20

Improving Productivity and Performance

20–1 THE BIG PICTURE

State of the Industry

The Business Roundtable Construction Industry Cost Effectiveness (CICE) study described in Chapter 1 found that the U.S. construction industry faced a number of problems in remaining competitive in the international construction market. However, it concluded that the majority of industry problems could be overcome by improved management of the construction effort. At the project management level, the study discovered inadequate management performance in a number of areas. These included construction safety, control of the use of overtime, training and education, worker motivation, and failure to adopt modern management systems. Thus, the purpose of this chapter is to look at ways in which construction managers can improve construction productivity and performance.

What Is Productivity?

There is serious disagreement about the proper definition of the term "productivity" within the construction industry. As usually employed, the term means the output of construction goods and services per unit of labor input. Obviously, such a definition ignores the contribution of technology and capital investment to the measured productivity. The heavy construction element of the industry has demonstrated that the use of larger and more productive earthmoving equipment can increase productivity and lower unit production costs in the face of generally rising labor and materials costs. The continued rapid growth of technology in the world economy makes it likely that new technology such as robotics and industrialized building processes will have a significant impact on construction productivity in the not too distant future.

Probably a better measure of construction industry performance is cost-effectiveness as used by the Business Roundtable CICE study. However, for the purpose of this chapter we will use the traditional definition of productivity as output per unit input of labor and focus our attention on ways in which construction industry productivity and cost-effectiveness can be increased by improved management.

Tools for Better Management

A number of studies, including the CICE study, have shown that most on-site delays and inefficiencies lie within the control of management. Management is responsible for planning, organizing, and controlling the work. If these management responsibilities were properly carried out, there would be few cases of workers standing idle waiting for job assignment, tools, or instructions. As you see, the scope of management responsibility is great and the techniques for efficiently carrying out these responsibilities are varied and complex. Many books have been written on individual topics and techniques in this area. Thus the purpose of this chapter is simply to introduce the reader to some of these techniques and their potential for improving the management of construction.

One of the major tools for improving construction productivity is *work improvement*: that is, the scientific study and optimization of work methods. Such techniques are also known as *work simplification, motion and time study, work study,* and *methods analysis.* Human factors, often not adequately considered, also play an important part in productivity. Workers' physical capacity, site working conditions, morale, and motivation are important elements in determining the most effective work methods and the resulting productivity for a particular task.

Other techniques available to assist the construction manager in improving construction productivity and cost-effectiveness include network planning methods, economic analyses, safety programs, quantitative management methods, simulation, and the use of computers. Many of these topics have been introduced in previous chapters. Other major topics are discussed in the following sections.

20–2 WORK IMPROVEMENT

What Is It?

Techniques for improving industrial production by scientific study of work methods can be traced back many centuries. However, only in the twentieth century did such techniques begin to be widely adopted by manufacturing industries. Frederick W. Taylor and Frank Gilbreth were among the early pioneers of what came to be known as *scientific management* and which today forms the basis for the field of industrial engineering. However, it is interesting to note that Frank Gilbreth began his career as a bricklayer and performed his early studies in that field. Another pioneer, D. J. Hauer, published his book *Modern Management Applied to Construction* in 1918. In spite of these early efforts by Gilbreth, Hauer, and others, work improvement methods were never widely adopted by the construction industry. Today there is renewed interest in these techniques by a construction industry faced with declining productivity and cost-effectiveness.

An important but often overlooked component of work improvement is preplanning, that is, detailed planning of work equipment and procedures prior to the start of work. Physical models as well as traditional work improvement charts and diagrams may be used to advantage in the preplanning process. Models are often used for large and complex projects such as power plants, dams, and petrochemical process plants to check physical dimensions, clearance between components, and general layout. Carried to a greater level of detail, they are very useful in planning concrete placement, blockouts for placing equipment, erection of structural components, and the actual procedure for placing equipment into a structure. Computer graphics and computer-aided design (CAD) can perform similar functions faster and at lower cost than can physical models or other manual techniques.

Traditional work improvement techniques, described in more detail in the following pages, include time studies, flow process charts, layout diagrams, and crew balance charts.

Time Studies

Time studies are used to collect time data relating to a construction activity for the purpose of either statistical analysis or of determining the level of work activity. In either case, it is important that the data collected be statistically valid. Hence a random-number procedure is usually employed in selecting the time for making each observation. The number of observations required for statistical validity depends on the type of study being made. For time analysis, the number of observations required depends on sample size, the standard deviation of the sample, and the level of accuracy and confidence desired. For effectiveness ratings, the number of observations required depends on the confidence desired, the acceptable error, and the measured percentage of effectiveness.

