0310
		2 x 2	12.7	BF	0310
		1 x 2	2.0	BF	0310
		3/4" ext ply	60.3	SF	0310
		Snapties 8"	24	Ea	0310
		Nails 8d	1.5	Lb	0310
		Nails 6d	.4	Lb	0310
		Form oil	.07	Gal	0310
8	Place bond beam rebar				
		#6 rebar (str.)	28.67	LF	0320
9	Cost and cure	Bond beam			
		Concrete	.35	CY	0330
		Curing compound	.05	Gal	0337
10	Strip forms and rub bond beam				
		Grout	1	CF	0339.2

Figure 13.5 Activity material list.

determination most frequently used are (1) unit pricing and (2) resource enumeration. If the work as defined by a given estimating account is fairly standard, the cost can be calculated by simply taking *dollar per unit* cost from company records and applying this cost with a qualitative correction factor to the quantity of work to be performed. For instance, if the project calls for 100 lineal feet of pipe and historical data in the company indicate that the pipe can be placed for $65 a lineal foot to include labor and materials, the direct cost calculation for the work would yield a value of $6,500. This value can then be adapted for special site conditions.

Unit pricing values are available in many standard estimating references. The standard references normally give a nationally averaged price per unit. A multiplier is used to adjust the national price to a particular area. These references are updated on an annual basis to keep them current. Among the largest and best known of these services are:

1. R. S. Means Company, *Building Construction Cost Data*
2. F. R. Walker's *The Building Estimator's Reference Book*
3. *The Richardson General Construction Estimating Standards*

Project Wall

Description	Activity code	Sub-quantity	Waste	Total quantity	Unit		Cost code
2 x 4 Lumber	Total	53.8	10%	60.0	BF		
	1	10.3					0100
	7	43.5					0310
2 x 4 Lumber	7	12.7	10%	14.0	BF		0310
1 x 2 Lumber	7	2.0	10%	2.25	BF		0310
3/4" Exterior plywood	7	60.3	10%	66	SF		0310
Curing compound	Total	.30		1	Gal		0337
	4	.25					
	9	.05					
Snap ties 8"	7	24.	5%	25	Ea		0310
Nails 8d	7	1.5		3	LB		0310
Nails 6d	7	.4		1	LB		0310
Form oil	7	.07		.25	Gal		0310

Figure 13.6 Construction support materials recap sheet.

These references contain listings of cost line items similar to the cost account line items a contractor would maintain.

The development of direct costs to include overhead and profit for a particular line item using the R. S. Means system is shown in Figure 13.7.

The line items specified in the R. S. Means Construction Cost Data are defined by using the Uniform Construction Index numerical designators. The system assumes a given crew composition and production rate for each line item. In the case illustrated a standard crew designated C-1 can construct 190 SFCA (square foot contact area) of plywood column form per shift (daily output). This underlines the fact that unit pricing data must make some assumption regarding the resource group (i.e., crew, equipment fleet, etc.) and the production rate being used. That is, although unit pricing data are presented in dollars-per-unit format, the cost of the resource group and the rate of production achieved must be considered. The dollars-per-unit value is calculated as follows:

$$\frac{\text{Cost of resources per unit time}}{\text{Production rate of resources}} = \frac{\$/\text{hr}}{\text{unit/hr}} = \$/\text{unit}$$

The unit cost is the ratio of resource costs to production rate. The crew composition and assumed cost for the crew are shown in the middle of Figure 13.7.

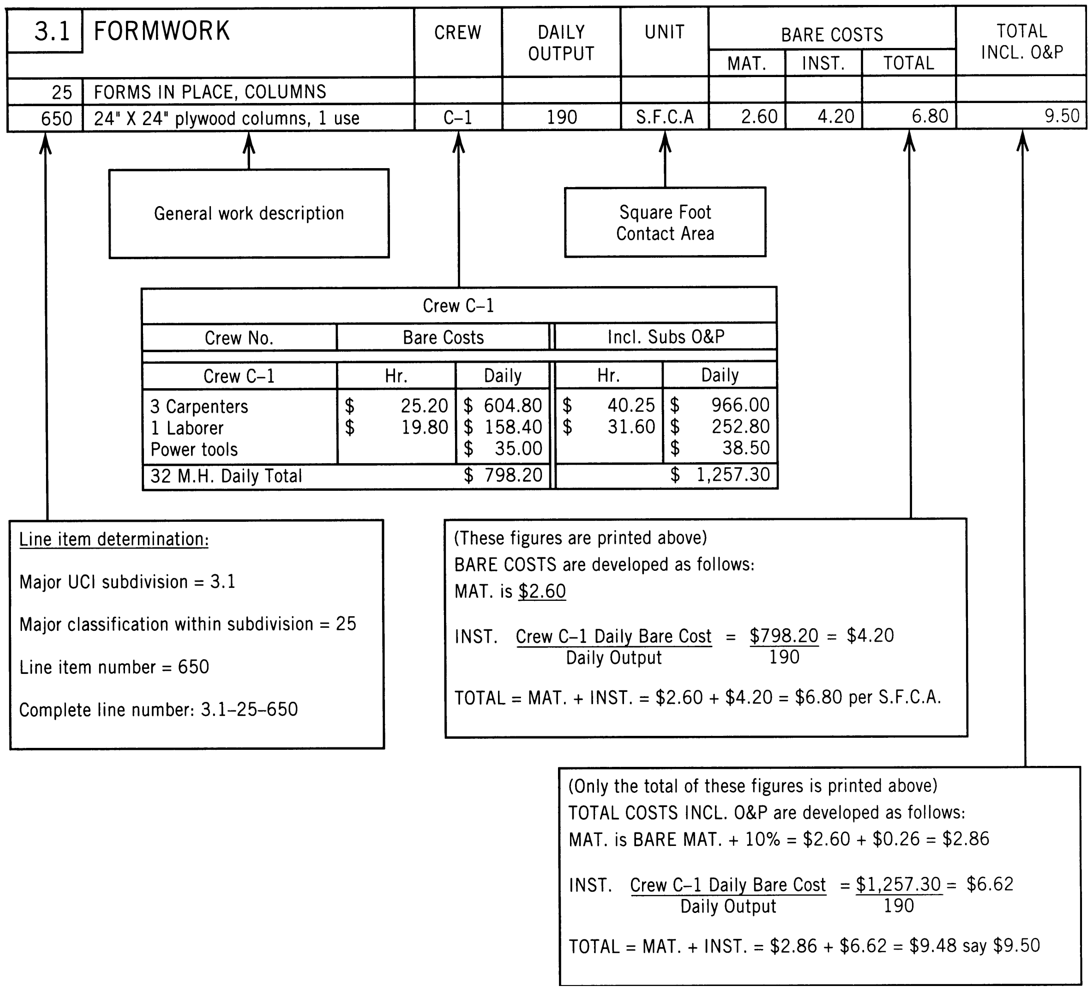


Figure 13.7 Line item cost development using R. S. Means data. "From Means Building Construction Cost Data 1981. Copyright Reed Construction Data, Kingston, MA 781-585-7880; All rights reserved."

In the R. S. Means system two costs are specified for each line item. The bare cost is the direct cost for labor and materials. The total cost includes the cost of burdens, taxes, and subcontractor overhead and profit (inclusive O&P). In Figure 13.7, the bare cost of the C-1 crew is calculated as $798.20 per shift. Therefore, the bare unit installation cost is

$$\frac{\$798.20/\text{shift}}{190\ \text{units/shift}} = \$4.20/\text{SFCA}$$

Combining this installation cost with the material cost per unit of $2.60 yields a bare unit cost for materials and installation of $6.80.

The overhead and profit (O&P) charges associated with labor (as considered in the Means system) are:

1. Fringe benefits (included in bare costs)
2. Workmen's compensation
3. Average fixed overhead
4. Subcontractor overhead
5. Subcontractor profit

In order to adjust the bare costs of installation to include subcontractor's O&P, the appropriate craft values for the members of the craft are located and applied. For the carpenters the total correction is 59.7%, or $15.05 per hour. Therefore, the carpenter rate to include O&P is $40.25 per hour. Similarly, the laborer rate is adjusted to $31.60 per hour to include O&P. A markup of 10% is applied to the power tools, yielding a daily rate of $38.50. The new installation rate to include O&P is

$$\frac{\$1{,}257.30}{190} = \$6.62/\text{SFCA}$$

The 10% markup is applied to the material cost, resulting in a $2.86 charge per SFCA. The combined cost of materials and installation is $9.48 per SFCA, which is rounded to $9.50.

13.7 PROBLEMS WITH UNIT-COST METHOD

The data that the contractor has available from company records are presented as dollars per unit, and in most cases no records of the crew composition, cost, and production rates is maintained. In fact, the dollars-per-unit value is typically an average of the values obtained on recent jobs. Since on each job the crew composition, costs, and production rates achieved are probably unique to the individual job, the figure represents an aggregate cost per unit. The actual number of man-hours used and the productivity achieved are masked by the dollar-per-unit figure. Unless the resource (i.e., man-hour, etc.) information is kept separately, it has been lost. Therefore, the unit price available from averaging values on previous jobs has to be treated with some caution. Since every job is unique, some of the estimator's intuition must be applied to ensure that the value is adapted to the conditions of the job being estimated. If the conditions of jobs vary very little, however, the application of the unit pricing approach is both practical and efficient.

Clearly, the numerator (cost of resources per unit time) of the unit-cost ratio will vary significantly over time as the costs of labor and machines vary. The costs of all components of the construction process have risen sharply over the past 20 years. This is shown dramatically in the *Engineering News Record* construction and building cost indexes shown in Chapter 2. In order to factor out the inflationary escalation inherent in resource costs, some contractors maintain the ratio of man-hours or resource-hours per hour to production. This establishes a company data-base tied to resource hours required rather than dollars per unit. Therefore, the contractor can retrieve a man-hour or resource-hour (RH) per unit value for each line item. The value is calculated as:

$$\frac{\text{Resource-hours per hour}}{\text{Units per hour}} = \text{RH/unit}$$

The cost per unit can then be calculated by multiplying the resource hours per unit value by the average hourly cost per resource. If it takes 25 resource-hours per unit and the average cost of a resource-hour is $20.00, the unit cost will be $500.00 per unit. This method recognizes that the number of resource-hours required per unit is much more stable over the years than the cost per unit. Therefore, data on resource-hours per unit collected over several years will not be affected by inflationary trends and escalation in the cost of goods and services.

Use of the unit-pricing approach assumes that historical data have been maintained for commonly encountered cost accounts. Data are collected and linked to a reference unit such as a cubic yard or square foot. The costs of materials and installation are aggregated and then presented as a cost per unit. Companies typically accumulate such data either manually or on the computer as a by-product of the job cost system. On a typical job 80 to 90% of the work to be accomplished can be estimated by calculating the number of reference units and multiplying this number by the unit price. Typically the estimator will intuitively adjust this price to reflect special characteristics of the job, such as access restrictions, difficult management environment, and the like. One approach to the quantification of these site and job unique factors is proposed by Louis Dallavia. Although the Dallavia method (*Estimating General Construction Costs*, 1957) is dated, it does reflect, in an approximate way, the factors that are considered by an estimator in adjusting general unit prices to a given project. The system defines a *percent efficiency factor* based on a production range index for each of eight job characteristics. The method of calculating the percent efficiency factor and the table production range indices are shown in Figure 13.8.

13.8 RESOURCE ENUMERATION

Although the unit-pricing approach is sufficiently accurate to estimate the common accounts encountered on a given project, almost every project has unique or special features for which unit-pricing data may not be available. Unusual architectural items that are unique to the structure and require special forming or erection procedures are typical of such work. In such cases, the price must be developed by breaking the special work item into its subfeatures and assigning a typical resource group to each subfeature. The productivity to be achieved by the resource group must be estimated by using either historical data or engineering intuition. The breakdown of the cost center into its subelements would occur much in the same fashion in which the wall of Section 13.5 was subdivided for quantity development purposes. The steps involved in applying the resource enumeration approach are shown in Figure 13.9.

An example of resource enumeration applied to a concrete-placing operation is shown in Figure 13.10. In this example a concrete placement crew consisting of a carpenter foreman, two cement masons, a pumping engineer (for operation of the concrete pump), and seven laborers for placing, screening, and vibrating the concrete has been selected. A concrete pump (i.e., an equipment resource) has also been included in the crew. Its hourly cost has been determined using methods described above. The total hourly rate for the crew is found to be \$370.00. The average assumed rate of production for the crew is 12 cu yd/hr. This results in an average labor cost per cubic yard of concrete of \$30.83. The line items requiring concrete are listed with the quantities developed from the plans and specifications. Consider the first item that pertains to foundation concrete. The basic quantity is adjusted for material waste. The cost per unit is adjusted to \$34.25 based on an efficiency factor for placement of foundation concrete estimated as 90%.

The resource enumeration approach has the advantage over unit pricing in that it allows the estimator to stylize the resource set or crew to be used to the work in question. The rates of pay applied to the resource group reflect the most recent pay and charge rates, and therefore incorporate inflationary or deflationary trends into the calculated price. The basic equation for unit pricing is

$$\frac{\text{Resource cost per unit time}}{\text{Production rate}} = \frac{\$/\text{hr}}{\text{unit/hr}} = \$/\text{unit}$$

In the unit-pricing approach the resource costs and the production rates are the aggregate values of resources and rates accumulated on a number of jobs over the period of historical data collection. With the resource enumeration approach, the estimator specifies a particular crew or resource group at a particular charge rate and a particular production level for the specific work element being estimated. This should yield a much more precise cost-per-unit definition. The disadvantage with such a detailed level of cost definition is the fact that it is time-consuming. Therefore, resource enumeration would be used only on (1) items for which no unit cost data are available (2) "big-ticket" items, which constitute a large percentage of the overall cost of the job and for which such a precise cost analysis may lead to cost

Production Range Index

Production Elements	Production Efficiency (%) 25 35 45 55 65 75 85 95 100 — Low	Average	High
1. *General Economy*	Prosperous	Normal	Hard times
Local business trend	Stimulated	Normal	Depressed
Construction volume	High	Normal	Low
Unemployment	Low	Normal	High
2. *Amount of Work*	Limited	Average	Extensive
Design areas	Unfavorable	Average	Favorable
Manual operations	Limited	Average	Extensive
Mechanized operations	Limited	Average	Extensive
3. *Labor*	Poor	Average	Good
Training	Poor	Average	Good
Pay	Low	Average	Good
Supply	Scarce	Average	Surplus
4. *Supervision*	Poor	Average	Good
Training	Poor	Average	Good
Pay	Low	Average	Good
Supply	Scarce	Average	Surplus
5. *Job Conditions*	Poor	Average	Good
Management	Poor	Average	Good
Site and materials	Unfavorable	Average	Favorable
Workmanship required	First rate	Regular	Passable
Length of operations	Short	Average	Long
6. *Weather*	Bad	Fair	Good
Precipitation	Much	Some	Occasional
Cold	Bitter	Moderate	Occasional
Heat	Oppressive	Moderate	Occasional
7. *Equipment*	Poor	Normal	Good
Applicability	Poor	Normal	Good
Condition	Poor	Fair	Good
Maintenance, repairs	Slow	Average	Quick
8. *Delay*	Numerous	Some	Minimum
Job flexibility	Poor	Average	Good
Delivery	Slow	Normal	Prompt
Expediting	Poor	Average	Good

Example: After studying a project on which he is bidding, a contractor makes the following evaluations of the production elements involved:

Production Element	*% Efficiency*
1. Present economy	75
2. Amount of work	90
3. Labor	70
4. Supervision	80
5. Job conditions	95
6. Weather	85
7. Methods and equipment	55
8. Delays	75
Total	625

As the total of the eight elements is 625, the average value will be 625/8, or 78%.

Figure 13.8 Dallavia method.

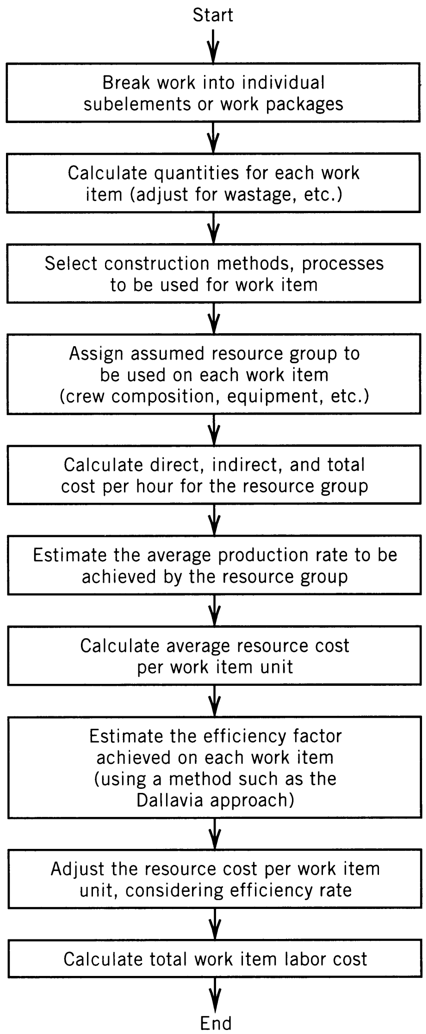


Figure 13.9 Resource enumeration method of estimating.

savings that may provide the winning margin at bid time, or (3) extremely complex work items on complicated and unique projects for which the use of the unit-pricing approach is deemed inadequate.

13.9 WORK PACKAGE OR ASSEMBLY-BASED ESTIMATING

In this approach to estimate development, a work package or assembly that is commonly encountered in construction is viewed as an estimating group, and appropriate dimensional and cost-related parameters are defined for the package. The wall of Figure 13.4 could be considered an assembly. In this case, the height, width, and depth of the footer, block portion, and cap beam would be specified each time the assembly is encountered. Pricing information for the defined wall would be retrieved from a pricing catalog. Since the reference subelement in this approach is the work package, an extensive listing of assemblies or packages into which the work can be subdivided is maintained.

A concrete footer assembly is shown in Figure 13.11. The relevant data required for takeoff are the dimensional values shown as items A through K. Data regarding the

Concrete Placing Crew

Quantity	Member	Rate	Total/Hour
1	Carpenter foreman	\$40.00	\$ 40.00
2	Cement masons	\$36.00	\$ 72.00
1	Pumping engineer	\$38.00	\$ 38.00
7	Laborers	\$28.00	\$196.00
1	Concrete pump	\$24.00	\$ 24.00
		Crew hourly rate	\$370.00

Production rate of crew under normal circumstances (efficiency factor 1) = 12 cu yd/hr.
Average labor cost/cubic yard = \$370/12 = \$30.83.

Area	Quantity	Percent Waste	Efficiency Factor	Labor Cost/ Cubic Yard	Activity Cost
1. Foundation	53.2	15	0.9	\$34.25	\$ 1,822
2. Wall to elevation 244.67	52.9	12	0.8	38.54	2,039
3. Slab 10 in.	1.3	30	0.3	102.77	134
4. Beams elevated 244.67	10.5	15	0.7	44.04	462
5. Beams elevated 245.17	9.1	15	0.7	40.44	401
6. Slab elevation 244.67	8.7	10	0.7	40.44	383
7. Interior wall to 244.67	5.5	15	0.4	77.07	424
8. Slab elevation 254.17	6.3	10	0.75	41.11	259
9. Walls 244.67 −254.17	57.2	10	0.8	38.54	2,205
10. Walls 254.17 −267	42.0	10	0.8	38.54	1,619
11. Floors elevated 267	8.9	10	0.9	34.25	305
12. Manhole walls	27.3	10	0.85	36.27	990
13. Roof	14.0	15	0.7	44.04	617
14. Headwall	8.5	10	0.8	38.59	328
Total direct labor cost for concrete				\$11,988 say	\$12,000

Figure 13.10 Labor resource enumeration.

methodology of placement and the relevant specifications are indicated by items (1) to (9) in the figure. Such work-package-based systems can be considered a structured extension of the resource enumeration approach and can be calculated manually. In general, most of these system-based (i.e., assembly-based) systems are computerized and are based on presenting the estimator with individual assemblies. The estimator is interrogated by the computer and provides the dimensional and methodology information in a question-and-answer format. This procedure is shown schematically in Figure 13.12. The estimator goes through the construction systems sequentially, selecting those that are relevant and providing the required data. These data are integrated with information from a pricing catalog. The pricing catalog allows for price, resource, and productivity adjustment. The manual or

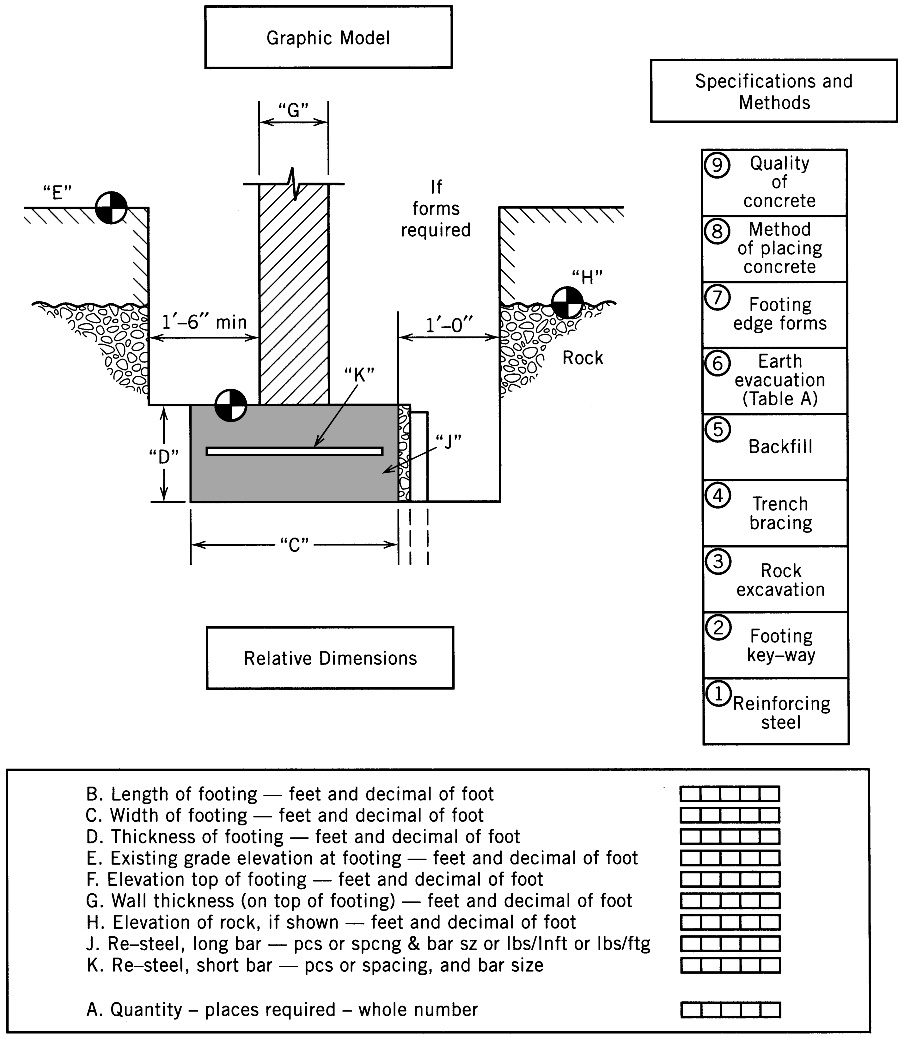


Figure 13.11 Construction systems concept—concrete footing.

computer program integration of these data produces the estimate reports required for bid preparation.

If a manual approach is used to estimate each work package, a work package takeoff sheet is helpful in organizing the collection of data. Such a work package or assembly collection sheet can be organized as shown in Figure 13.13. This form illustrates the development of an estimate for slab on grade in a building project. Material, labor, and equipment resources required for the package are shown on the left side of the sheet, together with target prices for each resource. It is interesting to note that the equipment resources are normally charged on a period basis since partial-day allocation of equipment is not a common practice. The right side of the sheet considers the productivity rate to be used, special notes or characteristics relating to the package, and a total cost summary for the package. This sheet is quite versatile and can be used for earthwork, masonry, and virtually any assembly encountered in the construction of a project. A similar sheet for earthwork is shown in Figure 13.14.

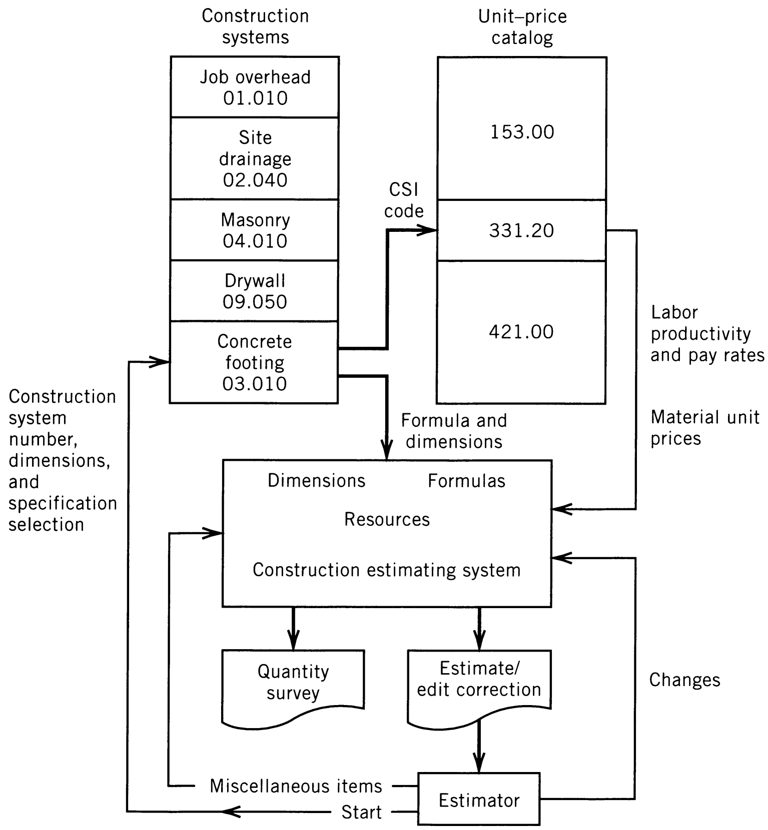


Figure 13.12 Work package concept.

WORK PACKAGE COLLECTION SHEET

System/Structure Identifier	02 • 133	Crew Level Work Package Identifier	03 • 131	Description	CONCRETE PLACEMENT, FLOAT FINISH GROUND SLAB, BUILDING 2

Permanent Materials (PM)

Resource Code	Description	Unit	QTY	Unit Cost Low	Unit Cost Target	Unit Cost High	Extension
1 3 2 5	CONCRETE, 2500 PSI	CY	135		30.90		4171.50
	+5% WASTE INCLUDED						
							4171.50

Other Materials and Supplies (M&S)

Resource Code	Description	Unit	QTY	Low	Target	High	Extension

Installed Equipment (IE)

Resource Code	Description	Unit	QTY	Low	Target	High	Extension

Crew Labor (L)

Resource Code	Description	NR.	Cost/Hour Low	Cost/Hour Target	Cost/Hour High	Extension
0 2 9 1	FOREMAN	1		10.90		87.20
0 2 9 3	LABORERS	4		10.40		332.80
0 2 9 2	FINISHER	4		12.85		411.20
						831.20

Equipment Not Charged As Job Indirects

Resource Code	Description	NR.	AVAILABILITY Periods	$/Period	USE Hours	$/Hour	Extension
7 3 1 1	VIBRATOR, GED	2			8	3.25	52.00
7 3 1 9	HAND TOOLS	1			8	1.00	8.00
7 3 1 2	FINISHER, GED	1			8	4.50	36.00
							96.00

Productivity

Base Unit for Productivity: CY CONCRETE

Total Quantity Base Unit: 128 CY

	Low	Target	High
Duration (Crew–Hours)		8	

Escalation Rates (%)

Materials

Labor

Equipment

Notes

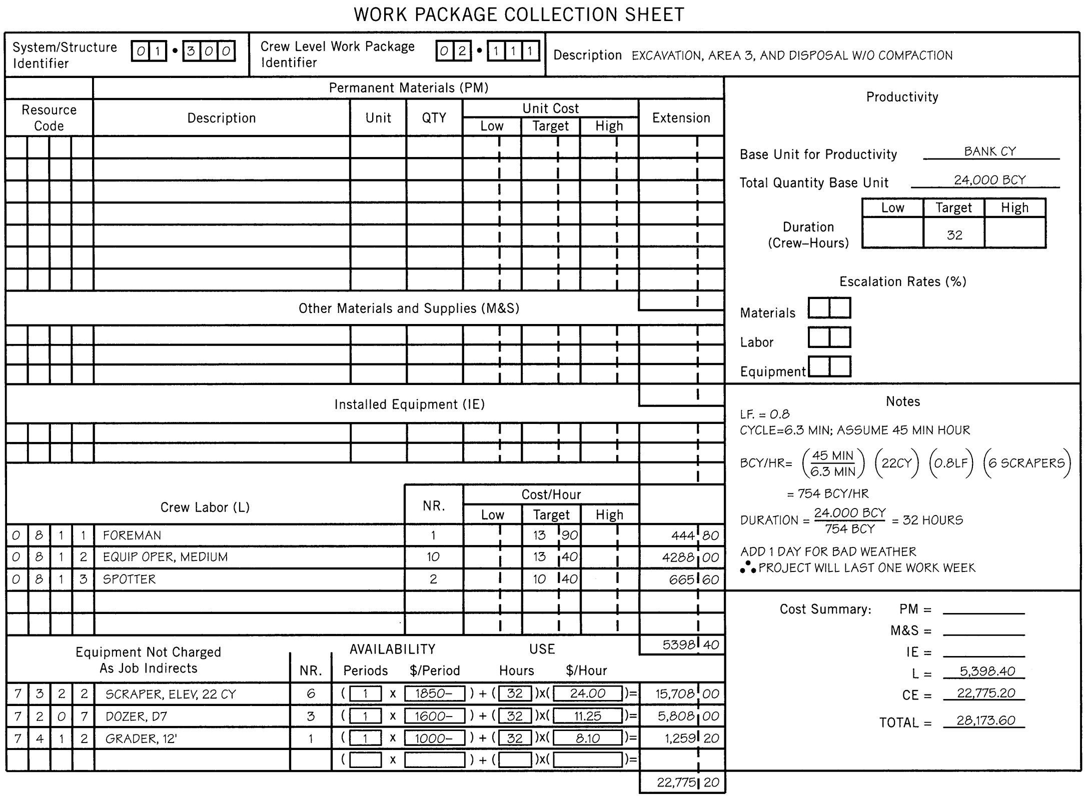
DURATION = 128 CY / 22 CY/HR. = 6 HRS

ALLOW 8 HRS WITH STARTUP AND CLEANUP

Cost Summary:

PM = 4171.50
M&S =
IE =
L = 831.20
CE = 96.00
TOTAL = 5098.70

Figure 13.13 Work package collection sheet—concrete slab (*Source:* J. M. Neil, *Construction Cost Estimating and Cost Control*, Englewood Cliffs, NJ: Prentice-Hall, 1982, p. 231).