Work sampling is the name for a time study conducted for the purpose of determining the level of activity of an operation. A study of a construction equipment operation, for example, may classify work activity into a number of categories, each designated as either active or nonworking. The number of active observations divided by the total number of observations will yield the level of activity. The distribution of observations by category will provide an indication to management of how machine time is being spent.

The types of work sampling performed to determine labor utilization and effectiveness include field ratings and 5-min ratings. *Field ratings* are used to measure the level of activity of a large work force. At the selected random times, each worker is observed and instantaneously classified as either working or nonworking. The number of working observations divided by the total number of observations yields the level of activity. The *5-min rating* is used primarily to measure the level of activity of a crew. Each crew member is observed for a minimum of 1 min (or a minimum of 12 min per crew). If the crew member is working more than 50% of the time observed, the observation is recorded as working.

Sampling for labor effectiveness may also divide observations into categories. Some common categories used include effective work, essential contributory work, ineffective work, and nonworking. Analysis of work by category will again assist management in determining how labor time is being utilized and provide clues to increasing labor effectiveness.

Although time studies are traditionally made using stopwatches and data sheets, there is growing use of time-lapse photography and video time-lapse recording for this purpose. The use of time-lapse equipment for conducting work improvement studies on construction projects provides several advantages over stopwatch studies. A permanent record of the activity is provided which can be studied as long as necessary to obtain necessary time data. In addition, a historical record of the activity is obtained which may be useful in training managers and supervisors as well as providing evidence in event of legal disputes.

Flow Process Charts

A *flow process chart* for a construction operation serves the same purpose as does a flowchart for a computer program. That is, it traces the flow of material or work through a series of processing steps (classified as operations, transportations, inspections, delays, or storages). Depending on the level of detail, it usually indicates the distance and time required for each transportation and the time required for each operation, inspection, or delay. From the chart the manager should be able to visualize the entire process and to tabulate the number of operations, transportations, inspections, delays, and storages involved, and the time required for each category.

In preparing a flow process chart (see Figure 20–1), list in sequence a brief description of each step as it occurs. Trace the work flow by connecting the appropriate symbol in the second column. Enter the transportation distance and the time involved for each step. Figure 20–1 illustrates a flow process chart for the assembly of the roof truss shown in Figure 20–2, employing a crew of two workers and a forklift. The production rate for the process is determined by the time required to perform those steps that cannot be performed concurrently. This time is called the *control factor*. The control factor can be reduced only by speeding up these steps or by devising a method that permits some of its activities to be performed concurrently.

After preparing a flow process chart, it should be analyzed and revised to reduce the number of operations, movements, storages, and delays, as well as the control factor, to a minimum. Challenge each step in the process. Ask yourself: Is it necessary? Is it being done at the proper place and in the most efficient manner? How can it be done faster and safer?

Layout Diagrams

A *layout diagram* is a scaled diagram that shows the location of all physical facilities, machines, and material involved in a process. Since the objective of a work improvement study is to minimize processing time and effort, use a layout diagram to assist in reducing the number of material movements and the distance between operations. A *flow diagram* is similar to a layout diagram but also shows the path followed by the worker or material being recorded on a flow process chart. The flow diagram should indicate the direction of movement and the locations where delays occur. Step numbers on a flow diagram should correspond to the sequence numbers used on the corresponding flow process chart.

It should be apparent that flow process charts, flow diagrams, and layout diagrams must be studied together for maximum benefit and must be consistent with each other. Since layout diagrams and flow diagrams help us to visualize the operation described by a flow process chart, these diagrams should suggest jobs that might be combined, storages that might be eliminated, or transportations that might be shortened. The objective is to position the materials and machines so that the shortest possible path can be used without creating traffic conflicts or safety hazards.

Crew Balance Charts

A *crew balance chart* uses a graphical format to document the activities of each member of a group of workers during one complete cycle of an operation. A vertical bar is drawn to represent the time of each crew member during the cycle. The bar is then divided into time

FLOW PROCESS CHART	NUMBER 101	PAGE NO. 1	NO. OF PAGES 1

PROCESS: Assemble Truss

☒ MAN OR ☐ MATERIAL

CHART BEGINS	CHART ENDS
Parts stack	Parts stack

CHARTED BY: J. Doe DATE: 7/13

ORGANIZATION: E Z Construction

SUMMARY						
ACTIONS	PRESENT		PROPOSED		DIFFERENCE	
	NO.	TIME	NO.	TIME	NO.	TIME
○ OPERATIONS	10	137				
⇨ TRANSPORTATIONS	9	90				
□ INSPECTIONS	0					
D DELAYS	0					
▽ STORAGES	0					
DISTANCE TRAVELLED (FEET)	300					