WORK PACKAGE COLLECTION SHEET

System/Structure Identifier 01 • 300 | Crew Level Work Package Identifier 02 • 111 | Description EXCAVATION, AREA 3, AND DISPOSAL W/O COMPACTION

Permanent Materials (PM)

Resource Code	Description	Unit	QTY	Unit Cost Low	Unit Cost Target	Unit Cost High	Extension

Other Materials and Supplies (M&S)

Installed Equipment (IE)

Crew Labor (L)		NR.	Cost/Hour Low	Cost/Hour Target	Cost/Hour High	Extension
0 8 1 1	FOREMAN	1		13 90		444 80
0 8 1 2	EQUIP OPER, MEDIUM	10		13 40		4288 00
0 8 1 3	SPOTTER	2		10 40		665 60
						5398 40

Equipment Not Charged As Job Indirects		NR.	AVAILABILITY Periods	$/Period	USE Hours	$/Hour	
7 3 2 2	SCRAPER, ELEV, 22 CY	6	(1 x	1850–) + (	32)x(	24.00)=	15,708 00
7 2 0 7	DOZER, D7	3	(1 x	1600–) + (	32)x(	11.25)=	5,808 00
7 4 1 2	GRADER, 12'	1	(1 x	1000–) + (	32)x(	8.10)=	1,259 20
			(x	) + (	)x(	)=	
							22,775 20

Productivity

Base Unit for Productivity: BANK CY

Total Quantity Base Unit: 24,000 BCY

Duration (Crew–Hours)	Low	Target	High
		32	

Escalation Rates (%)

Materials

Labor

Equipment

Notes

LF. = 0.8

CYCLE=6.3 MIN; ASSUME 45 MIN HOUR

BCY/HR= $\left(\frac{45\text{ MIN}}{6.3\text{ MIN}}\right)$ (22CY) (0.8LF) (6 SCRAPERS)

= 754 BCY/HR

DURATION = $\frac{24.000\text{ BCY}}{754\text{ BCY}}$ = 32 HOURS

ADD 1 DAY FOR BAD WEATHER

∴ PROJECT WILL LAST ONE WORK WEEK

Cost Summary:

PM =

M&S =

IE =

L = 5,398.40

CE = 22,775.20

TOTAL = 28,173.60

Figure 13.14 Work package collection sheet—excavation (*Source:* J. M. Neil, *Construction Cost Estimating and Cost Control*, Englewood Cliffs, NJ: Prentice-Hall, 1982, p. 221).

13.10 SUMMARY

The estimate is the basis for the contractor's bid and, as such, has a significant effect on whether or not a given project is profitable. In building construction the four levels of estimate preparation are (1) conceptual, (2) preliminary, (3) engineer's, and (4) bid.

The first three of these estimates are typically prepared by the architect/engineer and reflect the increasing refinement of the design. Large and complex projects include a magnitude and definitive estimate in addition to those noted above. The bid estimate is a detailed estimate prepared by the contractor. The steps involved in preparing a detailed estimate are shown graphically in Figure 13.15. The project to be estimated is subdivided for cost analysis purposes into estimating accounts or work packages. Quantities for each package or account are developed. These quantities are priced, and the extensions are calculated and checked for errors. At this stage, professional judgment and engineering intuition are utilized to adjust the bid to reflect special or unique factors peculiar to the particular job. Profit margin is also applied at this point, and the bid is revised as required and finalized. Steps 3 through 6 are quantitative in nature and involve the application of formulas and arithmetical concepts. Steps 1 and 2 require professional expertise. Steps 7 and 8 require a good deal of experience and engineering judgment.

In the development of the estimate three methods are commonly used. These are:

1. Unit-pricing or catalog lookup method
2. Resource enumeration
3. Work package/assembly method

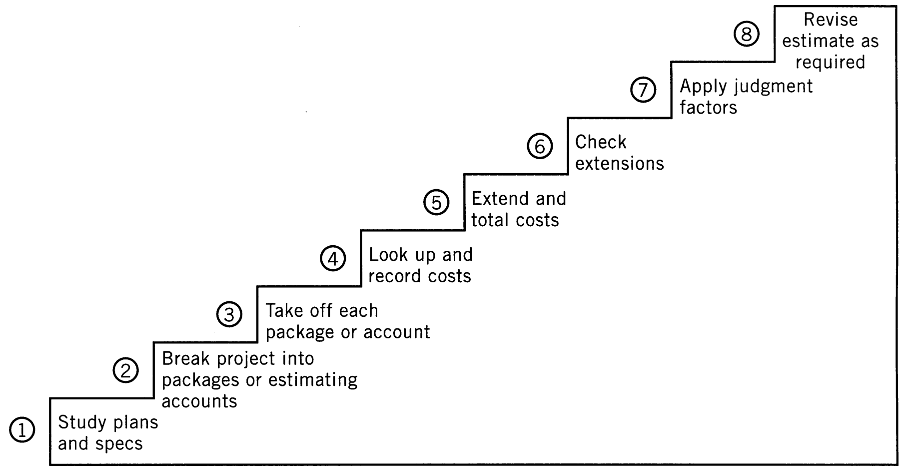


Figure 13.15 Steps in the estimating process.

The work package method can be thought of as an extension of the resource enumeration method. Different methods may be used on different parts of the job. On portions of the job that are very cost sensitive and constitute a large portion of the overall project, methods 2 and 3 may be appropriate. On parts of the work that are standard and straightforward, the unit-pricing approach is normally acceptable. Selection of methods is a tradeoff between the need for accuracy and the cost of obtaining that accuracy. The keys to a successful estimate are (1) the ability to assess the required level of accuracy and (2) the ability to achieve the required level of accuracy at minimal cost.

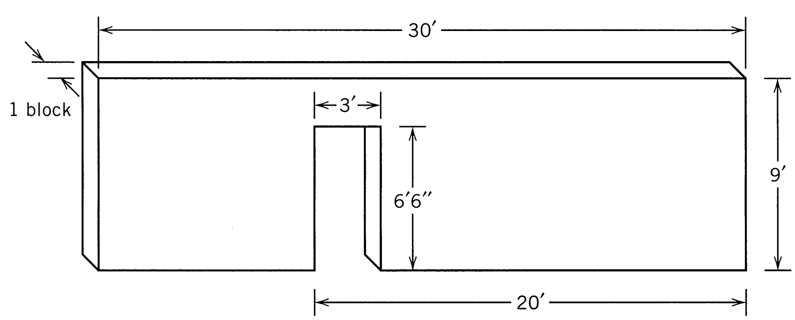
REVIEW QUESTIONS AND EXERCISES

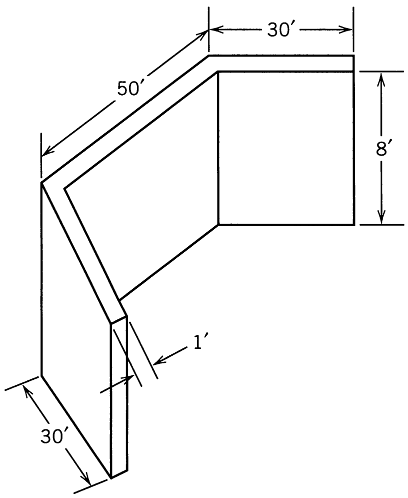
13.1 Explain the difference between unit-cost estimating methods and resource enumeration methods. When would you use unit cost? When would you use resource enumeration?

13.2 What is meant by contractor O&P? Give three components that are considered in the O&P.

13.3 What is the difference between labor cost and labor productivity? Use a sketch to illustrate.

13.4 The partition wall shown below is to be constructed of 8 × 16 × 6 block. Estimate the cost of the wall to include labor, materials, and contractor O&P using the R. S. Means building cost data or other appropriate estimating reference. The job is located in Cincinnati, Ohio.





13.5 Given the bridge abutment shown here, determine the number of man-hours required to form the structure using data from R. S. Means or other appropriate reference.

Chapter 14

Construction Labor

Biometric Identification Devices

Biometric Identification Recognition

The Need

The access control system plays a major role in site security. These days, only a few engineers and managers are needed to wholly control a 20-story building's physical security objects such as elevators, door locks, lights, security system control, etc. through computerized automatic systems. Controling and screening personnel entering a facility is almost impossible for a few security people to physically control. Even though visitors, office workers, and residents are given keys or id-tags after being screened, there is still a possibility that unauthorized people could access important property with fake id's or keys, etc. Recently, biometric technology has arisen as a new, effective, and secure method for identification recognition of personnel.

The Technology

Biometrics are computerized methods of recognizing people based on physical or behavioral characteristics. The main biometric technologies include face recognition, fingerprint, hand geometry, iris, palm prints, signature, and voice. Biometric technologies can work in two modes —authentication (one-to-one matching) and identification (one-to-many matching). However, only three biometrics are capable of the latter—face, finger and iris. This technology has great potential for controlling access to construction work sites as well as other facilities.

14.1 LABOR RESOURCE

The man-power component of the four Ms of construction is by far the most variable and unpredictable. It is, therefore, the element that demands the largest commitment of time and effort from the management team. Manpower or labor has four major aspects that are of interest to management. To properly understand the management and control of labor as a resource, the manager must be aware of the interplay among the following elements:

1. Labor organization
2. Labor law
3. Labor cost
4. Labor productivity

The cost and productivity components were central to the discussion of equipment management in Chapters 11 and 12. Labor includes the added human factor. This element can only be understood in the context of the prevailing legal and organizational climate that is characteristic of the construction industry.

14.2 SHORT HISTORY OF LABOR ORGANIZATIONS

The history of labor organizations begins in the early nineteenth century, and their growth parallels the increasing industrialization of modern society. Initially tradesmen possessing some skill or craft began organizing into groups variously called guilds, brotherhoods, or mechanics societies. Their objectives were to provide members, widows, and children with sickness and death benefits. In addition, these organizations were interested in the development of trade proficiency standards and the definition of skill levels such as apprentice and journeyman. They were often "secret" brotherhoods because such organizations were considered unlawful and illegal conspiracies posing a danger to society.

From the 1840s until the era of the New Deal[1] in the 1930s, the history of labor organizations is the saga of confrontation between management and workers, with the pendulum of power on the management side. With the coming of the New Deal and the need to rejuvenate the economy during the Depression, labor organizations won striking gains that virtually reversed the power relationship between managers and workers. The American Federation of Labor (AFL) was organized by Samuel Gompers in 1886. This was the first successful effort to organize skilled and craft workers such as cabinetmakers, leather tanners, and blacksmiths. Since its inception, the AFL has been identified with skilled craft workers as opposed to industrial "assembly line" type of workers. The Building and Construction Trades Department of the AFL, which is the umbrella organization representing all construction craft unions, was organized in 1908.

The semiskilled and unskilled factory workers in "sweat shop" plants and mills were largely unorganized at the time Gompers started the AFL. Many organizations were founded and ultimately failed in an attempt to organize the industrial worker. These organizations, with euphonious-sounding names, such as Industrial Workers of the World and the Knights of Labor, had strong political overtones and sought sweeping social reforms for all workers. This was particularly attractive to immigrant workers arriving from the socially repressive and politically stagnant atmosphere in Europe. Such organizations attracted political firebrands and anarchists preaching social change and upheaval at any cost. Confrontation with the police was common, and violent riots often led to maiming and killing. The most famous such riot occurred in the Haymarket in Chicago in 1886.

Gompers was seriously interested in protecting the rights of skilled workers and had little interest in the political and social oratory of the unskilled labor organizations. Therefore, separate labor movements representing skilled craft and semiskilled factory workers developed and did not combine until the 1930s. This led to different national and local organizational structures and bargaining procedures that are still utilized and strongly influence the labor picture even today.

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[1] The administration of President Franklin D. Roosevelt.

In the 1930s, industrial (i.e., factory semiskilled) workers began to organize effectively with the support of legislation evolving during the post-Depression period. The AFL, realizing such organizations might threaten its own dominance, recognized these organizations by bringing them into the AFL camp with the special designation of Federal Locals. Although nominally members, the industrial workers were generally treated as second-class citizens by the older and more established craft unions. This led to friction and rivalry that culminated in the formation of the Committee for Industrial Organizations (CIO). This committee was established in 1935 unilaterally by the industrial locals without permission from the governing body of the AFL. The act was labeled treasonous, and the AFL board ordered the Committee to disband or be expelled. The AFL suspended the industrial unions in 1936. In response, these unions organized as the Congress of Industrial Organizations (CIO), with John L. Lewis of the United Mine Workers as the first CIO president. Following this rift between the industrial and craft union movements, the need to cooperate and work together was apparent. However, philosophical and personal differences prevented this until 1955, at which time the two organizations combined to form the AFL–CIO. This organization remains the major labor entity in the United States today.

14.3 EARLY LABOR LEGISLATION

The courts and legislative bodies of the land have alternately operated to retard or accelerate the progress of labor organizations. The chronology of major items of legislation and the significant events in the labor movement are shown in Table 14.1. At the outset, the law was generally interpreted in order to check organization of labor and, therefore, management was successful in controlling the situation. The most classic illustration of this is the application of the Sherman Antitrust Law to enjoin workers from organizing. The Sherman Antitrust Act had originally been enacted in 1890 to suppress the formation of large corporate trusts and cartels, which dominated the market and acted to fix prices and restrain free trade. The oil and steel interests formed separate cartels in the late nineteenth century to manipulate the market. More recently, Microsoft Corporation has been reviewed by the Justice Department to prevent similar dominance in the computer market. To break up such potential market control, the Antitrust Law provides the government with the power to enjoin corporations from combining to control prices and restrict trade. In 1908 the Supreme Court ruled that the Antitrust Law could be applied to prevent labor from organizing. The argument ran roughly as follows: "If laborers are allowed to organize, they can act as a unit to fix wage prices and restrict free negotiations of wages. This is a restraint of trade and freedom within the labor market." Based on this interpretation, local courts were empowered to issue injunctions to stop labor from organizing. If a factory owner found his workers attempting to organize, he could simply go to the courts and request an injunction forbidding such activity.

In 1914, Congress acted to offset the effect of the Sherman Antitrust Act by passing the Clayton Act. This act authorized employees to organize to negotiate with a particular employer. However, in most cases the employer could demonstrate that the organizing activity was directed by parties outside the employer's shop. This implied that the action was not a local one and, therefore, was subject to action under the Sherman antitrust legislation. Therefore, the injunction remained a powerful management tool in resisting unionization.

14.4 NORRIS–LAGUARDIA ACT

The passing of the Norris–LaGuardia Act heralded the first major movement of the power pendulum away from management and toward labor. This act, sometimes referred to as the Anti-Injunction Act, accomplished what the Clayton Act had failed to do. It specifically stated that the courts could not intercede on the part of management so as to obstruct the

Table 14.1 Chronology of Labor Law and Organization

Labor Law		Labor Movement	
1890	Sherman Antitrust Act	1886	AFL founded by Samuel Gompers; Knights of Labor organized factory workers
1908	Supreme Court supported application to union activity	1905	Industrial Workers of the World
1914	Clayton Act Ineffective—individual basis—as court rules	1908	Building and Construction Trades Department of AFL founded
1931	Davis–Bacon Act On federal contracts wages and fringes paid at prevailing rate	1930s	Take in industrial workers as federal locals
1932	Norris–LaGuardia (Anti-Injunction Act)	1935	Committee for Industrial Organization-AFL ordered disbanding
1935	Wagner Act (National Labor Relations Act)	1936	Federal locals (CIO) thrown out
1938	Fair Labor Standards Act Minimum wages, maximum hours defined	1938	Congress of Industrial Organizations
1943	Smith–Connolly Act (War-Labor Disputes Act) Reaction to labor in wartime; ineffective	1940s	Wartime strikes accused of not supporting war effort Criminal activities alleged
1946	Hobbs Act—"Anti-Racketeering law" Protects employer from paying kickbacks to labor	1955	AFL and CIO reconcile differences and recombine as AFL–CIO
1947	Taft–Hartley (Labor Management Relations Act)		
1959	Landrum–Griffin Act (Labor Management Reporting and Disclosures)		
1964	Title IV Civil Rights Act		

formation of labor organizations. It effectively overrode the Supreme Court interpretation that the Sherman Antitrust Act could be applied to labor organizations. It curtailed the power of the courts to issue injunctions and protected the rights of workers to strike and picket peaceably. It also outlawed the use of "yellow-dog" contracts on the part of management. It was a common practice to have an employee sign a contract upon being hired in which he agreed not to join or become active in any union organization. Such yellow-dog contracts were declared illegal by the Norris–LaGuardia Act. This piece of legislation as interpreted by the Supreme Court during the period of the New Deal effectively freed labor from the constraints of the Sherman Antitrust Act.

14.5 DAVIS–BACON ACT

In 1931, a very far-reaching piece of legislation was passed that even today has a significant impact on the cost of federally funded projects throughout the United States. The Davis–Bacon act provides that wages and fringe benefits on all federal and federally funded projects shall be paid at the "prevailing" rate in the area. The level of prevailing rates is established by the secretary of labor, and a listing of these rates is published with the contract documents so that all contractors will be aware of the standards. To ensure that these rates are paid, the government requires submittal by all contractors of a certified payroll each month to the federal agency providing the funding. These rates are reviewed to determine whether any violations of the Davis–Bacon pay scale have occurred. This act is so far-reaching in its effect because much of public construction at the state and local level may be funded in part by federal grants. A large municipal mass-transit system or wastewater treatment plant, for instance, may be funded in part by a federal agency. In such cases, the prevailing rates must be paid. Since the Department of Labor generally accepts the most recently negotiated *union contract rates* as the prevailing ones, this allows union contractors to bid without fear of being underbid by nonunion contractors paying lower wage rates.

14.6 NATIONAL LABOR RELATIONS ACT

The National Labor Relations Act, also referred to as the Wagner Act, is a landmark piece of legislation that established a total framework within which labor management relations are to be conducted. Its central purposes are to protect union-organizing activity and encourage collective bargaining. Employers are required to bargain in good faith with the properly chosen representatives of the employees. Among other things, it establishes the procedures by which labor can organize and elect representatives. Discrimination against an employee for labor-organizing activities or participation in a union is forbidden by this act.

Employer unfair labor practices defining precisely what actions are not acceptable in management dealings with labor are specified. These practices are summarized in Table 14.2. Comparable unfair practices on the part of labor in dealing with management were not defined. It was assumed that labor was the abused party and would act equitably in its dealings with management. This trust had to be specifically spelled out later in the Taft–Hartley Act.

The act also established a "watch dog" organization to ensure its provisions were properly administered. This organization is the National Labor Relations Board (NLRB). The NLRB acts as the clearinghouse for all grievances and issues leading to complaints by labor against management and vice-versa. It is the highest tribunal below the Supreme Court for settling labor disputes and rules on most issues affecting labor–management relationships.

The act also established the concept of a *closed shop*. For years, labor organizations had fought for the right to force all members of a particular work activity (shop) to be members of a union. If the majority voted for union membership, then in order to work in the shop, a new employee had to belong to the union. This is in contrast to the *open shop* in which employees are not organized and do not belong to a union. The Wagner Act endorsed the concept of the closed shop and made it legal. This concept was later revoked by the Taft–Hartley Act and replaced by the *union shop*. The closed shop was attacked as illegal since it infringed upon a person's "right to work" and freedom of choice regarding union membership. The union shop will be discussed later in the section on the Taft–Hartley Act.

14.7 FAIR LABOR STANDARDS ACT

The Fair Labor Standards Act is commonly referred to as the minimum wage law. It was originally passed in 1938 and establishes the minimum wages and maximum hours for all workers. The minimum wage level is periodically changed to be consistent with changing wage rates. The law defines the 40-hour workweek and time over this amount as overtime. It is, generally, an outgrowth of the child labor abuses that occurred in the nineteenth century. It also forbids discrimination by establishing the concept of "equal pay for equal work." Recent arguments against increasing the minimum wage have hinged on the ideas that certain menial and domestic tasks that could provide unskilled workers with employment have become so expensive that it no longer is reasonable to perform them. The clearing of

Table 14.2 Employer Unfair Labor Practices

Under the National Labor Relations Act, as amended, an employer commits an unfair labor practice if he:

1. Interferes with, restrains, or coerces employees in the exercise of rights protected by the act, such as their right of self-organization for the purposes of collective bargaining or other mutual assistance {Section 8(a)(1)}.
2. Dominates or interferes with any labor organization in either its formation or its administration or contributes financial or other support to it {Section 8(a)(2)}. Thus "company" unions dominated by the employer are prohibited, and employers may not unlawfully assist any union financially or otherwise.
3. Discriminates against an employee in order to encourage or discourage union membership {Section 8(a)(3)}. It is illegal for an employer to discharge or demote an employee or to single him out in any other discriminatory manner simply because he is or is not a member of a union. In this regard, however, it is not unlawful for employers and unions to enter into compulsory union-membership agreements permitted by the National Labor Relations Act. This is subject to applicable state laws prohibiting compulsory unionism.
4. Discharges or otherwise discriminates against an employee because he has filed charges or given testimony under the act {Section 8(a)(4)}. This provision protects the employee from retaliation if he seeks help in enforcing his rights under the act.
5. Refuses to bargain in good faith about wages, hours, and other conditions of employment with the properly chosen representatives of his employees {Section 8(a)(5)}. Matters concerning rates of pay, wages, hours, and other conditions of employment are called mandatory subjects, about which the employer and the union must bargain in good faith, although the law does not require either party to agree to a proposal or to make concessions.
6. Enters into a hot-cargo agreement with a union {Section 8(e)}. Under a hot-cargo agreement, the employer promises not to do business with or not to handle, use, transport, sell, or otherwise deal in the products of another person or employer. Only in the garment industry and the construction industry (to a limited extent) are such agreements now lawful. This unfair labor practice can be committed only by an employer and a labor organization acting together.

Source: From Clough and Sears, *Construction Contracting,* 6th ed., John Wiley & Sons, New York, 1994.

refuse and cutting of grass along roadways were done in former times by hand labor at low wages. Increasing minimum wages make this too expensive.

14.8 UNION GROWTH

Under the provisions of the union legislation of the 1930s, the labor unions began to flourish. As is often the case during periods of transition, where inflexible barriers previously existed, a vacuum in favor of labor developed. The hard line of management was broken, and labor rushed in to organize and exploit the new situation. Along with the benefits accruing to the worker from these events, the inevitable abuses of the unstructured and unrestricted growth soon became apparent. In 1938, the unbridled actions of the unions and their leaders started to swing public opinion against them. Some unions flaunted their newfound power by introducing *restrictive labor practices* and *wartime strikes,* which shut down plants producing critical military supplies. Criminal activities within the unions were widespread and virtually unchecked. In 1943, Congress responded to this changing public perception of unions by passing the War Labor Disputes Act (Smith Connolly Act). This reflected public displeasure with the high-handed tactics and unpatriotic stance of the labor unions. It was designed to limit strikes in critical wartime industries and expedite settlement of disputes. It was largely ineffective but did reflect increasing public support of legislation that would control the prerogatives of labor unions. By 1947, thirty-seven states had enacted some form of labor control bill.

The inroads made by criminal elements active in union activities were recognized by the Hobbs (Anti-Racketeering) Act of 1946. This legislation was enacted to protect employers from threats, force, or violence by union officials extorting payments for "services rendered." Payments requested included commissions for various types of aid and assistance, gifts for controlling labor trouble, and equipment rentals forced on the employers at exorbitant costs. These laws and the continuing difficulties developing from abuse of power on the part of unions set the stage for the enactment of the Taft–Hartley Act of 1947.

14.9 LABOR MANAGEMENT RELATIONS ACT

The Labor Management Relations (Taft–Hartley) Act together with the Wagner Act form the two cornerstones of American labor relations legislation. The Taft–Hartley Act amended the Wagner Act and reversed the swing of the power pendulum once more, still leaving labor in a very strong position, but pushing the pendulum more toward center. It is the first post-Depression law to place effective constraints on the activities of labor. It restructured the makeup and operation of the NLRB, attempting to give management a stronger voice and to balance representation of labor and management. Section 7 of the bill defines the rights of workers to participate in or refrain from union activities. Section 8 provides the counterpoint to the Employer Unfair Practices Section of the Wagner Act. It defines *Union Unfair Labor Practices*, which specify tactics on the part of the labor that are illegal (see Table 14.3). The law also established the Federal Mediation and Conciliation Service, which acts as a third party in trying to expedite a meeting of the minds between unions and management involved in a dispute. This service has been very visible in meeting with representatives of players unions and sports team owners in order to work out the terms of player contracts.

Under the Taft–Hartley legislation, the president is empowered to enjoin workers on strike (or preparing to strike) to work for an 80-day cooling-off period during which time negotiators attempt to reach agreement on contractual or other disputes. This strike moratorium may be invoked in industries where a strike endangers the health of the national economy. The President has utilized his powers under this provision of the law on numerous occasions since 1947.

Section 14(b) is significant in that it redefines the legality of closed-shop operations and defines the *union shop*. A totally closed shop is one in which the worker must be a union member before he or she is considered for employment. As already stated this is declared illegal by the Taft–Hartley Act. The union shop *is* legal. A union shop is one in which a nonmember can be hired. The worker is given a grace period (usually 30 days in manufacturing shops and a shorter period in the construction industry), during which time he or she must become a union member. If the new employee does not become a member, the union can request that the candidate employee be released. Under the closed-shop concept, it was much easier for the unions to block a worker from gaining employment. This could be used to discriminate against a potential employee. The union shop gives the worker a chance to join the union (see Fig. 14.1). If the worker requests membership and the union refuses after 30 days,[2] management can ask the union to show cause why the employee has not been admitted to membership.

[2] The period shown in Figure 14.1 is 7 days. This is typical in the construction industry and recognizes the more transient nature of construction work.

Table 14.3 Union Unfair Labor Practices

Under the National Labor Relations Act, as amended, it is an unfair labor practice for a labor organization or its agents:

1. **a.** To restrain or coerce employees in the exercise of their rights guaranteed in Section 7 of the Taft–Hartley Act {Section 8(b)(1)(A)}. In essence Section 7 gives an employee the right to join a union or to assist in the promotion of a labor organization or to refrain from such activities. This section further provides that it is not intended to impair the right of a union to prescribe its own rules concerning membership.
   b. To restrain or coerce an employer in his selection of a representative for collective bargaining purposes {Section 8(b)(1)(B)}.
2. To cause an employer to discriminate against an employee in regard to wages, hours, or other conditions of employment for the purpose of encouraging or discouraging membership in a labor organization {Section 8(b)(2)}. This section includes employer discrimination against an employee whose membership in the union has been denied or terminated for cause other than failure to pay customary dues or initiation fees. Contracts or informal arrangements with a union under which an employer gives preferential treatment to union members are violations of this section. It is not unlawful, however, for an employer and a union to enter an agreement whereby the employer agrees to hire new employees exclusively through a union hiring hall so long as there is no discrimination against nonunion members. Union security agreements that require employees to become members of the union after they are hired are also permitted by this section.
3. To refuse to bargain in good faith with an employer about wages, hours, and other conditions of employment if the union is the representative of his employees {Section 8(b)(3)}. This section imposes on labor organizations the same duty to bargain in good faith that is imposed on employers.
4. To engage in, or to induce or encourage others to engage in, strike or boycott activities, or to threaten or coerce any person, if in either case an object thereof is:
   a. To force or require any employer or self-employed person to join any labor or employer organization, or to enter into a hot-cargo agreement that is prohibited by Section 8(e) {Section 8(b)(4)(A)}.
   b. To force or require any person to cease using or dealing in the products of any other producer or to cease doing business with any other person {Section 8(b)(4)(B)}. This is a prohibition against secondary boycotts, a subject discussed further in Section 14.18 of this text. This section of the National Labor Relations Act further provides that, when not otherwise unlawful, a primary strike or primary picketing is a permissible union activity.
   c. To force or require any employer to recognize or bargain with a particular labor organization as the representative of his employees that has not been certified as the representative of such employees {Section 8(b)(4)(C)}.
   d. To force or require any employer to assign certain work to the employees of a particular labor organization or craft rather than to employees in another labor organization or craft, unless the employer is failing to conform with an order or certification of the NLRB {Section 8(b)(4)(D)}. This provision is directed against jurisdictional disputes, a topic discussed in Section 14.12 of this text.
5. To require of employees covered by a valid union shop membership fees that the NLRB finds to be excessive or discriminatory {Section 8(b)(5)}.
6. To cause or attempt to cause an employer to pay or agree to pay for services that are not performed or not to be performed {Section 8(b)(6)}. This section forbids practices commonly known as featherbedding.
7. To picket or threaten to picket any employer to force him to recognize or bargain with a union:
   a. When the employees of the employer are already lawfully represented by another union {Section 8(b)(7)(A)}.
   b. When a valid election has been held within the past 12 months {Section 8(b)(7)(B)}.
   c. When no petition for a NLRB election has been filed within a reasonable period of time, not to exceed 30 days from the commencement of such picketing {Section 8(b)(7)(C)}.

Source: From Clough and Sears, *Construction Contracting,* 6th ed., John Wiley & Sons, New York, 1994.

All present employees who are members of the Union on the effective date of this agreement shall be required to remain members in good standing of the Union as a condition of their employment.

All present employees who are not members of the Union shall, from and after the 7th day following the date of execution of this agreement, be required to become and remain members in good standing of the Union as a condition of their employment.

All employees who are hired thereafter shall be required to become and remain members in good standing of the Union as a condition of their employment from and after the 7th day of their employment or the effective date of this Agreement, whichever is later, as long as Union membership is offered on the same terms as other members.

Any employee who fails to become a member of the Union or fails to maintain his membership therein in accordance with provisions of the paragraphs of this Section, shall forfeit his rights of employment and the employer shall within two (2) working days of being notified by the Union in writing as to the failure of an employee to join the Union or maintain his membership therein, discharge such employee. For this purpose, the requirements of membership and maintaining membership shall be consistent with State and Federal Laws. The Employer shall not be deemed in default unless he fails to act within the required period after receipt of registered written notice.

(Excerpted from Agreement Between Central Illinois Builders and The United Brotherhood of Carpenters and Joiners of America Local Union No. 44, Champaign-Urbana, Illinois.)

Figure 14.1 Contract typical member clause.

The law also recognizes the concept of "agency" shop. In such facilities a worker can refuse to join the union. The employee, therefore, has no vote in union affairs. The worker must, however, pay union dues since he or she theoretically benefits from the actions of the union and the union acts as his or her "agent." If the union, for instance, negotiates a favorable pay increase, all employees benefit and all are required to financially support the labor representation (i.e., the union negotiators).

Because of the way in which the law regarding closed shop under the Wagner Act was implemented, many workers felt that their constitutional right to work was being abrogated. That is, unless they were already union members, they were not free to work in certain firms. They had no choice. They were forced to either join the union or go elsewhere. The Taft–Hartley Act allows the individual states to enact right-to-work laws that essentially forbid the establishment of totally union shops. States in the South and the Southwest where unions are relatively weak have implemented this feature at the state level. Clough and Sears explain this as follows.

> *Section 14(b) of the Taft–Hartley Act provides that the individual states have the right to forbid negotiated labor agreements that require union membership as a condition of employment. In other words, any state or territory of the United States may, if it chooses, pass a law making a union-shop labor agreement illegal. This is called the "right-to-work" section of the act, and such state laws are termed right-to-work statutes. At the present writing, 21 states have such laws in force.*[3] *It is interesting to note that most of these state right-to-work laws go beyond the mere issues of compulsory unionism inherent in the union shop. Most of them outlaw the agency shop, under which nonunion workers must pay as a condition of continued employment the same initiation fees, dues, and assessments as union*

[3] Alabama, Arizona, Arkansas, Florida, Georgia, Idaho, Iowa, Kansas, Louisiana, Mississippi, Nebraska, Nevada, North Carolina, North Dakota, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, and Wyoming now have right-to-work legislation in effect.

employees, but are not required to join the union. Some of the laws explicitly forbid unions to strike over the issue of employment of nonunion workers.[4]

The fact that a right-to-work provision has been implemented can be detected by reading the language of the labor agreements within a given state. In states in which no right-to-work law is in effect, a clause is included indicating that a worker must join the union within a specified period. Such a clause taken from an Illinois labor contract is shown in Figure 14.1. This clause would be illegal in Georgia.

14.10 OTHER LABOR LEGISLATION

The Labor Management Reporting and Disclosure (Landrum–Griffin) Act was passed in 1959 to correct some of the deficiencies of previous legislation. Among its major objectives were (1) the protection of the individual union member, (2) improved control and oversight of union elections, and (3) an increased government role in auditing the records of unions. Misappropriation of union funds by unscrupulous officials and apparent election fraud were the central impetus in enacting this law. Under this law, all unions must periodically file reports with the Department of Labor regarding their organization finances and other activities. The act provides that employers cannot make payments directly to union officials. They can, however, pay dues and fringe benefits to qualified funds of the union for things such as health and welfare, vacation, apprenticeship programs, and the like. Records regarding these funds are subject to review by government auditors.

Title IV of the Civil Rights Act (enacted in 1964) establishes the concept of equal employment opportunity. This legislation was expanded by the Civil Right Act of 1991. It forbids discrimination on the basis of race, color, religion, sex, or national origin. It is administered by the Equal Employment Opportunity Commission (EEOC) and applies to discrimination in hiring, discharge, conditions of employment, and classification. Its application in the construction industry has led to considerable controversy. Individual workers can file an *unfair labor practice charge* against a union because of alleged discrimination. Unions found guilty face *cease-and-desist* orders as well as possible recision of their mandate to act as the authorized employee representative.

Executive Order 11246 issued by President Johnson in 1965 further amplified the government position on equal opportunity. It establishes affirmative action requirements on all federal government or federally funded construction work. It is administered by the Office of Federal Contract Compliance (OFCC). This office is instrumental in establishing the level of minority participation in government work. It has spawned a number of plans for including minority contractors in federally funded projects. Executive Order 11375 (1968) extends Order 11246 to include sex discrimination. Contractors working on federally funded work are required to submit affirmative action reports to the OFCC. If the plan is found to be deficient, the OFCC can suspend or terminate the contract for noncompliance.

14.11 VERTICAL VERSUS HORIZONTAL LABOR ORGANIZATION STRUCTURE

The traditional craft unions are normally referred to as horizontally structured unions. This is because of the strong power base that is located in the union local. Contract negotiations are conducted at the local level and all major decisions are concentrated at the local level. Construction unions are craft unions with a strong local organization. The local normally is run on a day-to-day basis by the *business agent*. Representatives at the individual job sites are called job stewards. The local elects officers and a board of directors on a periodic basis. The local president and business agent may be the same individuals. The bylaws of the local define the organizational structure and particulars of union structure. At the time

[4] R. H. Clough and G. A. Sears, *Construction Contracting,* 6th ed., John Wiley & Sons, New York, 1994, p. 372.

of contract negotiations, representatives from the local meet with representatives of the local union contractors to begin discussions. The Associated General Contractors (AGC) in the local area often act as the contractor's bargaining unit. This horizontal structure leads to a proliferation of contracts and a complex bargaining calendar for the contractors' association. If a contractors' group generally deals with 12 craft unions in the local area and renegotiates contracts on an annual or biennial basis, it is obvious that the process of meeting and bargaining can become complicated. Contracts are signed for each union operating in a given area. The national headquarters organizations for construction craft unions normally coordinate areas of national interest to the union, such as congressional lobbying, communication of information regarding recently negotiated contracts, national conventions, printing of newsletters and magazines, seminars, workshops, and other general activities. The real power in most issues, however, is concentrated at the local level. The horizontal organization then is similar to a confederation, with strength at the bottom and coordination at the top.

Vertically structured unions tend to concentrate more of the power at the national level. Significantly, labor contracts are negotiated at the national level. This means a contract is signed at the national level covering work throughout the country. This is considerably more efficient than the hundreds of locally negotiated contracts that are typical of horizontally structured unions. The industrial unions of the CIO have traditional organization in a vertical structure, while the construction unions of the AFL maintain the strong local horizontal structure. The construction elements within industrial unions usually follow the example of the parent union. The construction workers of the United Mine Workers (UMW) are an example of this. They sign a single contract with the mine owners covering all of the crafts from operating engineers to electricians. A list of scales covering all specialties (i.e., craft disciplines) is contained in the national contract. Since the members of the union are mine construction workers first and carpenters, operators, or electricians second, the jealousy regarding so-called craft lines and jurisdiction is less pronounced. It is not uncommon to see an equipment operator in a vertically structured union get down from a tractor and do some small carpentry. This would be impossible in a horizontally organized craft union situation because the carpenters would immediately start a jurisdictional dispute.

14.12 JURISDICTIONAL DISPUTES

In addition to the fragmentation of contracts by craft and local area, one of the major difficulties inherent in the horizontal craft structured union is the problem of craft jurisdiction. Job jurisdiction disputes arise when more than one union claims jurisdiction over a given item of work. This is true primarily because many unions regard a certain type of work as a proprietary right and jealously guard against any encroachment of their traditional sphere by other unions. As technology advances and new products are introduced, the question of which craft most appropriately should perform the work involved inevitably arises. A classical example in building construction is provided by the introduction of metal window and door frames. Traditionally, the installation of windows and doors had been considered a carpentry activity. However, the introduction of metal frames led to disputes between the carpenters and the metal workers as to which union had jurisdiction in the installation of these items. Such disputes can become very heated and lead to a walkout by one craft or the other. This may shut down the job. The contractor is sometimes simply an innocent bystander in such instances. If these disputes are not settled quickly, the repercussions for client and contractor can be very serious, as indicated by the following excerpt from the *Engineering News Record*:

> *The nozzle-dispute on the $1-billion Albany, N.Y., mall project has caused hundreds of stoppages on that job, which employs over 2,000 persons. The argument revolves around whether the teamster driving a fuel truck or the operating engineer running a machine shall*

hold the nozzle during the fueling operation. Both unions claim the job. Because holding the nozzle involves a certain amount of work, the question is why either union should want it, since regardless of which man does the job, the other still gets paid. The answer undoubtedly is that the union that gets jurisdiction will eventually be able to claim the need for a helper. This particular dispute has been reported as plaguing contractors in many states, including West Virginia, Oklahoma, Missouri, California and Washington.[5]

Although this is a rather extreme example, it is indicative of the jealousies that can arise between crafts.

Concern on the part of unions for jurisdiction is understandable since rulings that erode their area of work ultimately can lead to the craft slowly dwindling into a state of reduced work responsibilities and, eventually, into extinction. Therefore, the craft unions jealously protect their craft integrity. The following clause from a contract indicates how comprehensive the definition of craft responsibility can become.

Scope of Work

This Agreement shall cover all employees employed by the Employer engaged in work coming under all classifications listed under the trade autonomy of the United Brotherhood of Carpenters and Joiners of America.

The trade autonomy of the United Brotherhood of Carpenters and Joiners of America consists of the milling, fashioning, joining, assembling, erection, fastening or dismantling of all material of wood, plastic, metal, fiber, cork and composition, and all other substitute materials and the handling, cleaning, erecting, installing and dismantling of machinery, equipment and all materials used by members of the United Brotherhood.

Our claim of jurisdiction, therefore, extends over the following divisions and sub-divisions of the trade: Carpenters and Joiners; Millwrights; Pile Drivers; Bridge, Dock and Wharf Carpenters; Divers; Underpinners; Timbermen and Core Drillers; Shipwrights, Boat Builders, Ship Carpenters, Joiners and Caulkers; Cabinet Makers, Bench Hands, Stair Builders, Millmen; Wood and Resilient Floor Layers, and Finishers; Carpenter Layers; Shinglers; Siders; Insulators; Acoustic and Dry Wall Applicators; Shorers and House Movers; Loggers, Lumber and Sawmill Workers; Furniture Workers, Reed and Rattan Workers; Shingle Weavers; Casket and Coffin Makers; Box Makers, Railroad Carpenters and Car Builders, regardless of material used; and all those engaged in the operation of woodworking or other machinery required in the fashioning, milling or manufacturing of products used in the trade, or engaged as helpers to any of the above divisions or subdivisions' burning, welding, rigging and the use of any instrument or tool for layout work incidental to the trade. When the term "carpenter and joiner" is used, it shall mean all the subdivisions of the trade. The above occupational scope shall be subject to all agreements between International Representatives.[6]

Jurisdictional disputes present less problem in vertically structured unions since craft integrity is not a matter that determines the strength of the union. All major automobiles are assembled by members of the United Automobile Workers (UAW). The UAW is a typical vertically structured union. Technological changes do not mean the work could be shifted to another union. Therefore, UAW workers can be installing windows today and can be moved to installation of electrical wiring next month. Craft integrity does not have to be jealously protected.

European construction workers are organized into vertically structured unions. National agreements in countries such as Germany cover all workers and are signed periodically defining wage scales and general labor management procedures. Each worker has a primary

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[5] "Law Productivity: The Real Sin of High Wages," *Engineering News Record,* February 24, 1972.

[6] Excerpted from Agreement Between The United Brotherhood of Carpenters and Joiners of American Local No. 44 Champaign-Urbana, Illinois, and the Central Illinois Builders Chapter of Associated General Contractors of America.

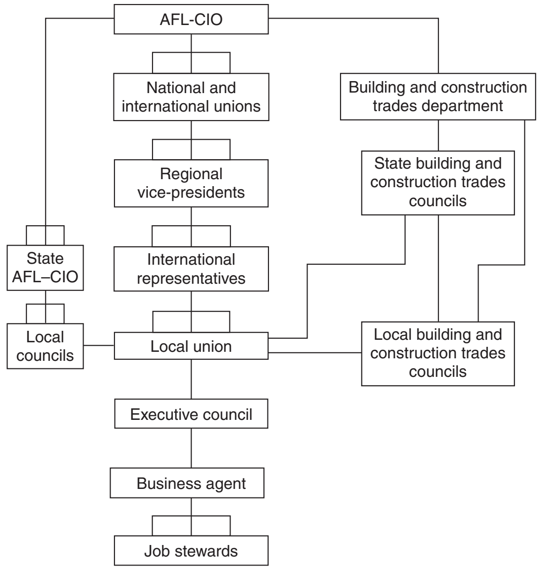

Figure 14.2 Structure typical of an affiliate of the Building and Construction Trades Department, AFL–CIO.

specialty and is paid at the rate established in the national agreement. Since craft jurisdiction is not a major issue, it is not unusual to see a worker who is operating a backhoe get down and work as part of a crew installing shoring. Similar mobility back and forth across craft lines is common in the United Mine Workers since it is also vertically structured.

14.13 UNION STRUCTURE

The largest labor organization in the United States is the AFL–CIO. The building and construction trade unions are craft unions and as such are affiliates of the Building and Construction Trades Department of the AFL–CIO. The structure of affiliates from local to national level is shown schematically in Figure 14.2. A list of the construction unions that are within the AFL–CIO is given in Table 14.4. Most construction-related unions are presently affiliated with the AFL–CIO.

There are two ways a national union may join the AFL–CIO. The first is for an already established union to apply for a charter. The other is for the federation to create a new union from a related group of locals that are not members of any national union but are directly associated with the AFL–CIO.

The top governing body of the AFL–CIO is the biennial convention. Between conventions, the executive council runs the affairs of the federation. The members are the president, secretary-treasurer, and several vice-presidents elected by the majority at the convention (usually from among the presidents of the national unions). The president has the authority to rule on any matters concerning the constitution or a convention decision between meetings of the council.

The AFL–CIO maintains trade departments at the level directly below the executive council. The mission of these major sections is to further unionization in the appropriate industry or trade. They also aid in the settlement of jurisdictional disputes between the members in their department. Disputes with a union in another department are appealed to the executive council. Departments also represent their members before Congress and other government agencies. The Building and Construction Trades Department is responsible for all construction craft unions.

Table 14.4 AFL–CIO Construction Unions

1.	International Association of Bridge, Structural, Ornamental, and Reinforcing Iron Workers
2.	International Association of Heating and Frost Insulators and Asbestos Workers
3.	International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers, and Helpers
4.	International Brotherhood of Electrical Workers
5.	International Brotherhood of Painters, and Allied Trades
6.	International Union of Bricklayers and Allied Craft Workers
7.	International Union of Elevator Constructors
8.	International Union of Operating Engineers
9.	Laborers International Union of North America
10.	Operative Plasterers and Cement Masons' International Association
11.	Sheet Metal Workers' International Association
12.	United Association of Journeymen and Apprentices of the Plumbing and Pipe Fitting Industry of the United States and Canada
13.	United Brotherhood of Carpenters and Joiners of America
14.	United Union of Roofers, Water proofers and Allied Workers

14.14 NATIONAL UNIONS

National unions are defined as those unions having collective bargaining agreements with different employers in more than one state and federal employee unions with exclusive bargaining rights. Because of their assumed role of collective bargaining in many areas, the national unions have become increasingly powerful. In construction unions, however, the locals still play the most important role in collective bargaining and, therefore, power still resides at the local level.

Each union has exclusive jurisdiction to function as the workers' representative in its trade or branch of industry. The jurisdiction of most unions is at least partially set forth in their charter and constitution. As the unions' outlook and purposes have changed or as their members' jobs have altered, many unions have changed their jurisdiction as well.

The daily conduct of union business is in the hands of the national president, whose influence is a big factor in deciding what issues the union executive board will discuss and vote on. What the president decides will have an effect on the general public as well as on the union. The president's more important powers are to decide on constitutional matters, issue or revoke local charters, hire or fire union employees, and sanction strikes. Most actions involving the powers of the president can be appealed to the board or to the convention.

The organizer or representative of the union provides contact between the locals and the national headquarters and attempts to gain new members for the union and to set up new locals. The organizer is the union advisor to all of the locals within his area and must explain national policies to them. At the same time, he informs the national level of local problems.

14.15 STATE FEDERATIONS AND CITY CENTRALS

State federations are concerned mostly with lobbying for needed legislation and public relations on the state level. They are composed of locals whose national union is a member of the AFL-CIO. Conventions are held annually where programs of interest to all of the state's workers are concerned.

City centrals are concerned more with economics, serving as a clearinghouse for locals and aiding in dealings with employers. They have become increasingly involved in general community affairs and activities that may indirectly benefit their members.

Joint boards and trade councils are composed of locals involved in similar trades or industries. Their principal duty is to ensure that workers present a unified front in collective bargaining and obtain uniform working conditions in their area. A joint board or council is usually required for unions with more than three locals in the same region. The joint board is made up of all locals of the same national union, while the trades council is composed of locals of different national unions in related trades in the same industry.

The prototype for local trades councils is the Building and Construction Trades Council, which has its higher-level counterpart in the Building and Construction Trades Department of the AFL–CIO. Its problems are not limited to labor–management relations; it is often involved in settling ticklish jurisdictional disputes. The Building and Construction Trades Council provides craft unions with an important advantage characteristic to the industrial unions: the ability to present a united front in dealings with management. Some councils negotiate city-wide agreements with employers or see that the agreements of their member locals all expire on the same date. They have a great deal of influence with the locals but may not make them act against national union policy.

14.16 UNION LOCALS

The locals are the smallest division of the national union. They provide a mechanism through which the national union can communicate with its members at the local level. Locals provide for contact with other workers in the same trade and are a means by which better working conditions are obtained, grievances are settled, and educational and political programs are implemented. They may be organized on an occupational or craft basis or on a plant or multiplant basis. In the building industry, it is common to have locals for each craft in large cities. The local officials who preside over the committees and the general meeting are the president, vice-president, treasurer, and various secretaries. They are usually unpaid or paid only a small amount and continue to work at their trade. They perform their union duties in their spare time. In small locals, a financial secretary will take care of the local books and records; but in large locals a trained bookkeeper is employed for this purpose.

The most important local official is the business agent, a full-time employee of the local. He exercises a great deal of leadership over the local and its affairs through the advice he provides to the membership and elected officials. He is usually trained and experienced in labor relations and possesses a large amount of knowledge of conditions on which other members are poorly informed.

The business agent's duties cover the entire range of the local's activities. He helps settle grievances with employers, negotiates agreements, points out violations of trade agreements, and operates the union hiring hall. He is also an organizer, trying to get unorganized workers into the union. Only locals with a large membership can afford a full-time agent, and over one-half of the locals employing agents are in the building trades where there is a greater need due to the transient nature of the work. For the locals who do not have enough money to employ their own business agent, an agent is usually maintained by the city central or state federation.

The shop steward is not a union official but is the representative who comes in closest contact with the members. He must see that union conditions are maintained on the job and handle grievances against the employer. The steward is a worker on the job site elected by his peers.

14.17 UNION HIRING HALLS

One of the salient features of construction labor is its transient nature. Construction workers are constantly moving from job site to job site and company to company. It is not uncommon for a construction worker to be employed by five or six different contractors in the same year. The union hiring hall provides a referral service that links available labor with contractor's requests. Following each jobs, a worker registers with the union hall and is referred to a new job site as positions become available. The procedures governing operation of the union hiring hall constitute an important part of the agreement between the union and the contractor. Articles of the labor contract specify precisely how the hiring hall is to operate. Although there are small variations from craft to craft and region to region, similar procedures are commonly used for referring workers through the union hall.

14.18 SECONDARY BOYCOTTS

The legality of boycotts to influence labor disputes has been an issue of primary importance throughout the history of labor–management relations. A boycott is an action by one party to exert some economic or social pressure on a second party with the intent of influencing the second party regarding some issue. A *secondary* boycott is one in which party A who has a dispute with party B attempts to bring pressure on B by boycotting party C who deals with B and who can bring strong indirect pressure on B to agree to some issue. This is shown schematically in Figure 14.3. If the electrical workers in a plant fabricating small appliances go to the factory and form a picket line to get an agreement, there is a primary boycott in progress. If, however, the workers send some of their members into the town and put pickets up at stores selling appliances from the plant, a secondary boycott is established. The store owners are a third party (C) being pressured to influence the factory to settle with the workers. The Taft–Hartley Act declared the use of a secondary boycott to be illegal.

In the construction industry, such secondary boycotts occur on sites with both union and nonunion workers when a union attempts to force a nonunion subcontractor to sign a union contract. In such cases, the union will put up a picket line at the entrance to the work site, in effect, to picket or boycott the nonunion subcontractor. Tradition among labor unions, however, demands that no union worker can cross another union's picket line. Therefore, the actual effect of the union picket line will be to prevent all union workers from entering the site. This may cause the shutdown of the entire site pending resolution of the nonunion subcontractor's presence on the site. In this situation, the general or prime contractor is a

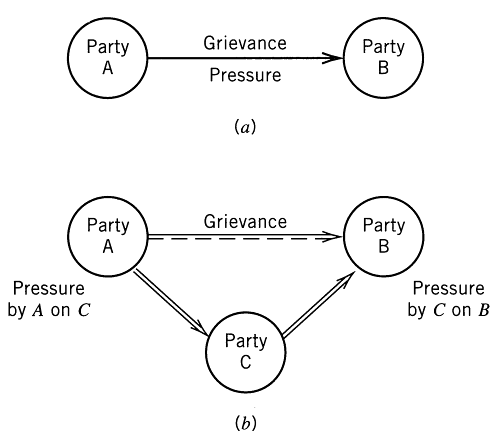

Figure 14.3 Types of boycotts: (*a*) primary boycott and (*b*) secondary boycott.

third party being pressured by the union to influence the nonunion subcontractor. This is called *common situs* picketing. In 1951, the U.S. Supreme Court ruled this practice to be a secondary boycott and, therefore, illegal under the Taft–Hartley Act. The high court made this ruling in the case of the Denver Building and Construction Trades Council.

Following this decision, the doctrine of "separate gates" was developed to deal with secondary boycott problems. Under this policy, the prime contractor establishes a separate or alternate gate for the nonunion subcontractor with whom the union has a dispute. The union is then directed to place its picket line at this gate rather than the main project gate. If it fails to comply, it can be enjoined from boycotting. Other union personnel entering the site can enter at the main gate without crossing the picket line of another union.

Certain interpretations of the secondary boycott have essentially provided exceptions in the construction industry. Unions normally have attempted to refrain from handling goods or products from nonunion shops. Such materials are called "hot cargo," and unions have bargained for hot-cargo contract clauses that, in effect, prevent a contractor from handling such materials from nonunion fabricators. This is a secondary boycott in the sense that the contractor becomes an innocent third party in the dispute between the union and the fabricator or product supplier. The Landrum–Griffin Act provides that such hot-cargo or subcontractor clauses that ban use of these materials or contact with these open shop units are illegal. An exemption is made, however, for the construction industry. As noted by Clough and Sears:

> *Subcontractor agreements typically require the general contractor to award work only to those subcontractors who are signatory to a specific union labor contract or who are under agreement with the appropriate union.*[7]

The Supreme Court also ruled in 1967 that prefabrication clauses that ban the use of certain prefabricated materials are exempted from the secondary boycott legislation if such prefabricated items threaten the craft integrity and eliminate work that would normally be done on site. Union carpenters, for instance, might refuse to install prefabricated door units since the doors and the frames are preassembled in a factory off site. This eliminates assembly work that could be done on site and endangers the union scope of work. Use of such prefabricated items could lead to the decay of the craft's jurisdiction and integrity. Therefore, the use of such clauses in labor agreements is not considered to be an unlawful practice in these instances.

14.19 OPEN-SHOP AND DOUBLE-BREASTED OPERATIONS

In recent years escalating union wage settlements have led to an upsurge in the number of open-shop contractors successfully bidding on large contracts. Restrictive work rules and high wages have made it difficult for union contractors to be competitive in some market areas. In an open-shop firm, there is no union agreement and workers are paid and advanced on a merit basis. The largest group of open-, or merit, shop contractors is represented by the Associated Builders and Contractors (ABC). Traditionally, open-shop contractors have bid successfully in the housing and small building market where the required skill level is not high. Union contractors have dominated the more sophisticated building and heavy construction markets based on their ability to attract skilled labor with higher wages and benefits.

Large open-shop contractors have been willing to meet or exceed the union wage rates in order to avoid the costly work delays associated with jurisdictional disputes and restrictive work rules. In some cases, the unions have responded by signing project agreements that relax certain work rules for the duration of a given job.

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[7] R.H. Clough and G. A. Sears, *Construction Contracting,* 6th ed., John Wiley & Sons, New York, 1994, p. 376.

In order to be able to bid in both open-shop and union formats, some firms have organized as *double-breasted* contractors. Large firms will have one subsidiary that operates with no union contracts. A separately managed company will be signed to all union contracts. In this way, the parent firm can bid both in union shop markets[8] and in markets in which the lower-priced open shop encourages more cost-competitive bidding.

14.20 LABOR AGREEMENTS

Just as the contractor enters into a contract with the client, with vendors supplying materials (i.e., purchase orders), and with subcontractors working under his direction, if union labor is utilized, the contractor also enters into contracts, or labor agreements, with each of the craft unions with whom he deals. These contracts usually cover a 1- or 2-year period and include clauses governing the reconciliation of disputes, work rules, wage scales, and fringe benefits. The wages are normally defined in step increases throughout the period of the contract. These step increases are normally contained in the addendum to the labor contract.

The opening sections of the agreement typically provide methods for reconciling disputes that can arise between the contractors and the union during the life of the contract. To handle disputes, articles in the contract set up a joint conference committee to reconcile disputes and provide for arbitration procedures for disputes that cannot be settled by the committee. Typical contracts also include provisions governing:

1. Maintenance of membership
2. Fringe benefits
3. Work rules
4. Apprentice program operation
5. Wages (addendum)
6. Hours
7. Worker control and union representation
8. Operation of the union hiring hall
9. Union area
10. Subcontractor clauses (see Section 14.18)
11. Special provisions

Fringe benefits are economic concessions gained by unions covering vacation pay, health and welfare, differentials in pay due to shift, contributions by the contractor to apprenticeship programs, and so-called industrial advancement funds. These are paid by the contractor in addition to the base wage and garnish the salary of the worker. The building and construction trades councils for each union area normally print summaries of contract wage and fringe benefit provisions that assist in the preparation of payroll. Such a summary is shown in Figure 14.4.