	DETAILS OF ☒ PRESENT ☐ PROPOSED METHOD	OPERATION / TRANSPORTATION / INSPECTION / DELAY / STORAGE	DISTANCE IN FEET	QUANTITY	TIME (sec)	NOTES
1	Remove chords from stack	○⇨□D▽		2	3	
2	Transport chord to jig	○⇨□D▽	25	2	10	
3	Position chords in jig	○⇨□D▽		2	5	
4	Return to parts stack	○⇨□D▽	25		6	
5	Remove rafters from stack	○⇨□D▽		2	3	
6	Transport rafters to jig	○⇨□D▽	25	2	10	
7	Position rafters in jig	○⇨□D▽		2	5	
8	Return to parts stack	○⇨□D▽	25		6	
9	Remove diagonals	○⇨□D▽		2	3	
10	Transport diagonals	○⇨□D▽	25	2	10	
11	Position diagonals in jig	○⇨□D▽		2	5	
12	Return to parts stack	○⇨□D▽	25		6	
13	Remove hanger from stack	○⇨□D▽		1	3	
14	Transport hanger to jig	○⇨□D▽	25	1	10	
15	Position hanger in jig	○⇨□D▽		1	5	
16	Fasten truss plates	○⇨□D▽		12	85	
17	Remove truss from jig	○⇨□D▽		1	20	
18	Trans & stack truss	○⇨□D▽	50	1	15	Using forklift
19	Return to parts stack	○⇨□D▽	75		17	
20		○⇨□D▽				Cycle time
21		○⇨□D▽				= 227 sec

Figure 20–1 Flow process chart.

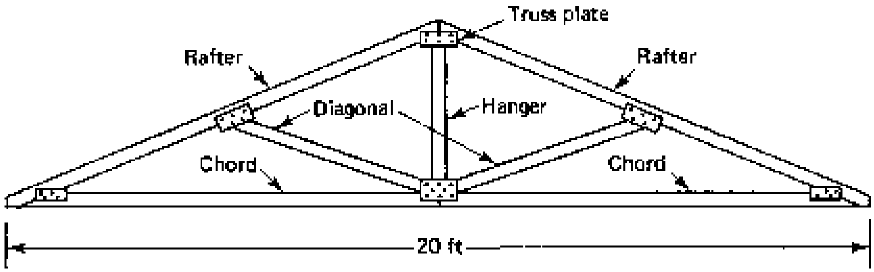


Figure 20–2 Roof truss diagram.

blocks showing the time spent by that crew member on each activity which occurs during the cycle. The usual convention utilizes a color code to indicate the level of activity during each time block. The darker the color, the higher the level of activity. Thus effective work might be shown by a dark block, contributory work by a lighter-colored block, and noneffective work or idle time by a white block. As the name indicates, the crew balance chart enables us easily to compare the level of activity of each worker during an operation cycle. Often its use will suggest ways to reduce crew size or to realign jobs so that work is equalized between crew members.

A crew balance chart for the assembly of the roof truss of Figure 20–2 is illustrated in Figure 20–3. However, note that here the crew size has been increased to four members instead of the two members used in the flow process chart of Figure 20–1.

Crew balance charts are sometimes referred to as *multiman charts.* Charts showing both crew activities and machine utilization are called *man-machine charts* or *multiman-and-machine charts.*

Human Factors

In attempting to improve construction productivity and cost-effectiveness, it is important to remember that people are the essential element in the construction process. Workers who are fatigued, bored, or hostile will never perform at an optimum level of effectiveness. Some major human factors to be considered include environmental conditions, safety conditions, physical effort requirements, work hours, and worker morale and motivation. Safety and health considerations, including work in extreme heat and cold, are discussed in Chapter 19.

There are several considerations involved in assessing the effect of physical exertion on workers. It has been found that the maximum long-term rate of human energy expenditure for the average worker is approximately equal to the energy expended in walking. Attempts at sustained higher levels of effort will only result in physical fatigue and lower performance. Therefore, physical work requirements should be adjusted to match worker capability. For example, Frederick Taylor found in his early studies that the best performance of workers loading material using hand shovels was obtained by matching shovel style, size, and weight to individual worker characteristics. Physical fatigue can be caused by holding an object in a fixed position for an extended period of time as well as by overexertion.