Workrules are an important item of negotiation and have a significant effect on the productivity of workers and the cost of installed construction. A typical work rule might require that all electrical materials on site will be handled by union electricians. Another might require that all trucks moving electrical materials on site be driven by union electricians. Such provisions can lead to expensive tradesmen doing work that could be done by less-expensive crafts or laborers. Therefore, work rules become major topics of discussion during the period of contract negotiation.

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[8] The owner may specify that union labor is to be used, or Davis–Bacon rulings may dictate that union rates will prevail.

CRAFT AND BUSINESS REPRESENTATIVE	WAGE RATE PER HOUR	FOREMAN	OVERTIME RATE	W—WELFARE P—PENSION A—APPRENTICE V—VACATION	TRAVEL PAY SUBSISTENCE	AUTOMATIC WAGE INCREASE	AUTOMATIC FRINGE INCREASES	EXPIRATION DATE
Asbestos Workers Local No. 18 Robert J. Scott, BR 946 North Highland Indianapolis, Indiana 46202	$21.57		Double	W—$1.95 P—$1.95 A—$0.38 V—$3.85 Deduct	$45 per day			5-31-98
Boilermakers Local No. 60 George Williams, BR 400 North Jefferson Peoria, Illinois 61603	$22.30	$1.50—F $3.00—GF	Double	W—$5.21 P—$1.95 A—$0.10	$40 per day	$3.00 9-1-97		8-31-98
Carpenters Local No. 44 Gene Stirewalt, BR 212 W. Hill St. Champaign, Illinois 61820	$19.70	12%	Double	W—$0.52 P—$0.90 A—$0.20 IAF—$0.10		$1.00 10-15-98	$0.35 4-15-98	4-15-99
Cement Finishers Local No. 143 Francis E. Ducey, BR 212 ½ South First St. Champaign, Illinois 61820	$16.89	$1.50 15% GF	Double	W—$0.55		$0.90 1-24-98		7-24-98
Electricians Local No. 601 Jack Hensler, BR 212 South First St. Champaign, Illinois 61820	$22.25	10% 20%—GF	Double	W—$0.70 A—0.2%		$1.00—11-1-97 $0.50—5-1-98 $0.50—11-1-98		4-30-99

Figure 14.4 Labor organizations and wage rates. (Figures provided are for demonstration only and do not purport to be accurate.)

14.21 LABOR COSTS

The large number of contributions and burdens associated with the wage of a worker makes the determination of a worker's cost to the contractor a complex calculation. The contractor must know how much cost to put in the bid to cover the salary and associated contributions for all of the workers. Assuming that the number of carpenters, ironworkers, operating engineers, and other craft workers required is known and the hours for each can be estimated, the average hourly cost of each craft can be multiplied by the required craft hours to arrive at the total labor cost. The hourly average cost of a worker to *the contractor* consists of the following components:

1. Direct wages
2. Fringe benefits
3. Social security contributions (FICA)
4. Unemployment insurance
5. Workmen's compensation insurance
6. Public liability and property damage insurance
7. Subsistence pay
8. Shift pay differentials

The direct wages and fringe benefits can be determined by referring to a summary of wage rates such as the one shown in Figure 14.4.

All workers must pay social security on a portion of their salary. For every dollar the worker pays, the employer must pay a matching dollar. The worker pays a fixed percent on every dollar earned up to a cutoff level. After the annual income has exceeded the cutoff level, the worker (and the worker's employer) need pay no more. The FICA contribution in 2004 was required on the first $87,900 of annual income at the rate of 7.65 percent. Therefore, a person making $87,900 or more in annual income would contribute $6724.35 and the person's employer or employers, the contractor, would contribute a like amount.

Unemployment insurance contributions are required of all employers. Each state sets a percent rate that must be paid by the employer. The premiums are escrowed on a monthly or quarterly basis and sent periodically to the state unemployment agency. The amount to be paid is based on certified payrolls submitted by the employer at the time of paying this contribution. The fund established by these contributions is used to pay benefits to workers who are temporariliy out of work through no fault of their own.

The states also require employers to maintain Workmen's Compensation Insurance for all workers in their employ. This insurance reimburses the worker for injuries incurred in the course of employment. Labor agreements also specifically state this requirement. This recognizes the employer's responsibility to provide a safe working environment and the employer's obligation to provide support to disabled workers. Without this insurance, workers injured in the course of their work activity could become financially dependent on the state. The rates paid for workmen's compensation are a function of the risk associated with the work activity. The contribution for a pressman in a printing plant is different from that of a worker erecting steel on a high-rise building. A typical listing of construction specialties and the corresponding rates is given in Table 14.5. Similar summaries of workmen's compensation rates are printed in the Quarterly Cost Roundup issues of the *Engineering News Record*. The rates are quoted in dollars of premium per $100 of payroll. The rate for an ironworker, for example, is $29.18 (or 29.2%) per hundred dollars of payroll paid to ironworkers and structural steel erectors. The premium paid for public liability and property damage (PL and PD) insurance is also tied to the craft risk level and given in Table 14.5.

Table 14.5 Building Craft Wage and Insurance Rates[a]

Locals	Wages	Pension	Health and Welfare	Vacation	Apprentice Training	Misc	Workmen's Compensation[b]	Public Liability[c]	Property Damage[c]
Asbestos Workers	$20.30	$1.20	$1.10		$0.20		$12.18	$2.00	$1.10
Boilermakers	$20.50	$1.50	$2.10		$0.04		$12.92	$0.74	$0.72
Bricklayers	$18.70	$1.00	$1.10	$1.30		$0.16 prom.	$ 7.10	$0.76	$0.54
Carpenters	$18.90	$ .90	$1.00		$0.04		$11.34	$0.80	$0.52
Cement Masons	$17.80	$1.10	$ .80			$0.40 bldg.	$ 5.02	$0.82	$0.58
Electricians	$20.90	1.1%	0.9%	0.8%	0.05%		$ 4.38	$0.34	$0.42
Operating Engineers	$18.70	$1.50	$1.00		$0.14	$0.20 admin.	$11.22	$1.86	$2.00
Iron Workers	$19.20	$1.14	$1.30	$1.00	$0.14		$29.18	$3.00	$1.88
Laborers	$12.50	$0.66	$0.40			$0.10 educ.	$ 7.50	$0.38	$0.40
Painters	$18.90	$1.30	$1.30		$500/yr		$ 7.18	$0.26	$0.88
Plasterers	$18.34	$1.10	$ .80			$0.40 bldg. $0.20 prom.	$ 6.96	$0.78	$0.54
Plumbers	$21.50	$1.00	$1.30		$0.22	$0.12 prom. $0.04 natl.	$ 5.60	$0.58	$1.18
Sheet Metal	$20.40	$1.40	$1.00		$0.08	$0.18 ind.	$ 7.14	$0.41	$0.40

Unemployment 5.0%
Social Security 7.65%

[a]These rates are only indicative of wage and insurance rates. They are not representative of current data.

[b]Rates are applied per $100 of pay.

[c]Public liability. Maximum coverage under these rates—$5000/person, $10,000 per accident
For higher coverage—$10,000/$20,000: 1.26 × basic rate
$25,000/50,000: 1.47 × basic rate
$50,000/100,000: 1.59 × basic rate
$300,000/300,000: 1.78 × basic rate

Property damage: Maximum coverage under these rates—$5000/person, $25,000 per accident
For higher coverage—$25,000/100,000: 1.23 × basic rate
$50,000/100,000: 1.30 × basic rate

When a construction project is underway, accidents occurring as a result of the work can injure persons in the area or cause damage to property in the vicinity. If a bag of cement falls from an upper story of a project and injures persons on the sidewalk below, these persons will normally seek a settlement to cover their injuries. The public liability (PL) arising out of this situation is the responsibility of the owner of the project. Owners, however, normally pass the requirement to insure against such liability to the contractor in the form of a clause in the *general conditions* of the construction contract. The general conditions direct the contractor to have sufficient insurance to cover such public liability claims. Similarly, if the bag of cement falls and breaks the windshield of a car parked near the construction site, the owner of the car will seek to be reimbursed for the damage. This is a property damage situation that the owner of the construction project becomes liable to pay. Property damage (PD) insurance carried by the contractor (for the owner) covers this kind of liability. Insurance carriers normally quote rates for PL and PD insurance on the same basis as for workmen's compensation insurance. Therefore, to provide PL and PD insurance, the contractor must pay \$3.00 for PL and \$1.88 for each one hundred dollars of steel erector salary paid on the job. These rates vary over time and geographical area and can be reduced by maintaining a safe record of operation. The total amount of premium is based on a certified payroll submitted to the insurance carrier.

Subsistence is paid to workers who must work outside of the normal area of the local. As a result, they incur additional cost because of their remoteness from home and the need to commute long distances or perhaps live away from home. If an elevator constructor in Chicago must work in Indianapolis for 2 weeks, he will be outside of the normal area of his local and will receive subsistence pay to defray his additional expenses.

Shift differentials are paid to workers in recognition that it may be less convenient to work during one part of the day than during another. Typical provisions in a sheet metal worker's contract are given in Figure 14.5. In this example, the differential results in an add-on to the basic wage rate. Shift differential can also be specified by indicating that a worker will be paid for more hours than he works. A typical provision from a California ironworkers contract provides the following standards for shift work: (a) If two shifts are

A shift differential premium of twenty (20) cents per hour will be paid for all time worked on the afternoon or second shift, and a shift differential of thirty (30) cents per hour will be paid for all time worked on the night or third shift as follows:

(1) *First Shift.* The day, or first, shift will include all Employees who commence work between 6 A.M. and 2 P.M. and who quit work at or before 6 P.M. of the same calendar day. No shift differential shall be paid for time worked on the day, or first, shift.

(2) *Second Shift.* The afternoon, or second, shift shall include all Employees who commence work at or after 2 P.M. and who quit work at or before 12 midnight of the same calendar day. A shift differential premium of twenty (20) cents per hour shall be paid for all time worked on the afternoon, or second, shift.

(3) *Third Shift.* The night, or third, shift shall include all Employees who commence work at or after 10 P.M. and who quit work at or before 8 A.M. of the next following calendar day. A shift differential premium of thirty (30) cents per hour shall be paid for all time worked on the night, or third, shift.

(4) *Cross Shift.* Where an Employee starts work during one shift, as above defined, and quits work during another shift, as above defined, said Employee shall not be paid any shift differential premium for time worked, if any, between the hours of 7 A.M. and 3 P.M.; but shall be paid a shift differential of twenty (20) cents per hour for all time worked, if any, between the hours of 3 P.M. and 11 P.M. and a shift differential premium of thirty (30) cents per hour for all time worked, if any, between the hours of 11 P.M. and 7 A.M.

Figure 14.5 Shift work provision.

Compute the average hourly cost to a contractor of an ironworker involved in structural steel erection in a subsistence area. The ironworker works on the second shift of a three-shift job and works six 10-hour days per week. The workers work 7 hours and are paid 8 hours under the shift pay agreement. Additional PL and PD insurance for $50,000/$100,000 coverage is desired. Use 6.2% FICA and 5.0% for unemployment insurance.

	Hours Worked	Straight Time-Hours (ST)	Premium Time (PT)
Monday–Friday	$5 \times 7 = 35$	$5 \times 8 = 40$	
	$5 \times 3 = 15$	$5 \times 3 = 15$	$1 \times 5 \times 3 = 15$
Saturday	$1 \times 7 = 7$	$1 \times 8 = 8$	$1 \times 1 \times 8 = 8$
	$1 \times 3 = 3$	$1 \times 3 = 3$	$1 \times 1 \times 3 = 3$
	60	66	26

Base Rate = \$19.20
ST 66 hours @ \$19.20 = \$1267.20
PT 26 hours @ \$19.20 = \$ 499.20
Gross Pay \$1766.40

Fringes:	Health and Welfare	$1.30 \times 66 =$ \$ 85.80
	Pension	$1.14 \times 66 =$ \$ 75.24
	Vacation	$1.00 \times 66 =$ \$ 66.00 (deferred wage)
	Apprenticeship training	$0.14 \times 66 =$ \$ 9.24
		$3.58 \times 66 =$ \$236.28

WC = \$29.18
PL $1.59 \times 3.00 =$ \$4.77
PD $1.30 \times 1.88 =$ \$2.44
Total = \$36.39 per \$100.00 of Payroll

$$\text{WC, PL, and PD} = \$36.39 \times \frac{1267.20}{100} = \$461.13$$

FICA = $0.0765 \times (\$1766.40 + \$66) = \$140.18$
Unemployment = $0.05 \times (\$1766.40 + \$66) = \$91.62$
Subsistence = 6 days $\times$ \$20.00/day = \$120.00

Total Cost = Base + Fringes + WC, PL, PD + UNEMPL + FICA + SUBS = \$2815.61

$$\text{Average Hourly Cost (to contractor)} = \frac{\$2815.61}{60} = \$46.93$$

Figure 14.6 Sample wage calculation.

in effect, each shift works 7.5 hours for 8 hours of pay and (b) if three shifts are in effect, each shift works 7 hours for 8 hours of pay. This means that if a three-shift project is being worked the ironworker will receive overtime for all time worked over 7 hours. In addition, he will be paid 8 hours pay for 7 hours work. Calculation of shift pay will be demonstrated in the following section.

14.22 AVERAGE HOURLY COST CALCULATION

A typical summary[9] of data regarding trade contracts in given areas is presented in Table 14.5. A worksheet showing the calculation of an ironworker's hourly cost to a contractor is shown in Figure 14.6. It is assumed that the ironworker is working in a subsistence area

[9] Although representative, data in this table are not current. Such information is dynamic and changes continuously.

on the second shift of a three-shift job during June and will be paid 8 hours for 7 hours of work (i.e., shift differential).

The ironworker works 10-hour shifts each day for 6 days, or 60 hours for the week. It is important to differentiate between those hours that are straight-time hours and those that are premium hours. Insurance premiums and fringe benefit contributions are based on straight-time hours. Social security and unemployment insurance contributions are calculated using the total income figure. The Hours Worked column breaks the weekday and Saturday hours into straight-time and premium-time components. Since the worker receives a shift differential, the first 7 hours are considered straight time and the other 3 hours are paid at overtime rate. The straight-time hours corresponding to the hours worked are shown in the second column. Eight hours are paid for the first 7 hours worked. The overtime is double time. The single-time portion, or first half of the double time, is credited to straight time. The second half of the double time is credited to the premium-time column. Based on the column totals the worker works 60 hours and will be paid 66 straight-time hours and 26 premium hours.

By consulting Table 14.5, it can be determined that the base wage rate for ironworkers is $19.20 per hour. This yields a straight-time wage of $1267.20 (66 hours) and premium pay of $499.20 (26 hours). Total gross pay is $1766.40.

Fringes are based on straight-time hours, and the rates are given in the contract wage summary. The fringes paid by the contractor to union funds amount to $3.58 per hour. The vacation portion of the fringe is considered to be a deferred income item and, therefore, is subject to FICA. It is also used in the calculation of unemployment insurance contribution.

The amounts to be paid to the insurance carrier for workmen's compensation (WC), PL, and PD can be taken from Table 14.5. The contract calls for increased PL and PD rates. The bodily injury (PL) portion and the property damage coverage are to be increased to cover $50,000 per person/$100,000 per occurrence. This introduces a multiplier of 1.59 for the PL rate and 1.30 for the PD rate (see footnotes at the bottom of Table 14.5). The total rate per $100 of payroll for WC, PL, and PD is $36.39. This is applied to the straight-time pay of $1267.20 and gives a premium to be escrowed of $461.13.

Both FICA and unemployment insurance are based on the total gross pay plus the deferred vacation fringe. Subsistence is $20.00 per day not including travel pay and time to travel to the site (not included in this calculation). By summing all of these cost components, the contractor's total cost becomes:

Gross pay	$1766.40
Fringes	$ 236.28
WC, PL, PD	$ 461.13
FICA	$ 140.18
Unemployment	$ 91.62
Subsistence	$ 120.00
Total	$2815.61
Hourly rate =	$2815.61/60 = $46.93 or approx. $47.00

This is considerably different from the base wage rate of $19.20 per hour. A contractor relying on the wage figure only to come up with an estimated price will grossly underbid the project and "lose his shirt."

It is particularly important to verify that the WC, PL, PD rate being used for a worker is the correct one. Particularly hazardous situations result in rates as high as $44 per $100 of payroll (e.g., tunneling). However, if a worker is simply installing miscellaneous metals, he should not be carried as a structural steel erector. The difference in the rates between the two specialties can be significant. It should also be noted that the rates given in Table 14.5 are for a particular geographical area and are the so-called manual rates. The manual rate is the one used for a firm for which no safety or experience records are available. These rates can be substantially reduced for firms that evidence over years of operation that they have an extremely safe record. This provides a powerful incentive for contractors to be safe. If the WC, PL, PD rate can be reduced by 30%, the contractor gains a significant edge in bidding against the competition.

The calculation of the hourly average wage indicates the complexity of payroll preparation. A contractor may deal with anywhere from 5 to 14 different crafts, and each craft union has its own wage rate and fringe benefit structure. Union contracts normally require that the payroll must be prepared on a weekly basis, further complicating the situation. In addition, all federal, state, and insurance agencies to which contributions or premiums must be paid require certified payrolls for verification purposes. Because of this, most contractors with a work force of any size use the computer for payroll preparation. Data are collected by field personnel using time cards. These time records are submitted to clerical personnel who prepare them for submittal to the computer. Most firms have in-house computers for this purpose. Some firms may utilize service bureaus to provide this payroll preparation function. Charges for this service run in the vicinity of $\frac{1}{2}$ to 1% of the total payroll amount.

REVIEW QUESTIONS AND EXERCISES

14.1 What is meant by the following terms:

(a) Yellow-dog contract

(b) Agency shop

(c) Subcontractor clause

14.2 What is a secondary boycott? Name two types of secondary boycotts. Does the legislation forbidding secondary boycotts apply to construction unions? Explain.

14.3 What is a jurisdictional dispute? Why does this kind of dispute present no problem in District 50 locals?

14.4 What are the basic differences between the AFL as a labor union and the CIO type of union?

14.5 What will be the impact on double-breasted operations and the right-to-work provision of the Taft-Hartley legislation if labor is able to revoke existing practices regarding common situs picketing?

14.6 Answer the following questions true (T) or false (F):

(a) ____________ Some state laws authorize use of closed shops.

(b) ____________ A union can legally strike a job site in order to *enforce* the provision of a subcontractor clause.

(c) ____________ The Teamsters union is the largest member of the AFL–CIO.

(d) ____________ Open-shop operations have caused construction labor unions to rethink their position vis à vis union contractors.

(e) ____________ The right-to-work clause of the Taft-Hartley law allows the individual states to determine whether union shops are legal.

(f) ____________ The unit-price contract is an incentive-type negotiated contract.

(g) ____________ The local AFL craft unions have very little authority and are directed mainly by the national headquarters of AFL–CIO.

(h) ____________ The Sherman Antitrust Law was originally designed to prevent the formation of large corporations or cartels that could dominate the market.

(i) ____________ The business agent is the representative of the union charged with enforcing the work rules of the labor agreement.

(j) ____________ A submittal must be verified for accuracy in accordance with contract plans and specifications.

(k) ____________ The Sherman Antitrust Act, enacted in 1890, was used to suppress the formation of large trusts and cartels, which dominated the market and acted to fix prices and restrain free trade.

(l) ____________ Yellow-dog contracts were used by employers to encourage their employees to join and become active in union organizations.

(m) ____________ Under the Taft–Hartley legislation, the president of the United States is empowered to enjoin workers on strike (or preparing to strike) to work for a 90-day cooling-off period during which time negotiators attempt to reach agreement on contractual or other disputes.

(n) ____________ The National Labor Relations Act was enacted to protect union-organizing activity and encourage collective bargaining.

(o) ____________ In an open-shop working environment, workers are paid based on which union hall they belong to.

(p) ____________ The calculation of fringe benefits is based on gross pay, whereas FICA is based on straight-time hours.

(q) ____________ If a general contractor does not feel like paying worker's compensation fees, then the contractor does not have to. Each state has appropriated funds that will cover this option.

14.7 Compute the average hourly cost of a carpenter to a contractor. Assume the work is in a subsistence area and the daily subsistence rate is $19.50. The carpenter works the second shift on a two-shift project where a project labor contract establishes a "work 7 pay 8 hour" pay basis for straight time. He works 6 days, 10 hours a day. In addition to time and a half for overtime Monday through Friday, the contract calls for double time for all work on weekends. Use 6.2% FICA and 5.0% for unemployment insurance. Assume all data relating to the WC, PL, PD, fringes, and wage are as given in Table 14.5.

14.8 Identify the local labor unions that operate in your region. List the relevant business agents and the locations of the hiring halls.

14.9 List the labor unions that you consider would be involved in a project similar to the gas station project of Appendix I.

14.10 Visit a local contractor and a local hiring hall and determine the procedure to be followed in the hiring of labor.

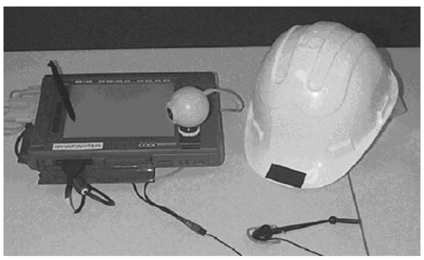
Chapter 15

Cost Control

Digital Hardhat System

The Need

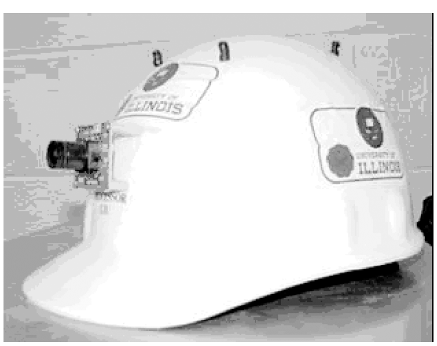
The cost and time required to travel between construction sites limits the ability of personnel to quickly respond to problems at remote sites and to communicate issues between all necessary decision makers. Also, it is difficult to organize and transmit multimedia project information (digital pictures, video, electronic documents, and audio recordings) so that others can access current project information in an intuitive and timely manner. The Digital Hardhat (DHH) technology enables dispersed users to capture and communicate multimedia field data to collaboratively solve problems, and collect and share information. The DHH is a pen-based personal computer with special Multimedia Facility Reporting System software that allows the field representative to save multimedia information into a project-specific database, which is then accessible to others through the World Wide Web.



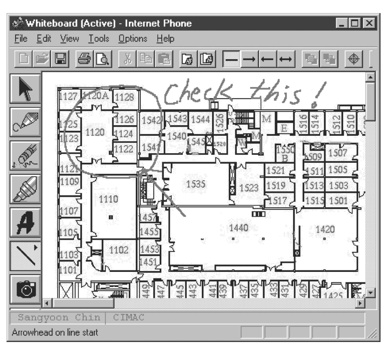
The mobile unit and a hardhat

The Technology

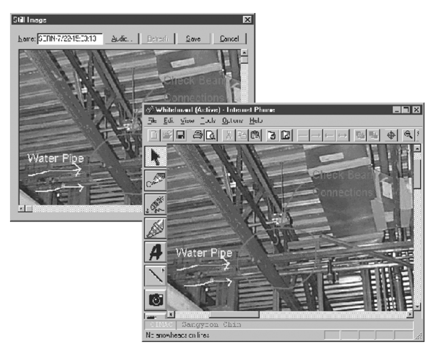
The Digital Hardhat (DHH) is a pen-based personal computer (PC) running a Windows operating system, which is used to collect multimedia information such as text, sound, video, and images. This pen-based computer can also be used to communicate between the construction site and other locations using various connection methods including a wireless network connection, which enables personnel to roam around the site and video teleconference live with others to solve problems collaboratively. In addition, special software called Multimedia Facility Reporting (MFR) System allows the field representative to save multimedia information into a project-specific database accessible through the internet. The project information collected through the system will help



Digital Hardhat



Using a whiteboard



Multimedia Information on MFR

document site conditions, progress, and problems in an organized manner so the information can be retrieved easily as needed by any project participant. In the application of this system, immediate reductions in travel cost will be the most obvious benefit; however, costs associated with more quickly resolving issues, reducing construction claims, and fewer time delays will be the ultimate benefit of this technology.

15.1 COST CONTROL AS A MANAGEMENT TOOL

The early detection of actual or potential cost overruns in field construction activities is vital to management. It provides the opportunity to initiate remedial action and increases the chance of eliminating such overruns or minimizing their impact. Since cost overruns increase project costs and diminish profits, it is easy to see why both project management and upper-level management must become sensitive to the costs of all project activities.

An important byproduct of an effective cost reporting system is the information that it can generate for management on the general cost performance of field construction activities. This information can be brought to bear on problems of great interest to project management. The determination of current project status, effectiveness of work progress, and preparation of progress payment requests require data generated by both project planning and cost control reporting systems. Project cost control data are important not only to project management in decision-making processes but also to the company's estimating and planning departments because these data provide feedback information essential for effective estimates and bids on new projects. Thus a project control system should both serve current project management efforts and provide the field performance database for estimating future projects.

15.2 PROJECT COST CONTROL SYSTEMS

The design, implementation, and maintenance of a project cost control system can be considered a multistep process. The five steps, shown schematically in Figure 15.1, form the basis for establishing and maintaining a cost control system. The following questions regarding each step in the implementation of the cost control system must be addressed.

1. ***Chart of Cost Accounts.*** What will be the basis adopted for developing estimated project expenditures, and how will this basis be related to the firm's general accounts and accounting functions? What will be the level of detail adopted in defining the project cost accounts, and how will they interface with other financial accounts?
2. ***Project Cost Plan.*** How will the cost accounts be utilized to allow comparisons between the project estimate and cost plan with actual costs as recorded in the field? How will the project budget estimate be related to the construction plan and schedule in the formation of a project cost control framework?
3. ***Cost Data Collection.*** How will cost data be collected and integrated into the cost reporting system?
4. ***Project Cost Reporting.*** What project cost reports are relevant and required by project management in its cost management of the project?
5. ***Cost Engineering.*** What cost engineering procedures should project management implement in its efforts to minimize costs?

These are basic questions that management must address in setting up the cost control system. The structure of cost accounts will be discussed in this chapter.

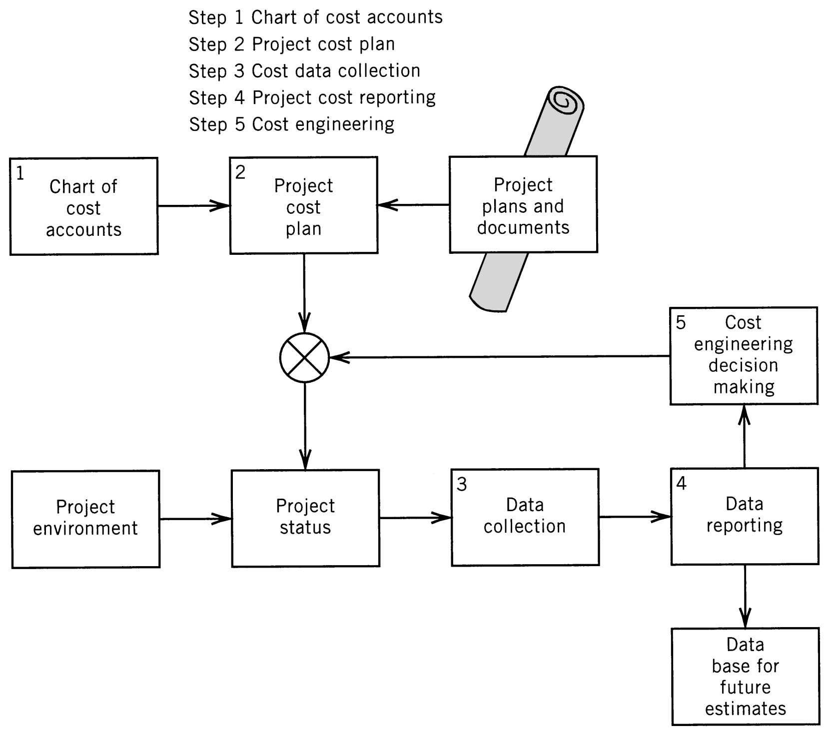


Figure 15.1 Steps in cost control.

15.3 COST ACCOUNTS

The first step in establishing a cost control system for a construction job is the definition of project-level cost centers. The primary function of the cost account section of a chart of accounts is to divide the total project into significant control units, each consisting of a given type of work that can be measured in the field (see Fig. 15.2). Once job cost accounts are established, each account is then assigned an identifying code known as a cost code. Once segregated by associated cost centers, all the elements of expense (direct labor, indirect labor, materials, supplies, equipment costs, etc.) constituting work units can be properly recorded by cost code.

The design, structure, and development of a cost coding system and its associated set of expense accounts have a significant impact on the cost management of a company or project. The job cost accounting system is essentially an accounting information system. Therefore, management is free to establish its own chart of accounts in any way that helps it in reaching specific financial and cost control objectives, whether these objectives are related to general company performance, to the control of a specific project, or to specific contract requirements.