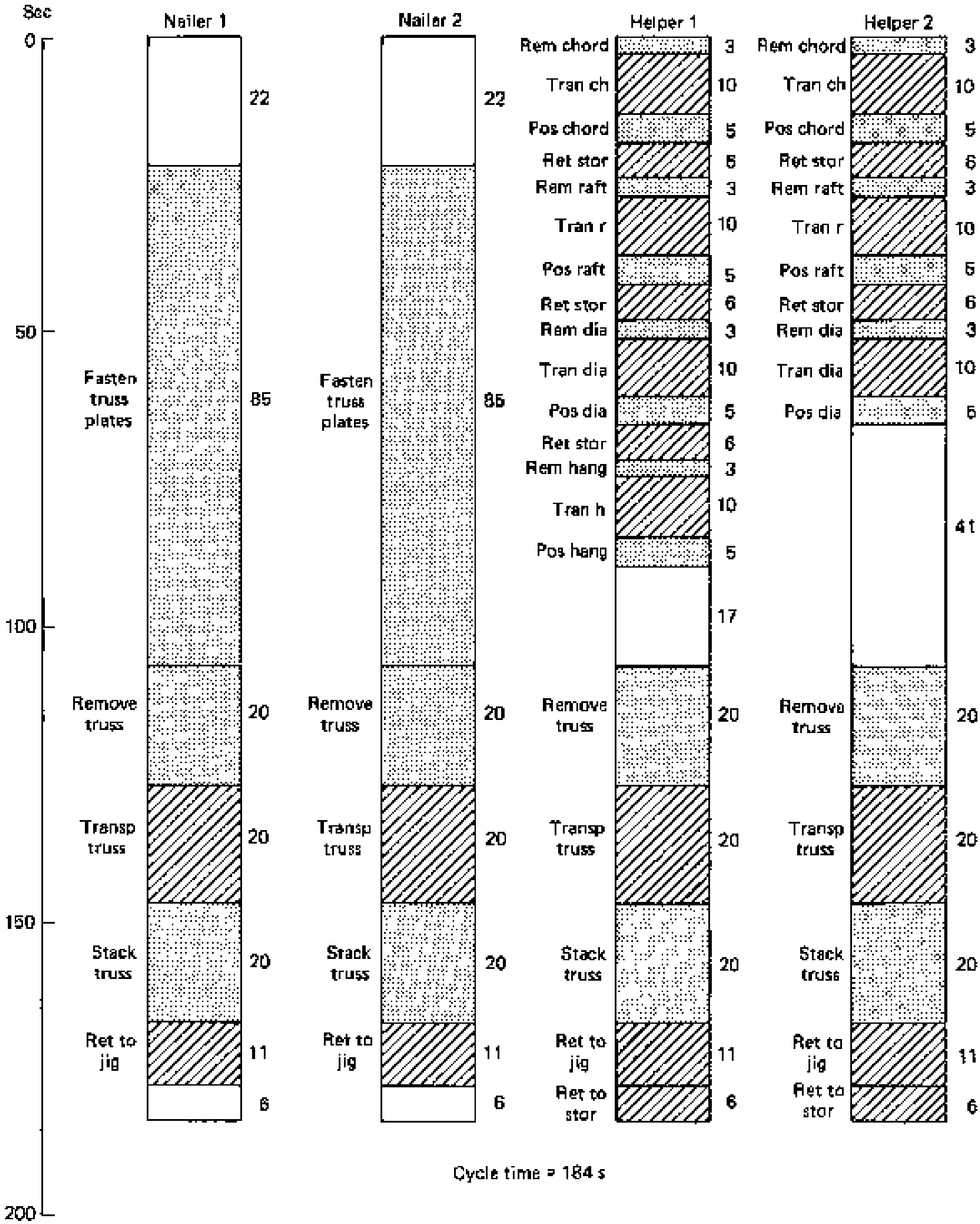


Figure 20–3 Crew balance chart.

Studies (see reference 11) have shown that worker productivity is seriously reduced by sustained periods of overtime work. In general, a 40-h workweek appears to be the optimum for U.S. construction workers. When construction workers are put on a scheduled overtime basis, productivity usually drops sharply during the first week, recovers somewhat during the following three weeks, then continues to decline until it finally levels off after about 9 weeks. When first put on overtime, total worker production per week is initially higher than for a standard 40-h week. However, as productivity continues to decline, the total output for a 50-h or 60-h week falls to that of a 40-h week after about 8 weeks. When the premium cost of overtime is considered, it is apparent that the labor cost per unit of production will always be higher for overtime work than for normal work. As the length of the overtime period increases, the cost differential becomes sizable. For example, if the hourly pay rate for overtime work (work beyond 40 h) is 150% of the standard rate, the labor cost per unit of production for a 60-h week after 8 weeks would be more than 80% higher than for a 40-h week.