15.4 COST CODING SYSTEMS

A variety of cost coding systems exist in practice, and standard charts of accounts are published by organizations such as the American Road Builders Association, Associated General Contractors, and the Construction Specifications Institute. In many industries, cost codes have a company-wide accounting focus emphasizing expense generation based on a departmental breakdown of the firm. In some construction firms, cost systems have a structured sequence corresponding to the order of appearance of the various trades or types of

MASTER LIST OF PROJECT COST ACCOUNTS
Subaccounts of General Ledger Account 80.000
PROJECT EXPENSE

		Project Work Accounts 100–699			Project Overhead Accounts 700–999
100		Clearing and grubbing	700		Project administration
101		Demolition		.01	Project manager
102		Underpinning		.02	Office engineer
103		Earth excavation	701		Construction supervision
104		Rock excavation		.01	Superintendent
105		Backfill		.02	Carpenter foreman
115		Wood structural piles		.03	Concrete foreman
116		Steel structural piles	702		Project office
117		Concrete structural piles		.01	Move in and move out
121		Steel sheet piling		.02	Furniture
240		Concrete, poured		.03	Supplies
	.01	Footings	703		Timekeeping and
	.05	Grade beams		.01	security
	.07	Slab on grade		.02	Timekeeper
	.08	Beams		.03	Watchmen
	.10	Slab on forms	705		Guards
	.11	Columns		.01	Utilities and services
	.12	Walls		.02	Water
	.16	Stairs		.03	Gas
	.20	Expansion joint		.04	Electricity
	.40	Screeds	710		Telephone
	.50	Float finish	711		Storage facilities
	.51	Trowel finish	712		Temporary fences
	.60	Rubbing	715		Temporary bulkheads
	.90	Curing	717		Storage area rental
245		Precast concrete	720		Job sign
260		Concrete forms	721		Drinking water
	.01	Footings	722		Sanitary facilities
	.05	Grade beams	725		First-aid facilities
	.07	Slab on grade	726		Temporary lighting
	.08	Beams	730		Temporary stairs
	.10	Slab	740		Load tests
	.11	Columns	750		Small tools
	.12	Walls	755		Permits and fees
270		Reinforcing steel	756		Concrete tests
	.01	Footings	760		Compaction tests
	.12	Walls	761		Photographs
280		Structural steel	765		Surveys
350		Masonry	770		Cutting and patching
	.01	8-in. block	780		Winter operation
	.02	12-in. block	785		Drayage
	.06	Common brick	790		Parking
	.20	Face brick			Protection of adjoining property
	.60	Glazed tile	795		Drawings
400		Carpentry	796		Engineering
440		Millwork	800		Worker transportation
500		Miscellaneous metals	805		Worker housing
	.01	Metal door frames	810		Worker feeding
	.20	Window sash	880		General clean-up
	.50	Toilet partitions	950		Equipment
560		Finish hardware		.01	Move in
620		Paving		.02	Set up
680		Allowances		.03	Dismantling
685		Fencing		.04	Move out

Figure 15.2 List of typical project expense (cost) accounts.

Table 15.1 Classification of Accounts: Major Divisions in Uniform Construction Index

Cost Centers			
0	Conditions of the contract	9	Finishes
1	General requirements	10	Specialties
2	Site work	11	Equipment
3	Concrete	12	Furnishings
4	Masonry	13	Special construction
5	Metals	14	Conveying system
6	Carpentry	15	Mechanical
7	Moisture prevention	16	Electrical
8	Doors, windows, and glass		

construction processes typical of the company's construction activity. In most construction companies, detailed project cost accounts such as those shown in Figure 15.2 are used. This method recognizes the fact that construction work is project oriented and that to achieve the cost management goal of maximizing profit, projects must be accounted for individually. One project may be a winner while another is losing money. Such situations may be masked in the accounting system unless job cost accounts are maintained on a project-by-project basis. Therefore, both billings (revenue) and cost (work in progress) accounts are typically maintained for each project. The actual account descriptions or designations vary in accordance with the type of construction and the technologies and placement processes peculiar to that construction. Building contractors, for instance, are very interested in accounts that describe the cost aspects of forming and casting structural concrete as used in building frames. Heavy construction contractors, on the other hand, are interested in earthwork-related accounts such as grading, ditching, clearing and grubbing, and machine excavation. Standard cost accounts published by the American Road Builders Association emphasize these accounts, while the Uniform Construction Index (UCI), published by the Construction Specifications Institute, emphasizes building-oriented accounts. A breakdown of the major classifications within the UCI cost account system is shown in Table 15.1. A portion of the second level of detail for classifications 0 to 3 is shown in Figure 15.3.

15.5 PROJECT COST CODE STRUCTURE

The UCI Master Format code as used by the R. S. Means *Building Construction* Cost Data identifies three levels of detail. At the highest level the major work classification as given in Table 15.1 is defined. Also at this level major subdivisions within the work category are established. For instance, 30-level accounts pertain to concrete while 031 accounts are accounts specifically dealing with concrete forming. In a similar manner, 032 accounts are reserved for cost activity associated with concrete reinforcement.

At the next level down, a designation of the physical component or subelement of the construction is established. This is done by adding three digits to the work classification two-digit code. For instance, the three-digit code for footings is 158. Therefore, the code 031158 indicates an account dealing with concrete forming costs for footings.

At the third and lowest level, digits specifying a more precise definition of the physical subelement are used. For instance an account code of 0311585000 can indicate that this account records costs for forming concrete footings of a particular type (see Fig. 15.4). At this level the refinement of definition is very great, and the account can be made very sensitive to the peculiarities of the construction technology to be used. Further refinement could differentiate between forming different types of footings with different types of material.

	0 Conditions of the Contract
0000-0099.	unassigned
	1 General Requirements
0.100.	Alternates of Project Scope
0.101-0109.	unassigned
0110.	Schedules and Reports
0111-0119.	unassigned
0120.	Samples and Shop Drawings
0121-0129.	unassigned
0130.	Temporary Facilities
0131-0139.	unassigned
0140.	Cleaning Up
0141-0149.	unassigned
0150.	Project closeout
0151-0159.	unassigned
0160.	Allowances
0161-0169.	unassigned
	2 Site Work
0200.	Alternates
0210-0209.	unassigned
0120.	Clearing of Site
0211.	Declination
0212.	Structures moving
0213.	Clearing and grubbing
0214-0219.	unassigned
0220.	Earthwork
0221.	Site grading
0222.	Excavating and backfilling
0223.	Dewatering
0224.	Subdrainage
0225.	Soil poisoning
0226.	Soil compaction control
0227.	Soil stabilization
0228-0229.	unassigned
0230.	Piling
0231-0234.	unassigned
0235.	Caissons
0236-0239.	unassigned
0240.	Shoring and bracing
0241.	Sheeting
0242.	Underpinning
0243-0249.	unassigned
0250.	Site drainage
0251-0254.	unassigned
0255.	Site utilities
0256-0259.	unassigned
0260.	Roads and Walks
0261.	Paving
0262.	Curbs and gutters
0263.	Walks
0264.	Road and parking Appurtenances
0265-0269.	unassigned
0270.	Site Improvements
0271.	Fences
0272.	Playing fields
0273.	Fountains
0274.	Irrigation systems
0275.	Yard improvements
0276-0279.	unassigned
0280.	Lawns and Planting
0281.	Soil Preparation
0282.	Lawns
0283.	Ground covers and other plants
0284.	Trees and shrubs
0285-0289.	unassigned
0290.	Railroad Work
0291-0294.	unassigned
0295.	Marine Work
0296.	Boat Facilities
0297.	Protective Marine Structures
0298.	Dredging
0299.	unassigned
	3 Concrete
0300.	Alternates
0301-0309.	unassigned
0310.	Concrete Formwork
0311-0319.	unassigned
0320.	Concrete Reinforcement
0321-0329.	unassigned
0330.	Cast-in-Place Concrete
0331.	Heavyweight aggregate concrete
0332.	Lightweight aggregate concrete
0333.	Post-tensioned concrete
0334.	Nailable concrete
0335.	Specially finished concrete
0336.	Specially placed concrete
0337-0339.	unassigned
0340.	Precast Concrete
0341.	Precast concrete panel
0342.	Precast structural concrete
0343.	Precast prestressed concrete
0344-0349.	unassigned
0350.	Clementitious Decks
0351.	Poured gypsum deck
0352.	Insulating concrete roof decks
0353.	Cementitious unit decking
0354-0399.	unassigned

Figure 15.3 Detailed codes for classification within Uniform Construction Index.

031 | Concrete Formwork

031	Struct C.I.P. Formwork	CREW	DAILY OUTPUT	LABOR-HOURS	UNIT	1996 BARE COSTS MAT.	LABOR	EQUIP.	TOTAL	TOTAL INCL. O&P
158	FORMS IN PLACE, FOOTINGS Continuous wall, 1 use	C–1								
5000	Spread footings, 1 use		305	.105	SFCA	1.51	2.50	.09	4.10	5.75

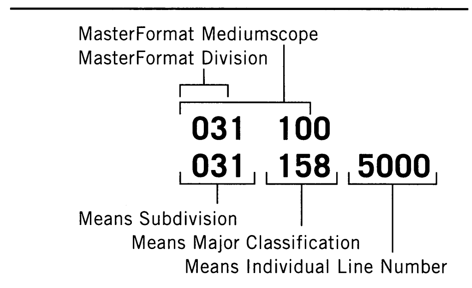


Figure 15.4 UCI cost (line item) structure in the master format code.

At this level, the cost engineer and construction manager have a great deal of flexibility in reflecting unique aspects of the placement technology that lead to cost fluctuations and thus must be considered in defining cost centers.

Large and complex projects in industrial and energy-related construction may require cost codes that reflect additional information, such as the project designation, the year in which the project was started, and the type of project. Long and complex codes in excess of 10 digits can result. An example of such a code is shown in Figure 15.5. This code, consisting of 13 digits, specifically defines the following items:

1. Year in which project was started (2004)
2. Project control number (15)
3. Project type (5 for power station)
4. Area code (16 for boiler house)
5. Functional division (2, indicating foundation area)
6. General work classification (0210, indicating site clearing)
7. Distribution code (6, indicating construction equipment)

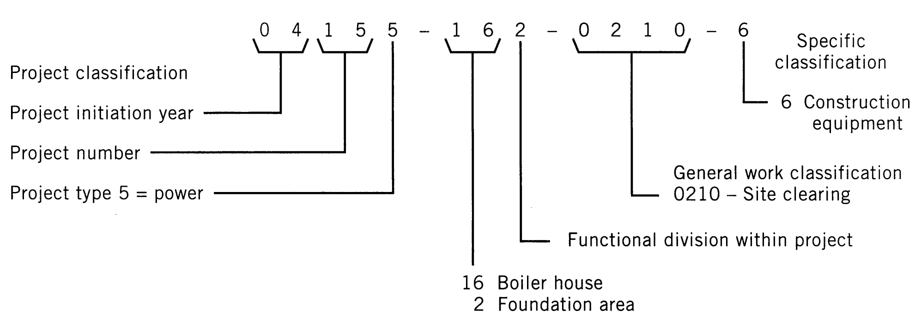


Figure 15.5 Classification of accounts: typical data structure for a computerized cost code.

The distribution code establishes what type of resource is being costed to the work process (i.e., clearing), the physical subelement (i.e., foundations) in what area of which project. Typical distribution codes might he as follows:

1. Labor
2. Permanent materials
3. Temporary materials
4. Installed equipment
5. Expendables
6. Construction equipment
7. Supply
8. Subcontract
9. Indirect

Clearly, a high concentration of information can be achieved by proper design of the cost code. Such codes are also ideally suited for data retrieval, sorting, and assembly of reports on the basis of selected parameters (e.g., all construction equipment costs for concrete forming on project 10 started in a given year). The desire to cram too much information into cost codes, however, can make them so large and unwieldy that they are confusing to upper-level management.

15.6 COST ACCOUNTS FOR INTEGRATED PROJECT MANAGEMENT

In large and complex projects, it is advantageous to break the project into common building blocks for control both of cost and time. The concept of a common unit within the project that integrates both scheduling and cost control has led to the development of the work breakdown approach. The basic common denominator in this scheme is the work package, which is a subelement of the project on which both the cost and time data are collected for project status reporting. The collection of time and cost data based on work packages has led to the term *integrated project management*. That is, the status reporting function has been integrated at the level of the work package. The set of work packages in a project constitutes its work breakdown structure (WBS).

The work breakdown structure and work packages for control of a project can be defined by developing a matrix similar to the one shown in Figure 15.6. The columns of this matrix are defined by breaking the down project into physical subcomponents. Thus we have a hierarchy of levels that begins with the project as a whole and, at the lowest level, subdivides the project into physical end items such as foundations and areas. As shown in Figure 15.6, the project is subdivided into systems. The individual systems are further divided into disciplines (e.g., civil, mechanical, electrical). The lowest level of the hierarchy indicates physical end items (foundation 1, etc.). Work packages at this lowest level of the hierarchy are called control accounts.

The rows of the matrix are defined by technology and responsibility. At the lowest level of this hierarchy, the responsibilities are shown in terms of tasks, such as concrete, framing, and earthwork. These tasks imply various craft specialties and technologies. Typical work packages then are defined as concrete tasks on foundation 1 and earthwork on foundations 1 and 2.

This approach can be expanded to a three-dimensional matrix by considering the resources to be used on each work package (see Fig. 15.7). Using this three-dimensional breakdown, we can develop definition in terms of physical subelement, task, and responsibility, as well as resource commitment. A cost code structure to reflect this matrix structure is given in Figure 15.8. This 15-digit code defines units for collecting information in terms

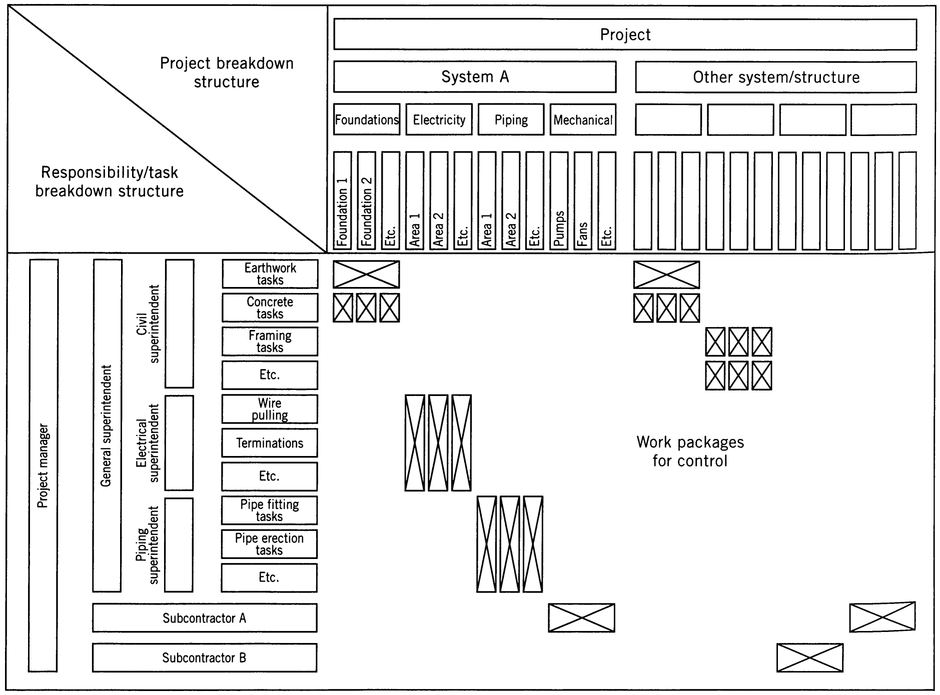


Figure 15.6 Project control matrix.

of work package and resource type. Resource usage in terms of monetary units, quantities, man-hours, and equipment-hours for a foundation in the boiler building would be collected under work package code 121002. If this work relates to placement and vibration of concrete by using a direct chute, the code is expanded to include the alphanumeric code DF441. The resource code for the concrete is 2121. Therefore, the complete code for concrete in the boiler building foundations placed by using a chute would be 121002-DF441-2121.

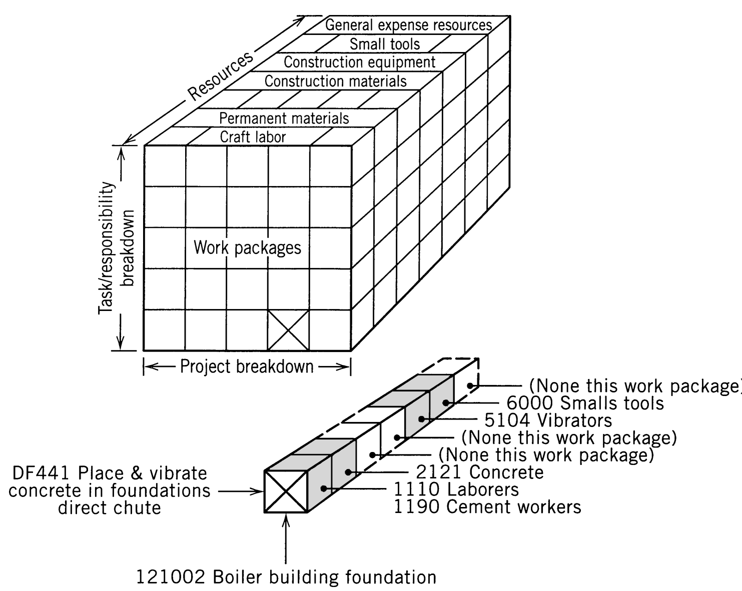


Figure 15.7 Three-dimensional visualization of work-package-oriented cost accounts.

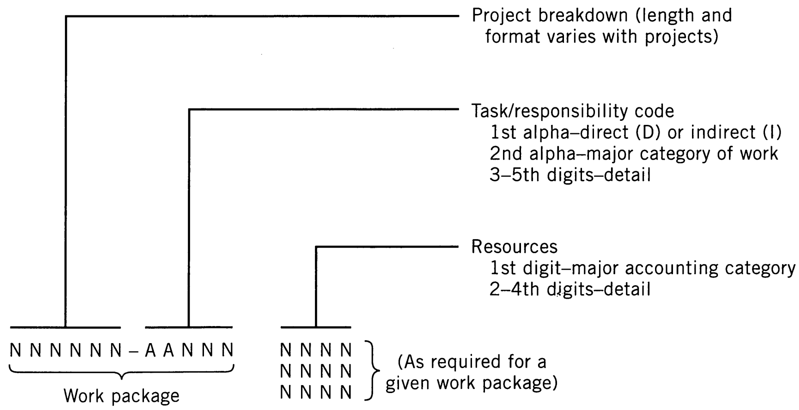


Figure 15.8 Basic cost code structure.

This code allows collection of cost data at a very fine level. Scheduling of this work is also referenced to the work package code as shown in Figure 15.9. The schedule activities are shown in this figure as subtasks related to the work package.

15.7 EARNED VALUE METHOD

One widely accepted way of calculating progress on complex projects using a work or account based breakdown system is the "earned value" approach. This system of determining project progress addresses both schedule status (e.g., on schedule, behind schedule, etc.) and cost status (e.g., over budget, etc.). This method of tracking cost and schedule was originally implemented by the Department of Defense in the late 1970s to help better

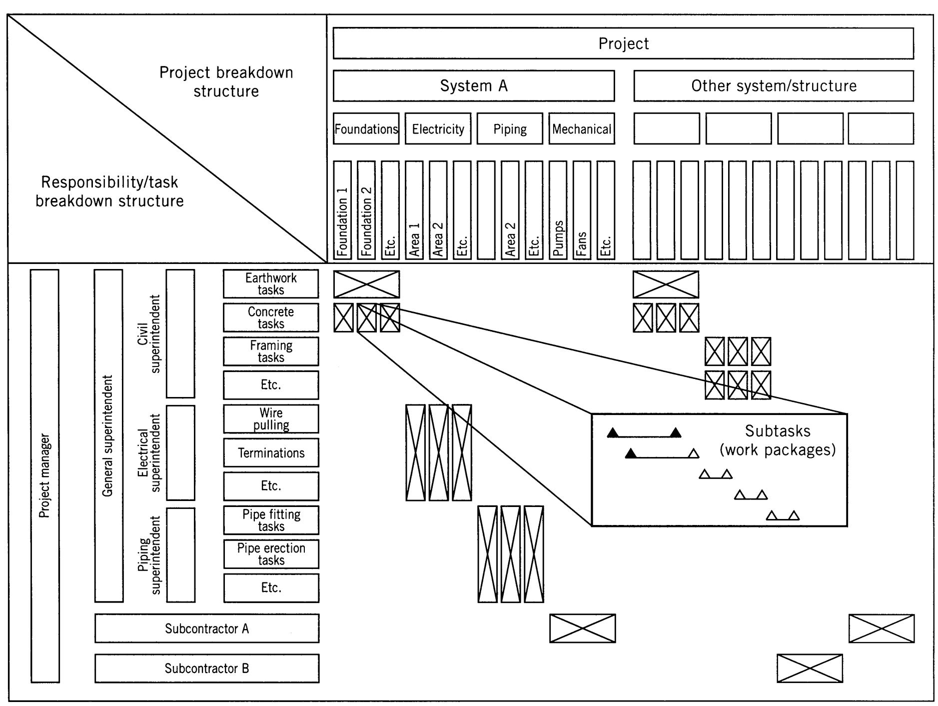


Figure 15.9 Project control matrix with scheduling of subtasks.

control complex projects. The system was called the Cost and Schedule Control Systems Criteria or C/SCSC. This method of monitoring contracts proved to be so effective that other government agencies (e.g., Department of Energy, etc.) adopted C/SCSC as a means of maintaining oversight on complex projects such as nuclear and conventional power plants. Private owners such as power companies implemented similar systems since reporting to various government authorities encouraged or required the use of C/SCSC and earned value concepts. Ultimately, owners of complex industrial projects began to use the system as well.

The idea of earned value is based upon a rigorous development of percent complete of the budgeted costs associated with individual work packages or line items. Each work package has an initial budget or estimate which is defined as the Budgeted Cost at Completion or BCAC. As work proceeds on an individual work package or account, assessment of the percent complete is made at various study dates. The initial schedule establishes an expected level of work completion as of the study date. The level of expected production is often shown as an S-Curve plotting the cost or units of production (e.g., units produced, work hours expended, etc.) against time. This cost/production curve is referred to as the baseline. At any given time (study date), the units of cost/production indicated by the baseline are called the Budgeted Cost of Work Scheduled (BCWS).

The tracking system requires that field reports provide information about the Actual Cost of Work Performed (ACWP) and the Actual Quantity of Work Performed (AQWP). The “earned value” is the Budgeted Cost of Work Performed (BCWP). The relative values for a given work package or account at a given point in time (see Fig. 15.10) provide information about the status in terms of cost and schedule variance. The six parameters which form the foundation of the “earned value” concept are:

BCWS: Budgeted Cost of Work Scheduled = Value of the baseline at a given time
ACWP: Actual Cost of Work Performed − Measured in the field
BCWP: Budgeted Cost of Work Performed = [% Complete] × BCAC
BCAC: Budgeted Cost At Completion = Contracted Total Cost for the Work Package
AQWP: Actual Quantity of Work Performed − Measured in the field
BQAC: Budgeted Quantity at Completion − Value of the Quantity Baseline as Projected at a given Point.

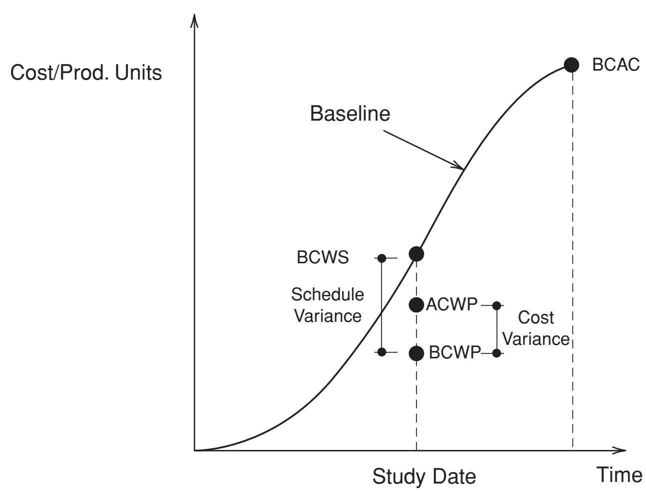


Figure 15.10 Control Values for Earned Value Analysis.

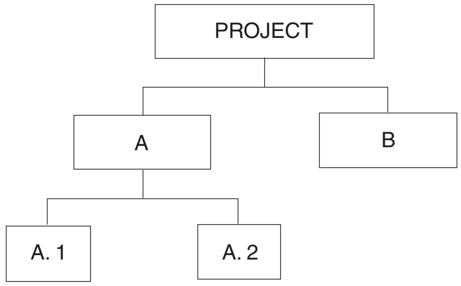


Figure 15.11 A Simple Project Hierarchy.

In order to put these terms into context, consider the small project shown in Figure 15.11. The project consists of two control accounts—“A” and “B”. “A” consists of two sub-accounts, A.1 and A.2. The study date (e.g., September 1, etc.) information for these work packages is given in Table 15.2. In this example, the budget is expressed in worker hours so the baseline for control is in worker hours. The estimated total number of worker hours for this scope of work is 215 (the sum of the estimated worker hours for A.1, A.2, and B). The BCWP or earned value for a given work package is given as:

$$\mathrm{BCWP}_i = \mathrm{PC}_i \times \mathrm{BCAC}_i$$

where i is the work package or account label, and PC is the percent complete as of the study date.

The percent complete (PC) for each package is based on the ratio of the Actual Quantities (AQWP) divided by the Budgeted Quantity at Completion (BQAC) based on the latest quantity assessment. If we know the original quantity estimate is 100 units but updated information indicates that a total of 120 units will be required to complete the work, completion of 50 units would not indicate 50 percent complete. The correct PC would be 50/120 (e.g., AQWP/BQAC).

Based on the information in Table 15.2, the PC for each work package in the small project would be:

$$\mathrm{PC\ (A.1)} = 35/105 = 0.333$$
$$\mathrm{PC(A.2)} = 60/77 = 0.780$$
$$\mathrm{PC(B)} = 100/125 = 0.800$$

Then

$$\mathrm{BCWP\ (Project)} = .333\ (100) + .78\ (50) + .8\ (65) = 33.3 + 39 + 52 = 124.3$$

Table 15.2 Study Date Data for Simple Project

	BCAC	ACWP	BQAC	AQWP	PC (%)	BCWP	ECAC
A							
A.1	100	40	105	35	33.3	33.3	120
A.2	50	35	77	60	78.0	39.0	45
B	65	50	125	100	80.0	52.0	62.5
TOTAL	215	125	—	—	57.8	124.3	227.5

Project PC (PPC) = Total BCWP ÷ Total BCAC = 124.3 ÷ 215 = 57.8%
$\mathrm{ECAC_i}$ = Estimated Cost at Completion for Work Package i = $\mathrm{ACWP_i} \div \mathrm{PC_i}$

Therefore, the Project Percent Complete (PPC) for the small project is:

$$\text{PPC } \{124.3/215\} \times 100 = 57.8 \text{ percent}$$

This simple example illustrates several points:

1. The PC for a given package is based on the ratios of the AQWP/BQAC.
2. The PPC is calculated by relating the total BCWP (i.e., earned value) to the total BCAC for the project scope of work.
3. The total work earned is compared to the work required. The values of units to be earned are based on the originally budgeted units in an account/work package and the percent earned is based on the latest projected quantity of units at completion.

Worker hours are used to here to demonstrate the development of the PPC. However, other cost or control units may be used according to the needs of management.

It is very important to know that schedule and cost objectives are being achieved. Schedule and cost performance can be characterized by cost and schedule variances as well as cost performance and schedule performance indices. These values in C/SCSC are defined as follows:

$$\text{CV, Cost Variance} = \text{BCWP} - \text{ACWP}$$
$$\text{SV, Schedule Variance} = \text{BCWP} - \text{BCWS}$$
$$\text{CPI, Cost Performance Index} = \text{BCWP/ACWP}$$
$$\text{SPI, Schedule Performance Index} = \text{BCWP/BCWS}$$

Figures 15.12 a, b, and c plot the values of BCWP, ACWP, and BCWS for the small project data given in Table 15.2. At any given study date, management will want to know what are the cost and schedule variance for each work packages. The variances can be calculated as follows:

$$\text{CV (A.1)} = \text{BCWP (A.1)} - \text{ACWP (A.1)} = 33.3 - 40 = -6.7$$
$$\text{CV (A.2)} = \text{BCWP (A.2)} - \text{ACWP (A.2)} = 39 - 35 = +4$$
$$\text{CV (B)} = \text{BCWP (B)} - \text{ACWP (B)} = 52 - 50 = +2$$

Since the CV values for A.2 and B are positive, those accounts are within budget (i.e., the budgeted cost earned is greater than the actual cost). In other words, less is being paid in the field than was originally budgeted. The negative variance for A.1 indicates it is overrunning budget. That is, actual cost is greater than the cost budgeted.