Worker morale and motivation have also been found to be important factors in construction worker productivity. In studies of 12 large power-plant construction projects, Borcherding and Garner (reference 4) analyzed the factors inhibiting craft productivity on these projects. Of the factors studied, nonavailability of material was the most significant, followed by nonavailability of tools, and the need to redo work. Interfacing of crews, overcrowded work areas, delays for inspection, craft turnover, absenteeism, changes in foremen, and incompetence of foremen were also found to inhibit productivity. However, these factors were much less significant than were the first three factors cited above. The same study identified a number of circumstances that acted as worker motivators or demotivators on these projects. As might be expected, the most productive projects tended to have the highest number of worker motivators and the lowest number of worker demotivators. It appears from the study that the presence of worker demotivators has more effect on productivity than does the presence of worker motivators. Some of the worker demotivators identified by the study included:

- Disrespectful treatment of workers.
- Lack of sense of accomplishment.
- Nonavailability of materials and tools.
- Necessity to redo work.
- Discontinuity in crew makeup.
- Confusion on the project.
- Lack of recognition for accomplishments.
- Failure to utilize worker skills.
- Incompetent personnel.
- Lack of cooperation between crafts.
- Overcrowded work areas.
- Poor inspection programs.
- Inadequate communication between project elements.

- Unsafe working conditions.
- Workers not involved in decision making.

Some of the worker motivators identified in the study include:

- Good relations between crafts.
- Good worker orientation programs.
- Good safety programs.
- Enjoyable work.
- Good pay.
- Recognition for accomplishments.
- Well-defined goals.
- Well-planned projects.

20–3 QUANTITATIVE MANAGEMENT METHODS

The science that uses mathematical methods to solve operational or management problems is called *operations research.* After World War II, operations research techniques began to be employed by industry to provide management with a more logical method for making sound predictions and decisions. Basically, these techniques deal with the allocation of resources to various activities so as to maximize some overall measure of effectiveness. Although a number of mathematical optimization techniques are available, linear programming is by far the most widely used for management purposes. In this section we consider briefly the application of linear programming to construction management.

Linear Programming—Graphical Solution

As the name implies, all relationships considered in linear programming must be linear functions. To apply linear programming, it is necessary to have a set of linear *constraint* (boundary) *equations* and a linear *objective function* which is to be maximized or minimized. We consider first a graphical solution technique that may be employed when only two variables are present. This relatively simple case, which is illustrated by Example 20–1, should enable us to visualize the nature of the solution procedure. As you recognize, it would be impossible to use a graphical procedure to solve a problem involving more than three variables.

EXAMPLE 20–1

A project manager for a large earthmoving project is faced with the task of selecting the dozers to be used on a relatively remote project. The project manager is advised by the equipment division manager that both heavy and medium dozers are available for the project. However, only 10 heavy dozers are available. The supply of medium dozers is relatively unlimited. Because of time and transportation limitations, a maximum of 1080 tons of dozers may be transported to the site. The project manager also has the following information on dozer performance and weight.

Dozer	Weight (tons)	Production Index
Heavy	60	2 units/day
Medium	40	1 unit/day

SOLUTION

We must first formulate the constraint equations defining the limits of the solution. Obviously, the number of each type of dozer must be zero or greater. (This assumption is implicit in all linear programming solution procedures.) If we let X_1 represent the number of heavy dozers and X_2 represent the number of medium dozers, these constraints become

$$X_1 \geq 0 \quad \textbf{(1)}$$

$$X_2 \geq 0 \quad \textbf{(2)}$$

Another constraint is that the number of heavy dozers cannot exceed 10. Hence

$$X_1 \leq 10 \quad \textbf{(3)}$$

Finally, the maximum weight to be transported is 1080 tons. Hence

$$60\,X_1 + 40\,X_2 \leq 1080 \quad \textbf{(4)}$$

After establishing the constraints, we must define the objective function that is to be maximized or minimized. In this case we want to maximize some measure of production of the dozer fleet. Since each heavy dozer will produce twice as much as each medium dozer, the objective function can be expressed as

$$\text{(maximize) } 2\,X_1 + X_2$$

Summarizing the equations, we have:

Constraints:

$$X_1 \geq 0 \qquad \text{(Eq 1)}$$

$$X_2 \geq 0 \qquad \text{(Eq 2)}$$

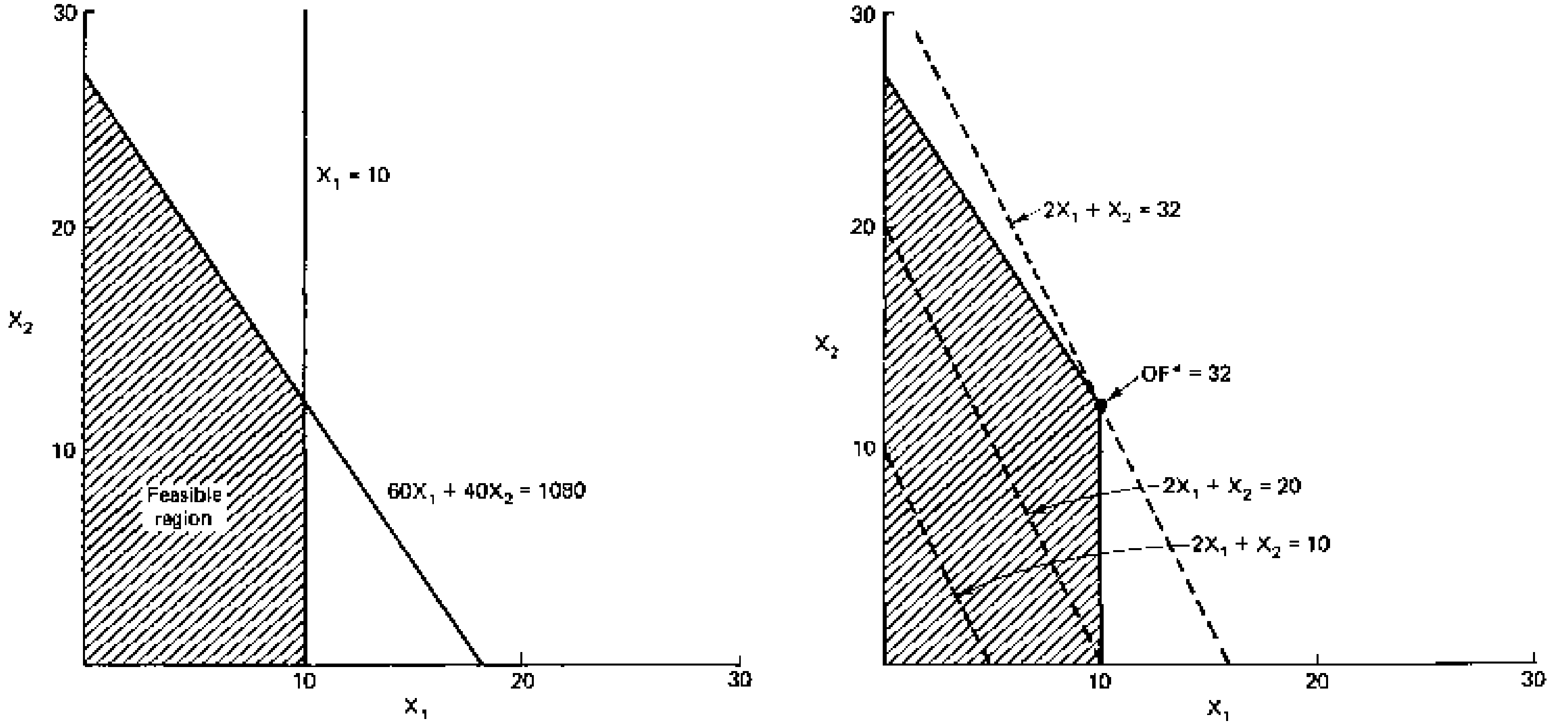
$$X_1 \leq 10 \qquad \text{(Eq 3)}$$

$$60\,X_1 + 40\,X_2 \leq 1080 \qquad \text{(Eq 4)}$$

Objective function:

$$\text{(maximize) } 2\,X_1 + X_2$$

The graphical solution procedure is illustrated in Figure 20–4. The feasible region for a solution as defined by the constraint equations is shown in Figure 20–4a. In Figure 20–4b, the objective function has been set equal to 10 and to 20. Notice that the objective function can be represented by a family of lines having a slope of -2. As this line is moved away from the origin, the value of the objective function increases. Since we wish to maximize the



a. Feasible region for solution

b. Optimum solution

Figure 20–4 Graphical solution of Example 20–1.

value of this function, the optimum value of the objective function will be obtained when this line is as far from the origin as possible while remaining in the feasible region. In this case, the optimum value occurs at the point (10, 12) defined by the intersection of constraints 3 and 4. Following the usual convention for mathematical optimization procedures, we designate optimum values using an asterisk. Hence for our problem

$$X_1^* = 10$$
$$X_2^* = 12$$
$$OF^* = 32$$

As the reader may recognize, this very simple problem could easily be solved by analytical procedures. However, for more complex problems, linear programming usually provides a much faster and simpler solution procedure than do other techniques.

Computer Solution

Since the graphical solution technique cannot be used for problems involving more than three variables, a more general solution procedure is required. A manual solution algorithm, the simplex method, is available for solving the general linear programming problem. However, the procedure is computationally cumbersome and, therefore, of practical value only for the solution of small problems. Moreover, computerized solution techniques are available which can rapidly solve linear programming problems involving thousands of variables and constraints.