This is confirmed by the values of the CPI for each package.

$\text{CPI (A.1)} = 33/40 < 1.0$ A value less that 1.0 indicates cost overrun of budget.
$\text{CPI (A.2)} = 39/35 > 1.0$
$\text{CPI (B)} = 52/50 > 1.0$ Values greater than 1.0 indicate actual cost less than budgeted cost

The schedule variances for each package are as follows:

$$\text{SV (A.1)} = \text{BCWP (A.1)} - \text{BCWS (A.1)} = 33.3 - 50 = -16.7$$
$$\text{SV (A.2)} = \text{BCWP (A.2)} - \text{BCWS (A.2)} = 39 - 32 = +7$$
$$\text{SV (B)} = \text{BCWP (B)} - \text{BCWS (B)} = 52 - 45 = +7$$

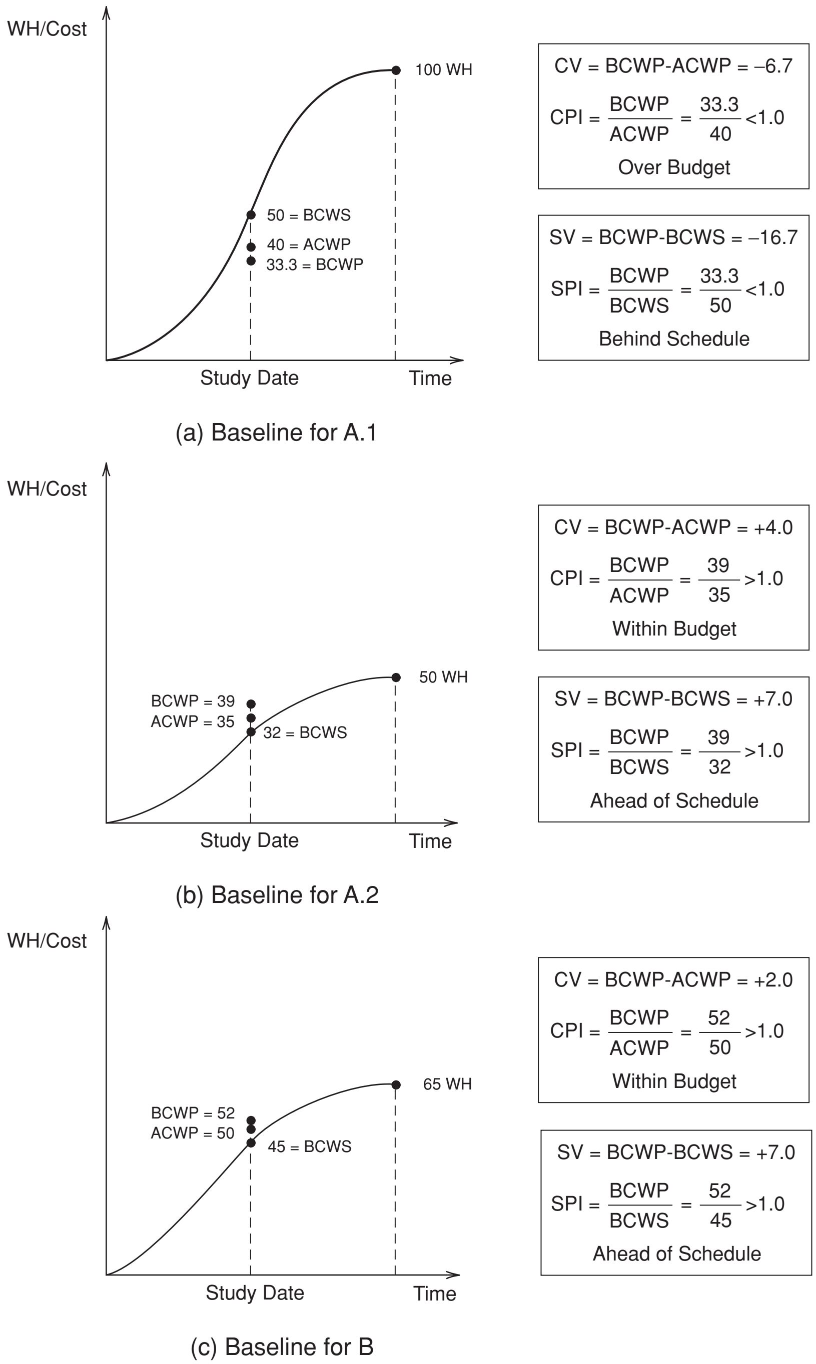


Figure 15.12 States of Control Account for Single Project.

The positive values for A.2 and B indicate that these items are ahead of schedule. The negative value for A.1 indicates a scheduling problem. The calculation of the SPI values will confirm this assessment. Overall, it can be stated that A.2 and B are ahead of schedule and below cost while A.1 is behind schedule and over cost.

Six scenarios for permutations of ACWP, BCWP, and BCWS are possible as established by Singh (Singh, 1991). The various combinations are shown in Figure 15.13 and Table 15.3.

The reader is encouraged to verify the information in Table 15.3.

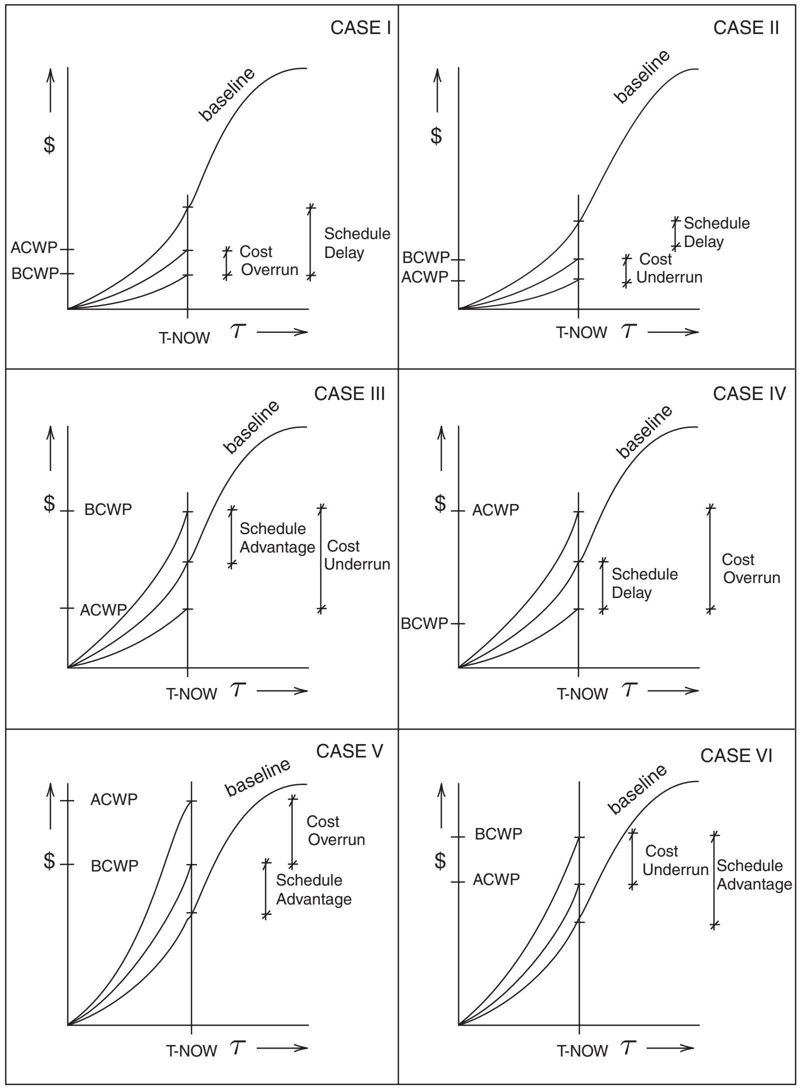


Figure 15.13 Scenarios for Permutations Between ACWP, BCWP, and BCWS (Singh, 1991).

The "earned" value approach requires a comprehensive knowledge of work packaging, budgeting, and scheduling. It is a data intensive procedure and requires the acquisition of current data on the ACWP and AQWP for each work package or account. It is a powerful tool, however, when management is confronted with complex projects consisting of hundreds of control accounts. In large projects consisting of thousands of activities and control accounts, it is a necessity. Without it, projects can quickly spiral out of control. A more detailed presentation of this topic is beyond the scope of this chapter. The interested reader should refer to current government publications which describe the Earned Value Management System (EVMS) and the inherent procedures associated with its implementation.

15.8 LABOR COST DATA COLLECTION

The purpose of the payroll system is to (1) determine the amount of and disburse wages to the labor force, (2) provide for payroll deductions, (3) maintain records for tax and other purposes, and (4) to provide information regarding labor expenses. The source document

Table 15.3 Values of CPI, CV, and SPI, SV for the Six Scenarios (Singh, 1991)

CPI < 1, CV < 0 → overrunning cost SPI < 1, SV < 0 → behind schedule CASE I	CPI > 1, CV > 0 → within budget SPI < 1, SV < 0 → behind schedule CASE II
CPI > 1, CV > 0 → within budget SPI > 1, SV > 0 → ahead of schedule CASE III	CPI < 1, CV < 0 → overrunning cost SPI < 1, SV < 0 → behind schedule CASE IV
CPI < 1, CV < 0 → overrunning cost SPI > 1, SV > 0 → ahead of schedule CASE V	CPI > 1, CV > 0 → within budget SPI > 1, SV > 0 → ahead of schedule CASE VI

used to collect data for payroll is a daily or weekly time card for each hourly employee similar to that shown in Figure 15.14. This card is usually prepared by foremen, checked by the superintendent or field office engineer, and transmitted via the project manager to the head office payroll section for processing. The makeup of the cards is such that the foreman or timekeeper has positions next to the name of each employee for the allocation of the time worked on appropriate cost subaccounts. The foreman in the distribution made in Figure 15.14 has charged 4 hours of A. Apple's time to an earth excavation account and 4 hours to rock excavation. Apple is a code 15 craft, indicating that he is an operating engineer (equipment operator). As noted, this distribution of time allows the generation of management information aligning work effort with cost center. If no allocation is made, these management data are lost.

The flow of data from the field through preparation and generation of checks to cost accounts and earnings accumulation records is shown in Figure 15.15.

This data structure establishes the flow of raw data or information from the field to management. Raw data enter the system as field entries and are processed to service both payroll and cost accounting functions. Temporary files are generated to calculate and produce checks and check register information. Simultaneously, information is derived from the field entries to update project cost accounts. These quantity data are not required by the financial accounting system and can be thought of as management data only.

From the time card, the worker's ID (badge number), pay rate, and hours in each cost account are fed to processing routines that cross check them against the worker data (permanent) file and use them to calculate gross earnings, deductions, and net earnings. Summations of gross earnings, deductions, and net earnings are carried to service the legal reporting requirements placed on the contractor by insurance carriers (Public Liability and Property Damage, workmen's compensation), the unions, and government agencies (e.g., Social Security and Unemployment).

Dewey, Cheatum, and Howe
Company

Report No. 16 | DAILY LABOR DISTRIBUTION REPORT | Date 12 September 04

Job No. 101

Foreman's signature: Don Duck | Location: Peachtree Corners Shopping Mall

Description of work performed and cost account number: 80,103 | 80,104 | 80,260.01 | 80,260.07

Employee or badge number	Name	Code	Craft or union	Rate	Hours (80,103)	Hours (80,104)	Hours (80,260.01)	Hours (80,260.07)	Hours	Hours	Total hours ST	Total hours PT
65	Adam Apple	ST	15	16.50	4	4					8	0
		PT										
14	Ella Del Fabbro	ST	10	12.50			8				8	0
		PT										
22	Charles Hoarse	ST	10	12.50			6	2			8	0
		PT										
		ST										
		PT										
		ST										
		PT										
		ST										
		PT										
		ST										
		PT										
		ST										
		PT										
		ST										
		PT										
Approved by				Totals	4	4	14	2			24	0

Figure 15.14 Foreman's daily labor distribution report.

15.9 CHARGES FOR INDIRECT AND OVERHEAD EXPENSE

Contractor-incurred expenses associated with the construction of a given facility relate to:

1. Direct cost consumed in the realization of a physical subelement of the project (e.g., labor and material costs involved in pouring a slab).
2. Production support costs incurred by the project-related support resources or required by the contractor (e.g., superintendent's salary, site office costs, various project related insurances) costs associated with the operation and management of the company as a viable business entity (e.g., home office overhead, such as the costs associated with preparation of payroll in the home office, preparation of the estimate, marketing, salaries of company officers).

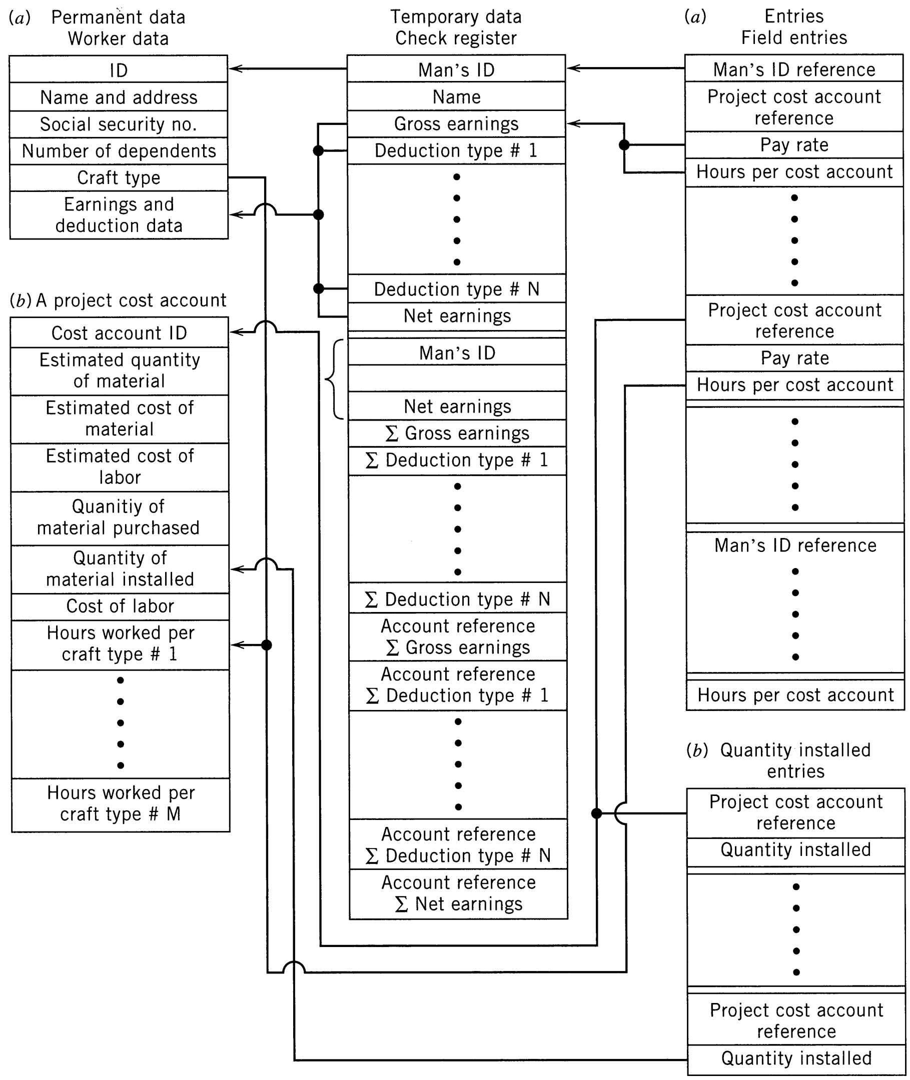


Figure 15.15 Payroll data structure.

The production support costs are typically referred to as project indirect costs. The home office charges are normally referred to as home office overhead. All of these costs must be recovered before income to the firm is generated. The home office overhead, or general and administrative (G&A) expense, can be treated as a period cost and charged separately from the project (direct costing). On the other hand, they may be prorated to the job and charged to the job cost overhead accounts and the work-in-progress expense ledger accounts (absorption costing).

15.10 PROJECT INDIRECT COSTS

Job-related indirect costs such as those listed in the labor cost report of Figure 15.16 (e.g., haul trash) are typically incurred as part of the on-site related cost associated with realizing the project. As such, they are charged to appropriate accounts within the job cost system. The level and amount of these costs should be projected during the estimating phase and included in the bid as individual estimate line items. Although it is recommended that job indirect

CENTURY CENTER BLDG #5 — **LABOR COST REPORT** — **WEEK 57** — **WEEK ENDING 10/11**
HALCON CONSTRUCTORS, INC.
ATLANTA DIVISION — **PAGE 1** — **PROJECT NUMBER 13-5265**
ATLANTA, GA

Cost Code	Cost Code Information			Quantity		Unit	Price		Cost	Projected Cost	
	Description	Units	% Comp	Estimated	Actual	Estimated	Actual	Estimated	Actual	To Date Over/Under	To Complete Over/Under
111	**This Week**		2		1		248.000		248	48	
	Haul Trash	Wk	68	50	34	200.000	92.765	10,000	3,154	3,646-	1,716-
112	**This Week**		1		1		543.000		543	326	
	Daily Clean	Wk	68	69	47	217.391	311.596	15,000	14,645	4,428	2,072
115									1,747	1,747	No Budg.
130	**This Week**		1		1		13.000		13	204-	
	Safety	Wk	81	69	56	217.391	206.304	15,000	11,553	621-	144-
131	Protect Trees	Ls						500	31		
132	Shoring	Ls	100	18	18	1,388.889	1,345.389	25,000	24,217	783-	Comp.
307	**This Week**		1		5		19.600		98	4	
	Hand Exc	Cy	97	725	705	18.793	19.569	13,625	13,796	547	15
310	Dewater	Ls	100					2,000	2,060	60	Comp.
312	Bkfl Hand	Cy	83	6,000	5,000	1.500	1.291	9,000	6,453	1,047-	209-
316	Fine Gr	Sf	99	15,000	14,830	.167	.135	2,500	1,999	501-	Comp.

Figure 15.16 Labor cost report (some typical line items).

be precisely defined during estimate development, many contractors prefer to handle these charges by adding a flat rate amount to cover them. Under this approach, the contractor calculates the direct costs (as defined above) and multiplies these charges by a percentage factor to cover both project indirects and home office fixed overhead. To illustrate, assume that the direct costs for a given project are determined to be \$200,000. If the contractor applies a fixed factor of 20% to cover field indirects and home office overhead, the required flat charge would be \$40,000. If he adds 10% for profit, his total bid amount would be \$264,000.

The estimate summary shown in Figure 13.3 establishes line items for indirect charges and calculates them on an item-by-item basis (rather than applying a flat rate). Typical items of job-related indirect cost that should be estimated for recovery in the bid are those listed in Figure 15.2 as project overhead accounts (700–999). This is the recommended procedure since it is felt that sufficient information is available to the contractor at the time of bid to allow relatively precise definition of these job-related indirect costs. The R. S. Means method of developing overhead and profit (illustrated in Fig. 13.7) represents a percentage rate approach that incorporates a charge into the estimate to cover overhead on a line item-by-item basis. This is essentially a variation of the flat rate application described above.

15.11 FIXED OVERHEAD

Whereas the project indirect charges are unique to the job and should be estimated on a job-by-job basis, home office overhead is a more or less fixed expense that maintains a constant level not directly tied to individual projects. In this case, the application of a percentage rate to prorate or allocate home office expense to each project is accepted practice, since it is not reasonable to try to estimate the precise allocation of home office to a given project. Rather, a percentage prorate or allocation factor is used to incorporate support of home office charges into the bid.

The calculation of this home office overhead allocation factor is based on:

1. The general and administrative (G&A) (home office) expenses incurred in the past year
2. The estimated sales (contract) volume for the coming year
3. The estimated gross margin (i.e., markup) for the coming year. This procedure is illustrated in the following example (Adrian, 1998).

Step 1: Estimate of Annual Overhead (G&A Expense)

Last year's G&A	\$270,000
10% inflation	27,000
Firm growth	23,000
Estimated G&A	\$320,000

Step 2: Estimate of \$ of Cost Basis for Allocation

Estimated volume	\$4,000,000
Gross margin	20% = \$800,000
Labor and material	\$3,200,000

Step 3: Calculate Overhead Percent

$$\frac{\text{Overhead costs estimated (G\&A)}}{\text{Labor and material estimate}} = \frac{320{,}000}{3{,}200{,}000} = 10\%$$

Step 4: Cost to Apply to a Specific Project

Estimated labor and material costs	\$500,000
Overhead to apply (@10 percent)	50,000
	\$550,000

In the example, the anticipated volume for the coming year is \$4,000,000. The G&A expense for home office operation in the previous year was \$270,000. This value is adjusted for inflation effects and expected expansion of home office operations. The assumption is that the overhead allocation factor will be applied to the direct labor and materials costs. These direct costs are calculated by factoring out the 20% gross margin. Gross margin, in this case, refers to the amount of overhead and profit anticipated.

Direct costs amount to \$3,200,000. The \$320,000 in G&A costs to be recovered indicate a 10% prorate to be applied against the \$3,200,000 of direct costs. This means that an overhead amount of \$50,000 would be added to a contract bid based on \$500,000 of direct cost to provide for G&A cost recovery. The profit would be added to the \$550,000 base recovery amount.

15.12 CONSIDERATIONS IN ESTABLISHING FIXED OVERHEAD

In considering costs from a business point of view, it is common to categorize them either as variable costs or fixed costs. Variable costs are costs directly associated with the production process. In construction they are the direct costs for labor, machines, and materials as well as the field indirect costs (i.e., production support costs). These costs are considered variable since they vary as a function of the volume of work underway. Fixed costs are incurred at a more or less constant rate independent of the volume of work in progress. In order to be in business, a certain minimum of staff in the home office, space for home office operations, telephones, supplies, and the like must be maintained, and costs for these items are incurred. These central administrative costs are generally constant over a given range of sales/construction volume. If volume expands drastically, home office support may have to be expanded also. For purposes of analysis, however, these costs are considered fixed or constant over the year. Fixed costs are essentially the general and administrative costs referred to above.

As described in Section 15.11, the level of G&A (fixed) costs can be estimated by referring to the actual costs incurred during the previous year's operation. The method of projecting fixed overhead as a percentage of the estimated total direct costs projected for the coming year is widely used. Since the fixed overhead incurred in the previous year is typically available as a percentage of the previous year's total sales volume, a simple conversion must be made to reflect it as a percentage of the total direct cost. The formula for this conversion is

$$P_c = \frac{P_s}{(100 - P_s)}$$

where P_c = percentage applied to the project's total direct cost for the coming year

P_s = percentage of total volume in the reference year incurred as fixed or G&A expense

If, for instance, \$800,000 is incurred as home office G&A expense in a reference year in which the total volume billed was \$4,000,000, the P value would be 20% (\$800,000/\$4,000,000 $\times$ 100). The calculated percentage to be added to direct costs estimates for the coming year to cover G&A fixed overhead would be

$$P_c = \frac{20}{100 - 20} = 25\%$$

If the direct cost estimate (e.g., labor, materials, equipment, and field indirects) for a job is $1,000,000, $250,000 would be added to cover fixed overhead. Profit would be added to the total of field direct and indirects plus fixed overhead. The field (variable) costs plus the fixed overhead (G&A) charge plus profit yield the bid price. In this example, if profit is included at 10%, the total bid would be $1,375.000. It is obvious that coverage of the field overhead is dependent on generating enough billings to offset both fixed and variable costs.

Certain companies prefer to include a charge for fixed overhead that is more responsive to the source of overhead support. The assumption here is that home office support for management of certain resources is greater or smaller, and this effect should be included in charging for overhead. For instance, the cost of preparing payroll and support for labor in the field may be considerably higher than the support needed in administering materials procurement and subcontracts. Therefore, a 25% rate for fixed overhead is applied to labor and equipment direct cost, while a 15% rate on materials and subcontract costs is used. If differing fixed overhead rates are used on various subcomponents of the field (variable) costs in the bid, the fixed overhead charge will reflect the mix of resources used. This is shown in Table 15.4 in which a fixed rate of 20% on the total direct costs for three jobs is compared to the use of a 25% rate on labor and equipment and a 15% rate on materials and subcontracts.

It can be seen that the fixed overhead amounts using the 25/15% approach are smaller on jobs 101 and 102 than the flat 20% rate. This reflects the fact that the amount of labor and equipment direct cost on these projects is smaller than the materials and subcontract costs. The assumption is that support requirements on labor and equipment will also be proportionately smaller. On job 102, for instance, it appears that most of the job is subcontracted with only $200,000 of labor and equipment in house. Therefore, the support costs for labor and equipment will be minimal, and the bulk of the support cost will relate to management of materials procurement and subcontract administration. This leads to a significant difference in fixed overhead charge when the 20% flat rate is used, as opposed to the 25/15% modified rates (i.e., $440,000 vs. $350,000).

On job 103, the fixed overhead charge is the same with either of the rate structures, since the amount of labor and equipment cost is the same as the amount of the materials and subcontract cost.

Table 15.4 Comparison of Fixed Overhead Rate Structures

			20% on Total Direct	25% on Labor and Equipment; 15% on Material and Subcontracts
	Labor and equipment	$ 800,000	$160,000	$200,000
Job 101	Materials and subcontracts	$1,200,000	240,000	180,000
			$400,000	$380,000
	Labor and equipment	200,000	$ 40,000	$ 50,000
Job 102	Materials and subcontracts	2,000,000	400,000	300,000
			$440,000	$350,000
	Labor and equipment	700,000	$140,000	$175,000
Job 103	Materials and subcontracts	700,000	140,000	105,000
			$280,000	$280,000

It should be obvious that in tight bidding situations use of the stylized rate system, which attempts to better link overhead costs to the types of support required, might give the bidder an edge in reducing his bid. Of course, in the example given (i.e., the 25/15% rate vs. 20%) the 20% flat rate would yield a lower overall charge for fixed overhead on labor- and equipment-intensive jobs. The main point is that the charge for fixed overhead should be reflective of the support required. Because the multiple rate structure tends to reflect this better, some firms now arrive at fixed overhead charges by using this approach rather than the flat rate applied to total direct cost.

REVIEW QUESTIONS AND EXERCISES

15.1 As a construction project manager, what general categories of information would you want to have on a cost control report to properly evaluate what you think is a developing overrun on an operation, "place foundation concrete," that is now under way and has at least 5 weeks to go before it is completed?

15.2 What are the major functions of a project coding system?

15.3 List advantages and disadvantages of the UCI coding system.

15.4 Assume you are the cost engineer on a new $12 million commercial building project. Starting with your company's standard cost code, explain how you would develop a project cost code for this job. Be sure the differences in purpose and content between these two types of cost codes are clear in your explanation. Specify any additional information that may be needed to draw up the project cost code.

15.5 Develop a cost code system that gives information regarding:

- **a.** When project started
- **b.** Project number
- **c.** Physical area on project where cost accrued
- **d.** Division in Uniform Construction Index
- **e.** Subdivision
- **f.** Resource classification (labor, equipment)

15.6 The following planned figures for a trenching job are available:

Quantity	**Resources (hours)**	**Cost**
Excavation—	Machines 1000	$100,000
second hauling	Labor 5000	$100,000
100,000 cu yd	Trucks 2000	$ 62,500

At a particular time during the construction, the site manager realizes that the actual excavation will be in the range of 110,000 cu yd. Based on the new quantity, he figures that he will have 30,000 cu yd left.

From the main office, the following job information is available:

Resources		**Cost**
Machines	895 hours	85,000
Labor	6011 man-hours	79,000
Trucks	1684 hours	50,140

What would concern you as manager of this job?

15.7 Categorize the following costs as (a) direct, (b) project indirect, or (c) fixed overhead:

Labor

Materials

Main office rental

Tools and minor equipment

Field office

Performance bond

Sales tax

Main office utilities

Salaries of managers, clerical personnel, and estimators

15.8 The following data are available on Del Fabbro International, Inc. The fixed (home office) overhead for the past year was $365,200. Total volume was $5,400,000. It is assumed that G&A costs will account for $1,080,000 of this volume. Del Fabbro uses a profit markup of 10%. The estimating department has indicated that the direct and field indirects for a renovation job will be $800,000. What bid price should be submitted to ensure proper coverage of fixed overhead? Assume a 5% inflation factor and a 12% growth factor in the calculation.

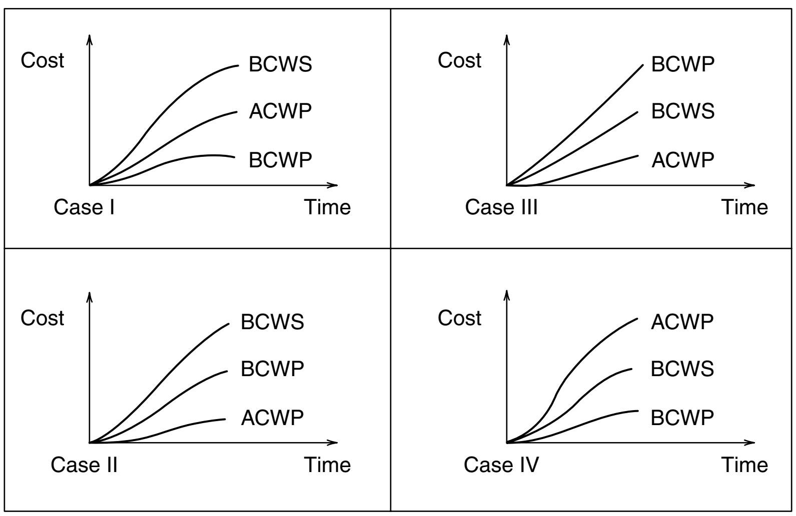
15.9 Calculate the cost and scheduling variances for each of the work packages shown. What is the percent complete for the entire package?