Because of the wide availability of microcomputers and linear programming software, this discussion will be confined to the use of computers for solving the general linear programming problem. As we have learned, the essential elements in the formulation of a linear programming problem are a set of constraint equations and an objective function. Care must be taken to ensure that constraint equations are not mutually exclusive, which would result in there being no feasible region for a solution. In such a case, the computer output will advise you that no feasible solution exists. While linear programming computer programs differ somewhat, the user is normally required to enter the number of variables, number of constraint equations, and whether the objective function is to be maximized or minimized. Then, for each constraint equation, enter the coefficient for each variable, the equality relationship ($\leq$, $=$, or $\geq$), and the right-hand-side constant. Finally, the coefficient of each variable in the objective function is entered. The program output will indicate whether a feasible solution exists. If it does, the optimum value of each variable and of the objective function will be given. A sensitivity analysis is often provided which indicates the effect on the objective function resulting from a unit change in the right-hand-side constant of each binding constraint. A computer solution produced by a microcomputer for the problem of Example 20–2 is shown in Figure 20–5.

EXAMPLE 20–2

A paving contractor is planning his work schedule for the following week. He has a choice of either of two types of concrete, plain concrete or concrete with an additive. The use of additive concrete reduces concrete finishing time but increases the time required for placement. Cost records indicate that the contractor can expect a profit of $4 per cubic yard for plain concrete and $3 per cubic yard for additive concrete. Naturally, the objective of the

```
THE FOLLOWING LINEAR OPTIMIZATION MODEL WILL BE MAXIMIZED

THE OBJECTIVE FUNCTION =     +4.000X 1     +3.000X 2

SUBJECT TO THE FOLLOWING CONSTRAINTS

          +0.11X 1     +0.21X 2   <=   80
          +0.81X 1     +1.01X 2   <=   440
          +0.52X 1     +0.22X 2   <=   160

THE FEASIBLE SOLUTION FOUND AFTER     2     ITERATIONS

    ITERATION        3                OBJECTIVE =     0
    ITERATION        4                OBJECTIVE =     1230.77
    ITERATION        5                OBJECTIVE =     1600

VARIABLES IN THE SOLUTION

    VARIABLES        2                AMOUNT =        282.353
    VARIABLE         1                AMOUNT =        188.235

VARIABLES OUT OF THE SOLUTION

BINDING CONSTRAINTS

    CONSTRAINT       3                SHADOW PRICE = 6
    CONSTRAINT       1                SHADOW PRICE = 8

SLACK CONSTRAINTS

    CONSTRAINT       2                SLACK =         2.35294

THE OPTIMUM OBJECTIVE FUNCTION IS       1600
```

Figure 20–5 Computer solution of Example 20–2.

contractor is to maximize his profits. However, he does not want to hire additional workers. Labor requirements [in man-hours per cubic yard (mh/cy)] for each type of concrete are given below. Assuming that sufficient demand exists, how many cubic yards of each type of concrete should the contractor place the following week? The contractor works a 40-h week.

		Labor Required	
Type	***Number***	***Plain***	***Additive***
Foreperson	2	0.11 mh/cy	0.21 mh/cy
Laborer	11	0.81 mh/cy	1.01 mh/cy
Finishers	4	0.52 mh/cy	0.22 mh/cy

SOLUTION

From the table of labor requirements it is determined that 80 foreperson man-hours, 440 laborer man-hours, and 160 finisher man-hours are available each week. We will let X_1 represent the quantity of plain concrete to be placed and X_2 represent the quantity of additive concrete. Hence the constraint equations and objective function are as follows:

Constraints:

$$0.11\,X_1 + 0.21\,X_2 \le 80$$
$$0.81\,X_1 + 1.01\,X_2 \le 440$$
$$0.52\,X_1 + 0.22\,X_2 \le 160$$

Objective function:

$$\text{(maximize) } 4.00\,X_1 + 3.00\,X_2$$

The optimum solution, shown in Figure 20–5, is

$$X_1^* = 188.235 \text{ cu yd (plain concrete)}$$
$$X_2^* = 282.353 \text{ cu yd (additive concrete)}$$
$$OF^* = \$1600.00 \text{ (profit)}$$

The shadow prices shown for the binding constraints indicate the amount by which the objective function (profit) would be increased if the respective constraint constant were increased by one unit. That is, profit would be increased by \$8 if the number of foreperson man-hours available were increased to 81. Similarly, profit would be increased by \$6 if the number of finisher man-hours were increased to 161. Note also that there are slightly over 2 excess laborer man-hours available at the optimum solution.