	WORK HOURS			QUANTITIES		
	EST	ACT	FORECAST	EST	ACT	FORECAST
A	15000	8940	15500	1000	600	1100
B	2000	1246	1960	200	93	195
C	500	356	510	665	540	680

15.10 Draw a Hierarchical diagram of the work packages given, using the WBS code values. Calculate the BCWP and *percent complete* for all codes and work packages to include A.00 and B.00. Finally, compute the total percent complete of the project.

		WORK HOURS			QUANTITIES		
CODE	DESCRIPTION	EST	ACT	FORECAST	EST	ACT	FORECAST
A. 00	E/W Duct	440					
A.10	Partitions	230	150	225	25	14	25
A.20	Hangers	210	130	220	3	2.2	3.8
B.00	N/W Duct	645					
B.10	Partitions	370	75	390	50	12	48
B.20	Hangers	275	85	260	16	4.5	16

15.11 Given the following diagrams of progress on individual work packages of a project answer the following questions:



(a) For Case 1, is the project ahead or behind schedule?

(b) For Case 2, is the project over or under cost?

(c) For Case 3, is the Cost Performance Index greater than 1?

(d) For Case 1, is the SPI greater than 1? Explain by calculation.

(e) For Case 4, is the project on schedule and budget or not? Explain.

Chapter 16

Material Management

Dry Dock #4 Pearl Harbor, Hawaii.

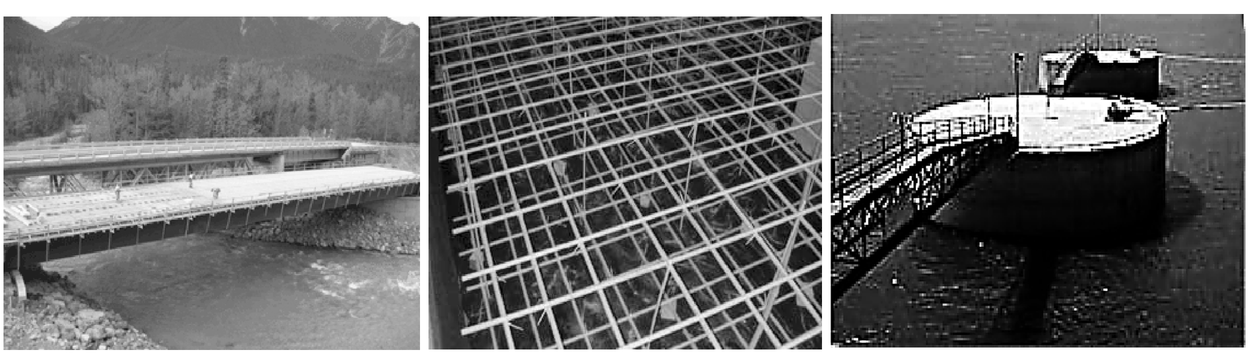
Fiber Reinforced Polymer Rebar

The Need

Reinforced concrete is a very common building material for the construction of facilities and structures. As a complement to concrete's very limited tensile strength, steel rebar has been an effective and cost-efficient reinforcement. However, insufficient concrete cover, poor design or workmanship, and the presence of large amounts of aggressive agents in the concrete as well as environmental factors all can lead to cracking of the concrete and corrosion of the steel rebar. For instance, in the United States, almost 40% of bridges are structurally deficient or functionally obsolete largely due to cracking and corrosion.

The Technology

Composite materials made of fibers embedded in a polymeric resin, also known as fiber-reinforced polymers (FRPs), have become an alternative to steel reinforcement for concrete structures. Aramid fiber-reinforced polymer (AFRP), carbon fiber-reinforced polymer (CFRP), and glass fiber-reinforced polymer (GFRP) rods are commercially available products for use in the construction industry. They have been proposed for use in lieu of steel reinforcement or steel prestressing tendons in nonprestressed or prestressed concrete structures. The problems of steel corrosion are avoided with the use of FRPs because FRP materials are nonmetallic and noncorrosive. In addition, FRP materials exhibit several properties including high tensile strength, which make them suitable for use as structural reinforcement. Fiberglass rebar may be a suitable alternative to steel reinforcing in architectural concrete, in concrete exposed to de-icing or marine salts, and in concrete used near electromagnetic equipment.



Caissons and port facilities.

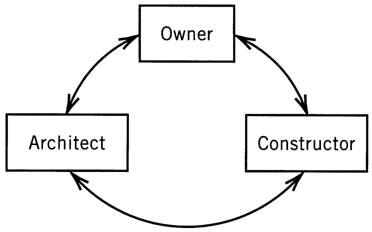


Figure 16.1 The owner–architect–construction relationship.

16.1 MATERIAL MANAGEMENT PROCESS

In the traditional contractual relationship, the owner contracts with a general contractor or construction manager to build his facilities and with an architect to perform the design. The general contractor, through this contract with the owner, is obligated to perform the work in accordance with the architect's instructions, specifications, and drawings. Thus, the architect is the owner's agent during the design and construction of a project. The lines of communication between the three parties are established as shown in Figure 16.1.

The materials that comprise facilities in building construction are subject to review by the architect or design professional. The contractor usually delegates responsibility for some of the categories of work involved in the project to subcontractors and suppliers. This delegation is accomplished through subcontracts and purchase orders. As a result of this delegation, a distinct life cycle evolves for the materials that make up the project. The four main phases of this cycle are depicted in Figure 16.2.

16.2 THE ORDER

When the contract for construction is awarded, the contractor immediately begins awarding subcontracts and purchase orders for the various parts of the work. How much of the work is subcontracted depends on the individual contractor. Some contractors subcontract virtually all of the work in an effort to reduce the risk of cost overruns and to have every cost item assured through stipulated-sum subcontract quotations. Others perform almost all the work with their own field forces.

The subcontract agreement defines the specialized portion of the work to be performed and binds the contractor and subcontractor to certain obligations. The subcontractor, through the agreement, must provide all materials and perform all work described in the agreement. The Associated General Contractors (AGC) of America publish the *Standard Subcontract Agreement* for use by their members.

A sample of this agreement can be found in Appendix G. Most contractors either adopt a standard agreement, such as that provided by the AGC, or implement their own agreement. In most cases, a well-defined and well-prepared subcontract is used for subcontracting work.

All provisions of the agreement between the owner and contractor are made part of the subcontract agreement by reference. The most important referenced document in the subcontract agreement is the General Conditions. Procedures for the submittal of shop drawings and samples of certain materials are established in the General Conditions. The General Conditions provide that "Where a Shop Drawing or Sample is required by the

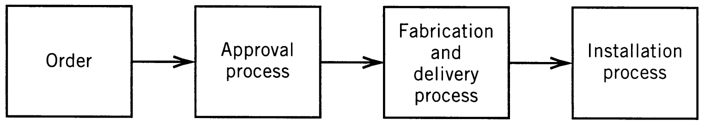


Figure 16.2 Material life cycle.

Special Purchase Order

HCB HENRY C BECK COMPANY

VENDOR:

MAIL INVOICE TO:
HENRY C. BECK COMPANY
1210 S. Old Dixie Highway
Jupiter, Florida 33458

DATE:

CHG. TO JOB #21330 ____

SHIP TO: 1210 S. Old Dixie Highway / Jupiter, Florida 33458

QUANTITY	ARTICLE	U.P.	AMOUNT	COST CODE

STATE AND LOCAL SALES TAXES MUST BE SET OUT SEPARATELY ON INVOICE

Invoice in Triplicate
To Above Address
No Later Than 25th of Month — Vendor's Acceptance (when required) SUPT. OR PROJECT MGR.
Show S.P.O. Number On Invoice WHITE (ORIGINAL) - VENDOR'S COPY PINK - SUPERINTENDENT'S COPY
CANARY - JOB OFFICE COPY GOLDENROD - PROJECT MANAGER'S COPY
(MAIL TO DALLAS WITH INVOICE)

Figure 16.3 Field purchase order (courtesy of Henry C. Beck Co.).

Contract Documents. . . , any related Work performed prior to ENGINEER's review and approval of the pertinent submittal will be at the sole expense and responsibility of the CONTRACTOR."

The purchase order is a purchase contract between the contractor and the supplier. This document describes the materials to be supplied, their quantities, and the amount of the purchase order.

Purchase orders vary in complexity and can be as simple as a mail order house (e.g., Sears) order form, or as complex as the construction contract itself. When complex and specially fabricated items are to be included in the construction, very detailed specifications and drawings become part of the purchase order. Some typical purchase order forms are shown in Figures 16.3 and 16.4. Figure 16.3 shows a form for field-purchased items procured from locally available sources. These items are usually purchased on a cash-and-carry basis. The purchase order in this case is used primarily to document the purchase for record-keeping and cost accounting purposes (rather than as a contractual document). A more formal purchase order used in a contractual sense is shown in Figure 16.4. It is used in the purchase of more complex items from sources that are remote to the site.

Regardless of the complexity of the transaction, certain basic elements are present in any purchase order. Five items can be identified as follows:

1. Quantity or number of items required.
2. Item description. This may be a standard description and stock number from a catalog or a complex set of drawings and specifications.
3. Unit price.
4. Special instructions.
5. Signatures of agents empowered to enter into a contractual agreement.

Letter or transmittal form accompanying this order when mailed to Vendor should show the number of shop drawings and/or samples to be furnished and the address to which they must be sent; also the address to which Vendor is to mail correspondence relating to this order.

PURCHASE ORDER

HCB HENRY C BECK COMPANY

No.

VENDOR
ADDRESS

______________________19____

JOB:
Job Mailing Address:

Please ship the following to HENRY C. BECK COMPANY, at

SHIP VIA:

It is agreed that shipment will be made on or before or right is reserved to cancel order.

IMPORTANT NOTE: It is IMPERATIVE in the interest of prompt payment that all invoices be rendered in the original with two (2) copies. Mail together with two (2) copies of bills of lading and/or other papers to JOB at address above.

ITEM NO.	QUANTITY	DESCRIPTION	UNIT	AMOUNT

SALES or USE TAX (is) (is not) included in amounts shown above.
F. O. B.
TERMS:

HENRY C. BECK COMPANY

By______________________

See above IMPORTANT NOTE for invoicing instructions. They MUST be complied with.

Accepted:______________________

Show above order number on invoices, and on the outside of each package containing Shipment.

By______________________

Figure 16.4 Formal purchase order (courtesy of Henry C. Beck Co.).

For simple purchase orders, the buyer normally prepares the order. If the vendor is dissatisfied with some element of the order, he may prepare his own purchase order document as a counterproposal.

The special instructions normally establish any special conditions surrounding the sale. In particular, they provide for shipping and invoicing procedures. An invoice is a billing document that states the billed price of shipped goods. When included with the shipped goods, it also constitutes an inventory of the contents of the shipment. One item of importance in the order is the basis of the price quotation and responsibility for shipment. Price quotations normally establish an FOB location at which point the vendor will make the goods available to the purchaser. FOB means Free On Board and defines the fact that the vendor will be responsible for presenting the goods free on board at some mutually

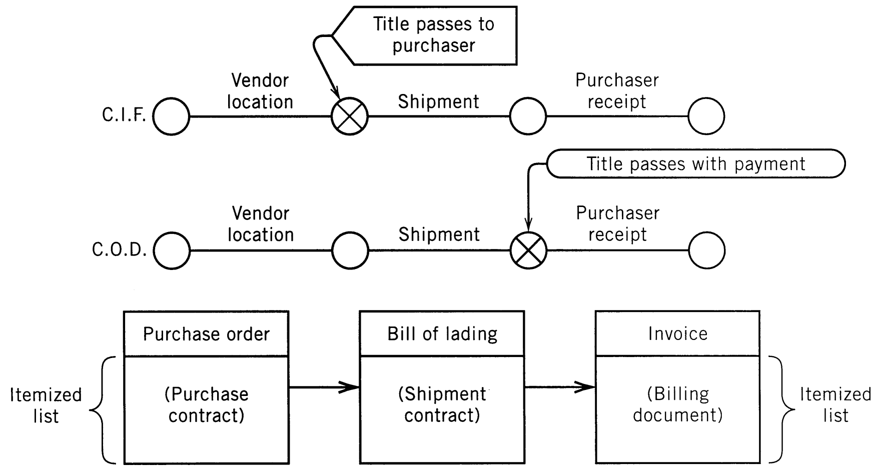


Figure 16.5 Procurement documents and title transfer sequence.

agreed-upon point such as the vendor's sales location, factory, or the purchaser's yard or job site. This is important because if the FOB location is other than the vendor's location, the vendor is indicating that the price includes shipment. The vendor may quote the price as cost, insurance, and freight (CIF). This indicates that the quoted price includes item cost plus the shipment cost to include freight and insurance expenses to the FOB location.

In the event the vendor ships the goods, it is of interest to establish at what point in time title of ownership passes from the vendor to the purchaser. This is established by the *bill of lading*. The bill of lading is a contractual agreement between a common carrier and a shipper to move a specified item or group of goods from point A to point B at a contracted price. If ownership passes to the purchaser at the vendor's location, the contract for shipment is made out between the purchaser and the common carrier. In cases in which the vendor has quoted a CIF price, he acts as the agent of the purchaser in retaining a carrier and establishing the agreement on behalf of the purchaser. The bill of lading is written to pass title of ownership at the time of pickup of the goods by the common carrier at the vendor's location. In such cases, if the common carrier has an accident and damages the goods during transfer, the purchaser must seek satisfaction for the damage since he is the owner.

If goods are to be paid cash on delivery (i.e., COD), the title of ownership passes at the time of payment. In such cases, the bill of lading is between vendor and common carrier. If damage should occur during shipment, recovery of loss falls to the vendor as owner.

The sequence of events in CIF and COD transactions is shown in Figure 16.5. This figure also indicates the relationship between order, bill of lading, and invoice. A typical bill of lading memorandum and invoice are shown in Figures 16.6 and 16.7.

The invoice normally states the payment procedures and establishes trade discounts that are available to the purchaser if payment is made in a timely fashion. Trade discounts are incentives offered by the vendor for early payment. If the purchaser pays within a specified period, he must pay the stated price minus a discount. Failure to pay within the discount period means that the full price is due and payable. Terminology relating to trade discounts is as follows:

1. ROG/AOG: The discount period begins upon receipt of goods (ROG) or arrival of goods (AOG).
2. 2/10 NET 30 ROG: This expression appearing on the invoice means 2% can be deducted from the invoiced amount if the contractor pays within 10 days of AOG/ROG. Full payment is due within 30 days of AOG/ROG.

This Shipping Order Carbon, and retained by the Agent.

Shipper's No. ____________

______________________________ Carrier's No. ____________
(Name of Carrier)

RECEIVED, subject to the classifications and tariffs in effect on the date of the issue of this Bill of Lading.

at HALLANDALE, FLA. Date 20xx From MEADOW STEEL PRODUCTS, INC.

The property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown), marked consigned, and destined as indicated below, which said carrier (the word carrier being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery of said destination, if on its own route, otherwise to deliver to another carrier on route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the terms and conditions of the Uniform Domestic Straight Bill of Lading set forth (1) in Official Southern, Western and Illinois Freight Classification in effect on the date thereof, if this is a rail or rail-water shipment, or (2) in the applicable motor carrier classification or tariff if this is a motor carrier shipment.

Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, including those on the back thereof, set forth in the classification or tariff which governs the transportation of this shipment, and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns.

Consigned to ______________________________
(Mail or street address of consignee—For purposes of notification only.)

Destination __________ State __________ Zip ______ County __________ Delivery Address* __________
(*To be filled in only when shipper desires and governing tariffs provide for delivery thereof.)

Route ______________________________

Delivering Carrier __________ Car or Vehicle Initials __________ No. __________

Figure 16.6 Typical bill of lading (courtesy of Augusta Meadow Steel Products, Inc.).

No. Packages	Kind of Package, Description of Articles, Special Marks, and Exceptions	*WEIGHT (Subject to Correction)	Class or Rate	Check Column
	REINFORCING STEEL ACCESSORIES		50	

*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is carrier's or shipper's weight.

NOTE: Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
Agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding
per

+The fibre boxes used for this shipment conform to the specifications set forth in the box maker's certificate thereon, and all other requirements of the Consolidated Freight Classification.

Subject to Section 7 of Conditions of applicable bill of lading, if this shipment is to be delivered to the consignee without recourse on the conignor the consignor shall sign the following statement:

The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

(Signature of Consignor)

If charges are to be prepaid, write or stamp here: "To Be Prepaid."

TO BE PREPAID

Received $________
to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per
(The signature here acknowledges only the amount prepaid.)

Charges Advanced:

$

+ Shipper's imprint in lieu of stamp; not a part of Bill of Lading approved by the Interstate Commerce Commission.

Agent must detach and retain this Shipping

MEADOW STEEL PRODUCTS, INC. Shipper, Per ________ **Order and must sign the Original Bill of Lading.**

Permanent post-office address of shipper **1804 SO. 31st AVE., HALLANDALE, FLA. 33009**

Figure 16.6 (*Continued*).

Bibb Steel & Supply Company INVOICE
INCORPORATED
FABRICATED STRUCTURAL STEEL

AREA CODE 912-788-7373
POST OFFICE BOX 3007
4105 BROADWAY
MACON, GA. 31205

SOLD TO Bellamy Brothers Contracting Co., Inc. DATE December 29, 1978
ADDRESS P. O. Box 218 Ellenwood, Georgia 30049 CUSTOMER'S ORDER NO.
SHIP TO Same @ Fulton-Clayton Cty's, Georgia Proj. # ACI-85-1 (154) 72 & PR-8500-2 (121) Bridge #1
VIA O. T. TERMS: Net 10th Prox.
1% PER MO. INTEREST CHARGED AFTER MATURITY.

✓	QUANTITY	DESCRIPTION	UNIT PRICE	GROSS	DISCOUNT	NET AMOUNT
		Revised lateral bracing connection for bridge #1 as designed				
		by Bibb Steel and approved by Georgia D.O.T.				$ 11 672 00
		3% Georgia Sales Tax				350 16
		1% MARTA Tax				116 72
						$ 12 138 88
		RECEIVED DATE 1-12-79 BELLAMY BROS., INC. 1654 SULLIVAN RD. COLLEGE PARK, GA 30339				
		Completes Contract-Bridge #1				

INVOICE NO. № 801 RECEIVED ABOVE IN GOOD CONDITION
RECEIVED BY

THANKS

Figure 16.7 Typical invoice (courtesy of Bibb Steel & Supply Company).

3. 2/10 PROX NET 30: A 2% cash discount is available if invoice is paid not later than the 10th of the month following ROG. Payment is due in full by the end of the following month.
4. 2/10 E.O.M.: The discount (2%) is available to the 11th of the month following ROG. Payment in full is due thereafter.

Trade discounts received are treated as earned income in financial statements.

The special conditions of the purchase order may include a "hold harmless" clause. Such clauses protect one of the parties to the purchase order from liability arising out of damages resulting from the conditions of the purchase order. A transit concrete mix company, for instance, may have the contractor submit his orders on their forms holding the vendor harmless for damages arising out of delivery of the concrete to the site. Thus, if the transit mix truck should back across a gas main on the site, rupturing it during normal delivery, liability for repair costs will accrue to the contractor since the concrete vendor is "held harmless." The converse could, of course, occur if the contractor uses his own purchase order form, which holds him harmless in such an event. These situations are not covered by normal liability insurance since such "contractually accruing" liability is considered to be outside the realm of normal liability. If the language of the order is prepared by the contractor, the hold harmless clause will operate to protect him. If the vendor's language is used, the special conditions will hold him harmless in these damages situations.

For the contractor's protection, reference is made in complex purchase orders (requiring special fabrication) to the contractor specifications and other documents that define the materials to be supplied. Specifications detail the required *shop drawings, product data*, and *samples* that must be submitted for approval prior to fabrication and delivery. The provisions of the purchase order and the subcontract agreement require the subcontractor and supplier to obtain approval for their materials.

16.3 APPROVAL PROCESS

The contract drawings prepared by the architect are generally not specific enough to facilitate accurate fabrication of the materials involved. Therefore, to produce the necessary materials for a project, subcontractors and suppliers must provide details that further amplify the contract drawings. These details can be classified into three groups: (1) shop drawings, (2) product data, and (3) samples.

Shop drawings are defined in the General Conditions as "All drawings, diagrams, illustrations, schedules, and other data or information which are specifically prepared or assembled by or for CONTRACTOR and submitted by CONTRACTOR to illustrate some portion of the Work." The detailing, production, and supplying of shop drawings are the sole responsibility of the contractor or the contracted agent. However, the design professional is responsible for verification that the supplied shop drawings correctly interpret the contract documents. Dimensions, quantities, and coordination with other trades are the responsibility of the contractor. Approved shop drawings become the critical working drawings of a project and are considered a part of the contract documents. Typically, shop drawings are submitted for materials such as reinforcing steel, formwork, precast concrete, structural steel, millwork, casework, metal doors, and curtain walls.

Product data may be submitted to illustrate the performance characteristics of the material items described by the shop drawings or may be submitted as verification that a standard product meets the contract specifications. Product data are illustrations, standard schedules, performance charts, instructions, brochures, diagrams, and other information furnished by the contractor to illustrate a material, product, or system for some portion of the work. Mill test reports, concrete mix designs, masonry fire rating tests, curtain wall wind test reports, and mechanical equipment performance tests are examples of product data.

Product data are particularly important when a subcontractor or supplier is submitting data on a product that is a variance from the contract specifications. The architect carefully analyzes the submitted data prior to rendering an approval of the substitution. Also, the product data are used extensively to coordinate the materials used by the mechanical and electrical subcontractors. The contractor must communicate the product data between these major subcontractors to ensure proper performance of their portion of the work.

Samples usually involve the finishes of a project and are physical examples of materials to be supplied. The architect may require samples of plastic laminate finishes for doors and counters, flooring, wall coverings, paint, stucco, precast concrete, ceilings, and other items. These are used by the architect in developing the overall building finish scheme.

The approval process involving shop drawings, product data, and samples has several substages that are critical to the material life cycle. These are: (1) submission by the subcontractor or supplier, (2) review of the submittal by the contractor, (3) review by the architect or design professional, and (4) return of submittal to the subcontractor or supplier.

At the time of awarding subcontracts and purchase orders, the contractor usually establishes the quantity, size, and other requirements for all submittals. In most cases, several blue line prints (usually six) are required when shop drawings are submitted for approval. The product data quantities required may range from three to six copies. The copies of a submittal may vary depending on the number of other subcontractors or vendors that must receive approved copies to coordinate their work. In all cases, careful planning of the quantity of submittals will expedite the other substages by eliminating the handling of unnecessary copies of submittals.

Timing of submittals is of utmost importance in the effective processing of material submittals. Subcontracts and purchase orders often contain language such as "all submittals must be made immediately" or "fifteen (15) days after execution of this agreement, all submittals must be made." In most cases, contractors do not preplan in detail the required submittal data from a subcontractor or supplier. The result is a landslide of submittals, most of which are not necessary, in the early stages of the project. Thus, field office personnel waste time sorting and determining the most critical submittals. A well-planned approach to scheduling submittals will ensure timely processing and better control of required submittals.

Once a submittal is received by the contractor, the process of checking for conformance with the intent of the contract documents is performed. A submittal, whether it is a shop drawing, product data, or sample, is governed by the contract drawings and specifications. The contractor's field or main office personnel in charge of submittals may make notations and comments to the designer or his engineers to clarify portions of the submittal or to correct the submittal. The submittal represents specific details of the project and is of primary importance in coordination, as well as depicting exactly what a supplier or subcontractor is providing. The contractor is required by the general conditions to *clearly* note to the architect or design professional any variation from the contract documents.

The amount of time involved in the contractor's review of submittals may vary from 1 to 5 days, depending on the nature of the submittal and its correctness. Reinforcing steel and structural steel shop drawings typically require the greatest amount of time. Also, schedules such as doors, hardware, and door frames consume a great deal of time because of the minute details that must be checked. However, the time expended in submittal processing by the contractor can most easily be controlled at this substage. It must be remembered that time spent in reviewing, checking, and coordinating submittals is one of the most effective methods of ensuring a highly coordinated and smooth running project.

Once the contractor has completed the review of a submittal, the document is transmitted to the architect for approval. The contractor may indicate on the transmittal the date when approval is needed. Here again, the amount of time required for the architect to review a submittal depends on its complexity and whether or not other engineers (i.e., mechanical, electrical, or structural) must participate in the review. As a general rule, 2–3 weeks is a good estimate for the time required by the architect to complete the review and return the submittal.

The period when a submittal is in the hands of the architect is probably the most critical substage of the approval process for materials. During this critical substage, the contractor's submittal can be "lost in the shuffle" if the architect's activities are not monitored daily. The most common method of monitoring submittals is through the use of a submittal log, which indicates the date, description, and quantity of each submittal. From this log the contractor can develop a listing of critical submittals to monitor on a daily basis. Once the submittal leaves the contractor's control in the field office, its return must be followed constantly or valuable time will be wasted.

The final substage of the approval process for a material item is the return of the submittal to the supplier or subcontractor. The submittal may be in one of the following four states when returned to the architect:

1. Approved.

2. Approved with noted corrections; no return submittal needed.

3. Approved with noted corrections; however, a final submittal is required.

4. Not approved; resubmit.

The first through third designations would release the vendor or subcontractor to commence fabrication and delivery. The fourth stage would require that the approval process be repeated. In some cases the disapproval by the architect is due to a subcontractor or supplier not communicating clearly through the submittal of the information needed. A meeting between all parties may then be arranged to seek a reasonable solution.

When the approval process is completed, the material has been accepted as part of the project. Its details have been carefully reviewed for conformance with the contract documents. Also, through this process, the item has been coordinated with all trades involved in its installation and verified for inclusion into the project. The material is now ready for fabrication and delivery.

16.4 FABRICATION AND DELIVERY PROCESS

As a submittal is returned to the subcontractor or supplier, the needed delivery date to meet the construction schedule is communicated on the transmittal, verbally, or through other correspondence. In any event, delivery requirements are established and agreed on. The supplier or subcontractor may be required to return to the contractor corrected file and field-use drawings, product data, or samples. These are used to distribute to the contractor's field personnel (i.e., superintendent or foreman) and the other subcontractors and suppliers that must utilize these final submittals.

Of the four phases of a material's life cycle the fabrication and delivery process is the most critical. Generally, the largest amount of time is lost and/or gained in this phase. The duration of the fabrication and delivery process depends directly on the nature of the material and the amount of physical transformation involved. For these reasons, the contractor must employ every available method of monitoring materials throughout the fabrication and delivery process.

Contractors generally devote the largest amount of time and effort to controlling and monitoring the fabrication and delivery phase. The term *expediting* is most commonly used to describe monitoring methods in this phase of a material item's life. Methods used to ensure timely fabrication and delivery may range from using checklists developed from the job schedule to actually including this phase as a separate activity on a job schedule. Unfortunately, the fabrication and delivery usually only become activities on the job schedule when the delivery becomes a problem. Extremely critical items requiring extended fabrication times often warrant visits by the contractor to the fabrication facility to ensure the material is actually in fabrication, and proceeding on schedule.

At the completion of fabrication, the delivery of the material is made and the final phase of the life cycle is begun. Materials delivered are checked for compliance with the approved submittal as regards quality, quantity, dimensions, and other requirements. Discrepancies are reported to the subcontractor or supplier. These discrepancies, whether they be shortages or fabrication errors, are subjected to the same monitoring and controlling processes as the entire order. Occasionally they become extremely critical to the project and must be given a great deal of attention until delivery is made.

16.5 INSTALLATION PROCESS

The installation process involves the physical incorporation into the project of a material item. Depending on how effectively materials are scheduled and expedited, materials arriving at the job site may be installed immediately, partially installed and partially stored, or completely stored for later installation. When storage occurs, the installation process becomes directly dependent on the effective storage of materials.

One of the most important aspects of the effective storage of materials is the physical protection of material items. Careful attention must be given to protection from weather hazards such as prevention of water damage or even freezing. Another important aspect is protection against vandalism and theft. Finish hardware, for instance, is generally installed over a considerable time period. A secure hardware room is usually set aside where it is sorted, shelved, and organized to accommodate the finish hardware installation process.

Location of materials stored outside the physical building on the project site or within the building must be carefully planned and organized to facilitate effective installation. In high-rise-building construction material storage, each floor can be disastrous if careful planning is not used. For instance, materials stored concurrently on a floor may include plumbing and electrical rough-in materials, ductwork, window wall framing, glazing materials, drywall studs, and other items. The magnitude of the amount of materials involved warrants meticulous layout of materials. Equally important is the storage of materials to facilitate hoisting with a minimal amount of second handling. Reinforcing steel, for instance, may be organized in a "lay-down" area and then directly hoisted as needed. Adequate lay-down areas must be provided within reach of vertical hoisting equipment.

16.6 MATERIAL TYPES

Building construction materials can be logically grouped into three major categories: (1) bulk materials that require little or no fabrication, (2) manufacturer's standard items that require some fabrication, and (3) items that are fabricated or customized for a particular project. Grouping materials into categories can be of value in determining which materials warrant major contractor control efforts. Obviously, material items that require fabrication have longer life cycles because of submittal requirements and fabrication. These materials require a great deal of control by the contractor.

The bulk material category includes those materials that require very little vendor modification and can be delivered from vendor storage locations to the job site with very little fabrication delay. Table 16.1 lists examples of typical bulk materials in building construction projects. These materials usually require only a 1- to 5-day delivery time, following execution of purchase order or subcontract and approved submittals. Submittal requirements generally include only product and performance data.

Manufacturer's standard material items include materials that are usually stocked in limited quantities and are manufactured for the project after the order is executed and submittals are approved. Table 16.2 illustrates typical materials that are included in this category. Submittal requirements include detailed shop drawings, product and performance data, and samples. Finish materials such as paints, wall coverings, floor coverings, and

Table 16.1 Typical Bulk Materials

Paving materials
Fill materials—crushed stone, soil, sand, etc.
Dampproofing membrane
Lumber and related supplies
Form materials—plywood, post shores, etc.
Ready-mix concrete
Wire mesh
Stock reinforcing steel and accessories
Masonry
Stock miscellaneous metals
Soil and waste piping
Water piping
Electrical conduit
Electrical rough-in materials—outlet boxes, switch boxes, etc.
Caulking and sealants

Table 16.2 Typical Standard Material Items

General Materials
Fencing materials
Formwork systems—metals and fiberglass pans, column forms, etc.
Brick paving
Brick or ceramic veneers
Standard structural steel members
Metal decking
Waterproofing products
Insulation products
Built-up roof materials
Caulking and sealants
Standard casework and millwork
Special doors
Metal-framed windows
Finish hardware and weather-stripping
Ceramic and quarry tile
Flooring materials
Acoustical ceilings
Paints and wallcoverings
Lath and plaster products
Miscellaneous specialties
Equipment—food service, bank, medical, incinerators, etc.
Building furnishings
Special construction items—radiation protection, vaults, swimming pools, integrated ceilings
Elevators, escalators, dumbwaiters, etc.
Mechanical and Plumbing Equipment and Materials
Fire protection equipment
Water supply equipment
Valves
Drains
Clean-outs
Plumbing fixtures
Gas-piping accessories
Pumps
Boilers
Cooling towers
Control systems
Air-handling equipment
Refrigeration units (chillers)

plastic laminates require a fully developed finish design for the project. Development of the finish design can have serious consequences on ordering and delivery of finish materials. Manufacturing and delivery times generally range from 3 to 12 weeks for these materials. These extended manufacturing and delivery times place considerable importance on planning and controlling these materials.

The fabricated category of construction materials must conform to a particular project's unique requirements. The fabricated item, however, is composed of or results from modification of standard components. Table 16.3 illustrates materials that fall into this category. Submittals required include highly detailed shop drawings, product data, and samples.

Table 16.3 Typical Fabricated Materials Items

Electrical Equipment and Materials
Busduct
Special conduit
Switchboards and panels
Transformers
Wire
Trim devices
Lighting fixtures
Underfloor duct
Communications devices
Motors and starters
Motor control centers
Electric heaters
Fire alarm equipment
Lightning protection equipment
Concrete reinforcement
Structural steel
Precast panels and decks
Stone veneers
Miscellaneous and special formed metals
Ornamental metals
Millwork
Custom casework and cabinetwork
Sheet metal work
Sheet metal veneers
Hollow metal doors and frames
Wood and plastic laminate doors
Glass and glazing
Storefront
Window walls and curtain walls

Fabrication and delivery times range from 2 weeks for items such as reinforcing steel and precast concrete to 10–12 weeks for curtainwall systems, doors and frames, and similar items.

REVIEW QUESTIONS AND EXERCISES

16.1 Name four important items of information that should be on a typical purchase order.

16.2 What are four good sources of price information about construction materials?

16.3 What is meant by the following expressions?

- **a.** CIF
- **b.** 2/10 E.O.M.
- **c.** 2/10 net 30
- **d.** ROG
- **e.** Bill of lading

16.4 Visit a local architect's office and ascertain how product data are obtained and used.

16.5 Visit a local building contractor and determine how he handles control of submittals from subcontractors to architect/engineer. What system does he use to ensure the job will not be held up due to procurement and approval delays?

16.6 Visit a construction site and determine what procedures are used for verifying receipt arrival and ensuring proper storage of materials at the site.

16.7 Determine what procedures are used for removing waste materials from a local construction (building) site. Is there any scrap value in these materials? Explain.

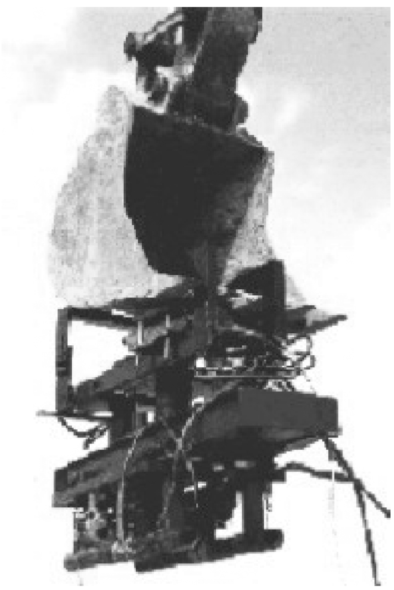
16.8 Determine the local prices for some bulk materials such as concrete, sand, cement, steel mesh, bricks, and lumber and compare them to the periodically published prices in the *Engineering News Record*.

16.9 Select a particular material item (e.g., concrete) and follow its material handling process from the local source through final installation in the building. What special equipment is needed (if any)?

16.10 What types of special materials handling equipment can be identified on local building sites? Do they take advantage of certain properties of the material being handled (e.g., the fluidity of concrete)?

Chapter 17

Safety



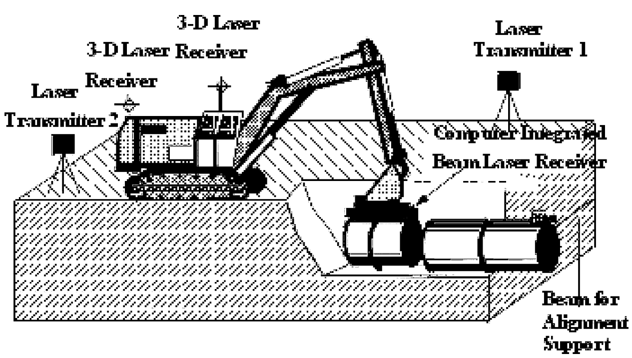
Pipe manipulator mounted on the excavator.

Safety in Trenches

The Need

Even though heavy construction equipment such as a crane or backhoe excavators is used to perform the task of pipe laying in the trench, workers are required to be inside the trench to guide the excavation, pipe laying, and final alignment. Work place safety has become a major concern in the construction industry over the past few decades, and trench cave-ins have caused serious and often fatal injuries to workers in the United States. It has become of crucial importance to implement the use of new technologies to prevent accidents in trench excavation and pipe installation.

Diverse approaches such as shoring, shielding, and sloping have been applied to protect workers from cave-ins in trenching and pipe laying operations. However, even when support systems are used, the danger of cave-ins still exist due to the nature of the soil and unexpected circumstances. The Construction Automation and Robotics Laboratory (CARL) at North Carolina State University has developed an alternative which involves advanced new technology: the prototype robotic excavation and pipe installation system called Pipeman.



Layout of the robotic trenching and pipe installation system (Huang & Bernold, 1993).

Overview of pipe manipulator.

The Technology

The basic Pipeman concept consists of a 3-D spatial positioning system (SPS), which is interfaced with an excavator to provide the location of the excavator and a beam laser. A pipe manipulator prototype is attached to the bucket of the excavator, which is capable of handling pipes of various sizes. A beam laser is also used to help the operator align pipes.

Integration of SPS with a CAD system will update the excavator position in real-time and provide an as-built drawing of pipe laying.

The main components of the concept are the man-machine interface, actuation system, laser beam and feedback system. The man-machine interface is used to keep the operator in a safe area and allow him to guide the Pipeman intelligently, while Pipeman works in a hazardous environment.

17.1 NEED FOR SAFE PRACTICE

A disabling injury or fatal accident on the job site has negative impact on operations at many levels. Accidents cost money and affect worker morale. Because of the type of work involved in construction, many dangers exist both for the workers and for the public. For this reason, the subject of safety offers one area of noncontroversial mutual interest between management and the work force. The necessity of safe operations and of protecting and conserving lives by preventing accidents is understood by all.

Although the fatality rate in construction has been reduced within recent years, the improvement in safety record achieved by the construction industry still lags seriously behind that achieved in other hazardous industries. The annual number of fatalities in the construction industry in 2003 exceeded the number of combat deaths during the first 18 months of armed conflict in Iraq (period 2003–2004). Construction is a dangerous business.

It is the contractor's responsibility to see that everything possible is done to provide a safe working environment for the work force and the public in general. The factors that motivate safe practices at the job site are generally identified as follows:

1. Humanitarian concerns
2. Economic costs and benefits
3. Legal and regulatory considerations

Society has taken the position that because of the high health and accident potential intrinsic to the construction industry, the contractor must accept the liabilities associated with this hazardous environment and make an appropriate commitment to safe practice and accident prevention.

17.2 HUMANITARIAN CONCERNS

It is normally accepted that day-to-day living has intrinsic risks that may result in members of the society being subjected to mental and physical hardship. One of the functions of society is to minimize pain and suffering. Particularly at the level of the work site, society has defined the principle that the employer is responsible for providing a safe environment for the work force. This is based on humanitarian concern. If, for instance, a worker loses a leg because of a job-related accident and is confined to a wheelchair, the worker is, in a sense, a casualty of the workplace. Through his desire to be a participating member of society and support members of his family, the worker is injured. Society has traditionally shouldered the responsibility for this limitation on a worker's abilities. Over the past 120 years, the principle of employer liability for death and injury resulting from accidents or health hazards occurring at the workplace has been firmly established in common law. The courts have further charged the employer with the following five responsibilities[1]:

1. To provide a reasonably safe workplace

[1] Lee E. Knack, in *Handbook of Construction Management and Organization,* Bonny and Frein (eds.), Van Nostrand Reinhold, New York, 1973, Chapter 25.

2. To provide reasonably safe appliances, tools, and equipment
3. To use reasonable care in selecting employees
4. To enforce reasonable safety rules
5. To provide reasonable instructions regarding the dangers of employment

Mandatory requirements for the employer to make formal provision for injuries and deaths on the job resulted in the enactment of workmen's compensation laws in all fifty states during the first half of the twentieth century.

In 1884, Germany enacted the first workmen's compensation act, followed by Austria in 1887 and England in 1897. The U.S. federal government passed the first American compensation act in 1908 covering government employees. Following several legal battles, the Supreme Court, in 1917, declared that states could enact and enforce compulsory Workmen's Compensation Laws under their power to provide for the public health, safety, and welfare.

17.3 ECONOMIC COSTS AND BENEFITS

Safety costs can be broken into three categories as follows:

1. Direct cost of previous accidents
   a. Insurance premiums and ratings
   b. Mandatory accident prevention methods
   c. Records, safety personnel
2. Direct cost of each accident occurrence
   a. Delay to project
   b. Uninsured damages
3. Indirect cost
   a. Investigation
   b. Loss of skilled workers
   c. Loss of equipment
   d. Lost production

Direct costs from previous accidents come primarily in the form of insurance premiums, which have a significant effect on a contractor's operating expense. Workmen's compensation and liability insurance premiums can be calculated using either manual or merit rating systems. Manual rating is based on the past losses of the industry as a whole. The premium rate for compensation is normally set by the individual state Compensation Rating Bureaus. Many states are guided by or actually have their rates set by the National Council on Compensation Insurance (NCCI). The premium rates are based on factors such as classification of operations, rates of pay, the frequency and severity of accidents in a particular classification, increases in the cost of cases, and the attitudes of various industrial compensation commissions. The rates as set and approved by each state insurance commissioner are known as the manual (standard) rates. These manual rates are published periodically in the *Engineering News Record* (ENR) *Quarterly Cost Roundup* issues. A listing of some of the rates as reported in the R. S. Means *Building Construction Cost Data* is given in Figure 17.1.

The merit rating system bases premiums on a particular company's safety record. High-risk (high-accident-rated) companies are therefore penalized with higher premiums than those paid by companies with low accident rates. In this way, a good safety program can result in substantial financial savings to a company. Higher returns on jobs can be realized, and the ability to bid lower and win more jobs is greatly enhanced.

State	5651 Carpentry — 3 stories or less	5437 Carpentry — interior cab. work	5403 Carpentry — general	5213 Concrete Work — NOC	5221 Concrete Work — flat (flr., sdwk.)	5190 Electrical Wiring — inside	6217 Excavation — earth NOC	6217 Excavation — rock	5462 Glaziers	5479 Insulation Work	5443 Lathing	5022 Masonry	5474 Painting & Decorating	6003 Pile Driving	5480 Plastering	5183 Plumbing	5551 Roofing	5538 Sheet Metal Work (HVAC)	5102 Steel Erection — door & sash	5102 Steel Erection — inter., ornam.	5040 Steel Erection — structure
GA	17.96	9.28	20.73	13.67	10.87	6.80	14.05	14.05	12.74	11.08	16.74	13.30	12.36	31.91	12.09	6.44	28.45	11.02	7.94	7.94	20.82
HI	11.66	9.32	39.81	13.93	9.03	8.89	10.81	10.81	14.80	20.18	9.51	17.35	7.68	28.43	19.16	5.36	40.64	8.32	14.10	14.10	27.94
ID	19.47	7.92	19.01	15.29	8.40	5.46	8.93	8.93	12.65	20.04	8.08	15.49	17.76	23.92	11.20	7.89	29.71	11.67	8.91	8.91	33.93
IL	23.15	14.22	23.28	37.47	14.13	10.95	12.08	12.08	35.98	29.13	14.87	23.41	16.53	52.50	18.54	16.13	39.95	19.17	24.90	24.90	80.46
IN	10.50	3.84	8.29	7.80	4.12	3.25	5.28	5.28	6.34	9.18	5.01	6.14	5.27	14.99	5.93	3.63	15.91	5.30	5.64	5.64	15.31
IA	8.81	6.56	14.86	15.22	5.78	4.94	5.29	5.29	11.73	11.99	6.21	12.64	10.60	19.81	10.94	7.47	23.45	7.66	12.14	12.14	35.92
KS	18.46	7.67	12.78	16.79	10.33	6.78	8.14	8.14	10.19	15.28	9.98	15.27	9.54	26.31	19.37	7.89	33.94	9.19	8.33	8.33	26.52
KY	16.47	15.26	24.34	22.12	9.53	8.95	13.67	13.67	15.96	14.68	10.62	22.00	19.83	30.44	13.94	10.38	32.83	15.92	13.21	13.21	45.21
LA	29.63	22.95	26.01	20.86	14.80	10.48	24.73	24.73	23.88	20.82	14.00	21.27	27.63	54.39	21.42	13.78	49.11	21.35	15.51	15.51	66.41
ME	13.43	10.42	43.59	24.29	11.12	10.02	14.75	14.75	13.35	15.39	14.03	17.26	16.07	31.44	17.95	11.12	32.07	17.70	15.08	15.08	37.84

Figure 17.1 Compensation insurance base rates for construction workers (selected states and crafts).

Once the premiums reach a value of $1000, the contractor is eligible for a merit system rating. That is, the cost of the premium will be individually calculated with the safety record of the company being the critical consideration. Under the merit system, there are two basic methods utilized to incorporate the safety record into the final cost of the premium. These are referred to as the *experience* rating and *retrospective* rating methods.

Most insurance carriers use the experience rating method, which is based on the company's record for the past 3 years not including the most recent preceding year. In this system, an experience modification rate is multiplied by the manual rate to establish the premium for a given firm. Data on losses, the actual project being insured, and other variables are considered in deriving the experience modification rate (EMR). If the company has an experience modification rate of 75%, it will pay only 75% of the manual premium. Good experience ratings (EMRs) can lead to significant savings. Clough and Sears (Wiley, 1994) illustrate this with the following example:

> *Assume that a building contractor does an annual volume of $10 million worth of work. Considering a typical amount of subcontracting and the cost of materials, this general contractor's annual payroll will be of the order of magnitude of $2.5 million. If his present workmen's compensation rate averages about 8%, his annual premium cost will be about $200,000. Now assume that an effective accident prevention program results in an experience modification rate (EMR) of 0.7. This will result in a reduction of the annual premium cost to about $140,000 for this contractor. Annual savings on the order of $60,000 are thereby realized on the cost of this one insurance coverage alone.*

Retrospective rating is somewhat like self-insurance. It is basically the same as experience rating except for one point. It utilizes the loss record of the contractor for the previous year or other defined retrospective period to compute the premium. This can raise or lower the premium cost based on performance during the retrospective period. The starting point or basis for this method is again the manual premium. A percentage (usually 20%) of the standard premium resulting from applying the experience modification factor to the manual rate is used to obtain the basic premium. The retrospective rate is then calculated as

$$\text{Retrospective rate} = (\text{Tax multiplier}) \times \{\text{Basic premium} + [(\text{Incurred loss}) \times (\text{Loss conversion factor})]\}$$

The incurred loss is the amount paid out to settle claims over the retrospective period. The loss conversion factor is a percentage loading used to weight the incurred losses to cover general claims investigation and adjustment expenses. The tax multiplier covers premium taxes that must be paid to the state. If the data for a given company are as follows:

Manual premium	$25,000
Experience modification rate (25% credit)	0.75

then

Standard premium = 0.75($25,000) = $18,750
Basic premium @ 20% of standard = 0.20($18,750) = $3750
Loss conversion factor = 1.135 (derived from experience)
Tax multiplier = 1.03 (based on state tax)
Incurred losses = $10,000

Then

$$\text{Retrospective premium} = 1.03[3750 + (1.135 \times \$10{,}000)] = \$15{,}553$$

This is a nice savings over the standard premium of $18,750 and provides the contractor with a clear incentive to minimize the incurred losses. By so doing, the contractor can expect a large premium rebate at the end of the year.

17.4 UNINSURED ACCIDENT COSTS

In addition to the cost of insurance premiums, additional direct costs for things such as the salary of the safety engineer and his staff as well as costs associated with the implementation of a good safety program can be identified. The precise amount of the costs associated with other safety cost categories is more difficult to assess, and these costs can be thought of as additional uninsured costs resulting from accidents. Typical uninsured costs associated with an accident are shown in Table 17.1.

Although varying slightly from source to source, hidden losses of this variety have been estimated to be as much as nine times the amount spent on comprehensive insurance. In addition to the costs noted in Table 17.1, another cost is that of paying an injured employee to show up for work even if he cannot perform at his best. This is common practice for minor injuries. This is done to avoid recording a lost time accident, which might impact the insurance premium. While it is very common to return injured workers to work, it is

Table 17.1 Uninsured Costs

Injuries	Associated Costs
1. First-aid expenses **2.** Transportation costs **3.** Cost of investigations **4.** Cost of processing reports	**1.** Difference between actual losses and amount recovered **2.** Rental of equipment to replace damaged equipment **3.** Surplus workers for replacement of injured workmen **4.** Wages or other benefits paid to disabled workers **5.** Overhead costs while production is stopped **6.** Loss of bonus or payment of forfeiture of delays
Wage Losses	**Off the Job Accidents**
1. Idle time of workers whose work is interrupted **2.** Man-hours spent in cleaning up accident area **3.** Time spent repairing damaged equipment **4.** Time lost by workers receiving first aid	**1.** Cost of medical services **2.** Time spent on injured workers' welfare **3.** Loss of skill and experience **4.** Training replacement worker **5.** Decreased production of replacement **6.** Benefits paid to injured worker or dependents
Production Losses	**Intangibles**
1. Product spoiled by accident **2.** Loss of skill and experience **3.** Lowered production of worker replacement **4.** Idle machine time	**1.** Lowered employee morale **2.** Increased labor conflict **3.** Unfavorable public relations

Source: From Lee E. Knack, in *Handbook of Construction Management and Organization*, Bonny and Frein (eds.), Van Nostrand Reinhold, New York, 1973, Chapter 25.

important that they not be returned to work too soon to avoid their being reinjured or injured more seriously.

The following situation illustrates the additional losses resulting from hidden costs. At a large industrial construction site, the survey party chief was on the way to the office to get a set of plans. The survey crew was to lay out four machine foundations that morning. The wooden walkway beneath the party chief collapsed. Due to the confusion resulting from the accident, work activity on the entire site was impacted. The party chief was in the hospital for 5 weeks with a shattered pelvis. Another party chief who was unfamiliar with the site was assigned to the surveying crew. As a result, the four machine foundations were constructed 2 ft farther west than called for in the plans. After this was discovered, six laborers worked for 20 hours removing the reinforced concrete. The survey crew of four spent another 5 hours laying out the foundations. Four carpenters worked 20 more hours preparing new forms. Five more hours were required for the ironworkers to place the steel reinforcement. The total indirect cost was approximately $5000. Although this activity was not on the critical path, if it had been, liquidated damages might have been charged to the contractor. Still, the accident resulted in costs amounting to one week's pay for the employees affected and the cost of material that had to be replaced.

17.5 FEDERAL LEGISLATION AND REGULATION

The federal government implemented a formal program of mandatory safety practices in 1969 with the passage of the Construction Safety Act as an amendment to the Contract Work Hours Standard Act. This legislation requires contractors working on federally funded projects to meet certain requirements to protect the worker against health and accident hazards. In addition, certain reporting and training provisions were established. This program of required procedures has been referred to as a *physical* approach to achieving safety. That is, regulations are prescribed that are designed to minimize the possibility of an unsafe condition arising. A typical physical measure of this type is the requirement to install guard rails around all open floors of a multistory building during construction. Guard rails are needed anytime there is change in elevation of 6 feet and the worker is not protected by a personnel fall arrest system, warning line, or warning attendant (used to watch workers and warn them if they're too close to falling).

Furthermore, physical measures are implemented to minimize injury in the event of an accident. An example of this is the requirement to wear a safety belt when working with high steel, and the installation of safety nets to protect a man who slips and falls. This physical approach is in contrast to the behavioral approach that is designed to make all levels of the work force from top management to the laborer think in a safe way and thus avoid unsafe situations. Research on the behavioral approach is discussed in detail in Levitt and Samelson, *Construction Safety Management*.

Shortly after the passage of the Construction Safety Act, a more comprehensive approach to mandatory safe practices was adopted in the form of the Williams–Steiger Occupational Safety and Health Act (OSHA) passed by Congress in 1970. This act established mandatory safety and health procedures to be followed by all firms operating in interstate commerce.

Under this act, all employers are required to provide "employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees." The provisions of the Construction Safety Act were included in the act by reference. The provisions of OSHA fall within the jurisdiction of the secretary of labor. In 1971, the law was implemented by publishing the code of Federal Regulation (CFR) 1926 that specifically refers to the construction industry and CFR 1910 that pertains to General Standards. Many existing standards issued by various standards organizations, including the American National Standards Institute (ANSI), were

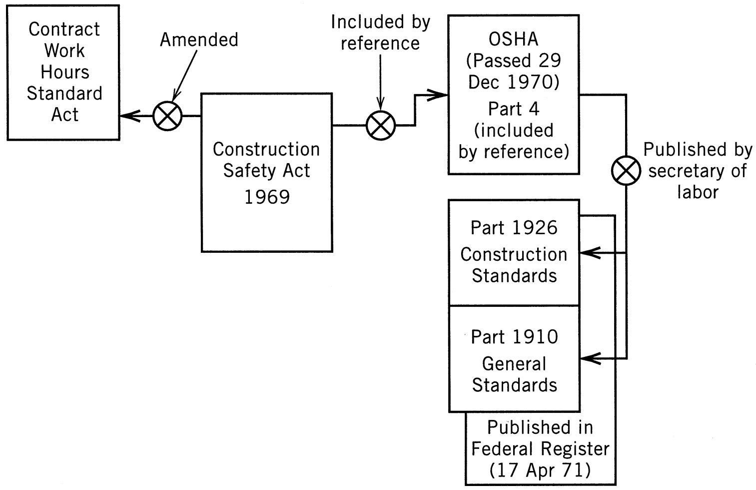


Figure 17.2 Development of OSHA legislation.

included in the basic law by reference. The schematic development of the legislation is shown in Figure 17.2 OSHA has a service for providing update information on standards that is designed to aid in keeping the six volumes of regulations current. The regulations are divided as follows:

Volume I: General Industry Standards

Volume II: Maritime Standards

Volume III: Construction Standards

Volume IV: Other Regulations and Procedures

Volume V: Field Operation Manual

Volume VI: Industrial Hygiene Manual

Under the OSHA legislation, the assistant secretary of labor for occupational safety and health administers and enforces OSHA through the labor department's Occupational Safety and Health Administration with its 10 regional offices around the country. The Occupational Safety and Health Review Commission is designed by OSHA as the review body to which citations for alleged violations and proposed penalties can be appealed. Research on safety topics is under the control of the National Institute for Occupational Safety and Health (NIOSH), which is part of the Department of Health and Human Services.

The OSHA legislation allows individual states to establish programs that operate in place of the federal program. Many contractors prefer a state-operated program since this affords a closer contact with the inspector and the regulatory agency. Appeals and requests for clarification are handled at a state level. This expedites the process of responding to citations and rectification of disputes if differences of opinion arise. The state agency must establish that it is able to administer the law as effectively as the federal government. Presently, 26 states operate approved state plans.

17.6 OSHA REQUIREMENTS

Employers must "make, keep and preserve, and make available to representatives of the Secretaries of Labor, and Health and Human Services" records of recordable occupational injuries and illnesses (Williams–Steiger Act, 1970). Any fatal or serious accidents must be reported to OSHA within 8 hours. Certain records of job-related fatalities, injuries, and illnesses must be maintained by firms having eight or more employees. The two key forms that must be available for review when a compliance officer makes an inspection are:

1. OSHA 300: This is a log that summarizes each reportable case as a single line entry and must be posted for employee inspection (see Fig. 17.3). The instructions that accompany the OSHA recordkeeping forms do include the following instructions. "You must post the Summary (Form 300A) only–not the Log (Form 300)–by February 1 of the year following the year covered by the form and keep it posted until April 30 of that year." OSHA allows the use of industry-generated forms similar to the OSHA forms as long as they have at least the same information as the OSHA forms.
2. First report of injury: Example in Figure 17.4.

These records must be preserved for 5 years.

The employer is also required to post at the work site records of citations and notices of employees' rights. There have been strong drives to change OSHA so that employers with scattered work sites, as in construction, can be allowed to maintain the required records at a central location (e.g., home office).

17.7 HOW THE LAW IS APPLIED

The 10 OSHA regional and area offices employ inspectors whose duties include visits to active projects to determine if the builders are conforming to the regulations. As noted, there are "State Plan States" that have their own laws, rules, and regulations. The OSHA legislation allows this as long as the program is "at least as effective" as the federal OSHA provisions. Indiana, for instance, operates a state system that simply adopted all of the federal OSHA rules, regulations, changes, and so forth. Michigan, on the other hand, writes and publishes its own rules, some of which go above and beyond what federal OSHA rules require.

An inspection can be initiated at random by OSHA or state safety inspectors or by an employee (or his union) who submits a written statement to the labor department that he believes there is a violation that threatens physical harm or imminent danger. All inspections must be on an unannounced basis during the working day. Rulings by the Supreme Court, however, require that an inspection warrant be obtained from the proper authority if access to the site is denied. It is not unusual that the contractor requires a warrant prior to permitting entry to the work site. This essentially changes the "surprise" nature of the inspection and allows the work site supervisor to prepare for the inspection.

The inspection is divided into four parts:

1. An opening conference with the employer.
2. Selection of a representative of the employees and of the employer to accompany the inspector on a tour of the workplace.
3. The walk-around inspection. The inspector is allowed to talk with any employees.
4. The closing conference during which the inspector discusses the conditions and practices he observed that might be safety or health violations. Only "alleged violations" are discussed. Any Safety Orders will follow via U.S. mail 2 weeks to 3 months after the actual inspection. However, correction of any items mentioned by the safety officer in the closing conference for which there is no basis for appeal should be corrected immediately. Fines may be proposed with the citations. The employer is allowed 15 days to appeal a penalty.

The appeals of citations, penalties, or abatement periods are made through a procedure to the Occupational Safety and Health Review Commission or appropriate state board. The