20–4 COMPUTERS AND OTHER TOOLS

Computers in Construction

As discussed in Chapter 1, perhaps the most exciting development in construction use of computers is the wide availability of electronic mail (e-mail) and the Internet (World Wide Web) with its almost unlimited resources. Electronic communications using computers permit contractors to exchange information and data among projects and between project sites and the main office. Equipment manufacturers are increasingly engaging in electronic communications with dealers and dealers with contractors. Manufacturers are also providing online parts catalogs and service and repair bulletins to dealers as well as processing equipment warranty claims electronically. While some manufacturers' information is available only to dealers and not to contractors, increasingly such data and services will become available to contractors. Electronic sales of new and used equipment and parts are also growing rapidly. Much information of value to contractors is available on the Internet. Appendix C provides addresses for a number of construction Internet resources.

A number of the end-of-chapter problems in the preceding chapters have illustrated the use of computers for solving construction engineering and management problems. For the most part, solutions to these problems have been obtained using computer programs written in a traditional computer language. However, a growing library of packaged computer software, as well as special-purpose computer programming languages, is available. Many of these can be profitably employed by the construction manager. Some of the widely used software packages include word processors, electronic spreadsheets, database programs, communications programs, graphics programs, and project and equipment management programs. Integrated software packages that include several of these programs utilizing a common file structure are also available. Some of the software written specifically for the construction industry includes estimating programs, bidding programs, project management programs, and programs for maintaining cost and performance data for equipment and labor. With the increasing power and declining cost of computers, more powerful user-friendly construction software is becoming available almost daily.

Word processors are used for general correspondence, as well as to prepare memos, reports, training manuals, and procedures manuals. They are particularly useful for preparing repetitive documents such as contract specifications, where much of the material is standard (often called "boilerplate") but is modified somewhat for each specific project. Word processors often have associated spelling checkers which identify words not contained in its standard dictionary. The user can correct the word, accept it without adding it to the dictionary, or add it to the dictionary. Mailing-list programs are also available for many word processors. These enable the user to prepare form letters and associated address files. Address files can be used to prepare mailing labels or envelopes as well as to merge names, addresses, and other data into form letters.

Electronic spreadsheets are a more powerful form of the familiar row-and-column spreadsheet used for tabulating such data as quantity, unit cost, total cost, sales price, and profit. By allowing the user to specify mathematical relationships between cells, results for any input data can be quickly calculated. For example, the value for each row of column 4 may be specified as that obtained by multiplying column 2 by column 3. Many electronic spreadsheet programs also contain built-in functions such as interest calculations, loan amortization, present value, future value, and internal rate of return. The use of such a program will enable the manager quickly to determine the effect produced by any change in the assumed or actual data.

Database programs are used to organize, maintain, and manipulate a collection of data. Special-purpose database programs are written for a specific purpose such as inventory control. Although such specialized programs are relatively easy to learn and put into use, they can be used only for the specific purpose for which they were written. Therefore, general-purpose database programs are much more widely used. General-purpose programs are very flexible but must be customized for each specific application. The two major types of general-purpose database programs are file managers and relational databases. File managers are simpler and usually less expensive than are relational databases. However, they can access only one data file at a time. Relational databases, on the other hand, are capable of using data from a number of files at the same time. For example, they are capable of integrating material, labor, and equipment cost data from many different cost files to produce total project cost.

Communications programs are used for communications between computer and with Internet Service Providers (ISPs). They can be used to access such information services as electronic mail, electronic bulletin boards, and the Internet. Used with a computer and modem, they allow wireless communication or communication over an ordinary telephone line.

Internet Service Providers (ISP's) provide access to e-mail and Internet services. Again a computer, modem, and the services of an ISP are all that are required to utilize these resources.

Graphics programs greatly speed up and facilitate the preparation of graphic material. They are widely used for preparing charts and other illustrations for reports and presentations. Computer-aided design and drafting programs are becoming widely used for construction design.

Project management programs are usually built around the network planning techniques described in Chapter 16. They often provide for maintaining and forecasting cost and resource data as well as time data. Some programs also contain functions capable of resource leveling.

Equipment management programs provide many capabilities for managing an equipment fleet. They can maintain equipment cost and maintenance history, schedule preventive maintenance, and inventory, order, and purchase repair parts.

Advanced Techniques

In addition to the quantitative management techniques and computer software described above, there are several more advanced techniques available to the progressive construction manager. For example, there are various optimization techniques available for the solution of optimization problems involving nonlinear functions.

Computer simulation is a powerful tool for analyzing problems not easily solved by analytical methods. The application of simulation techniques to network planning methods has been described in Chapter 16. The simulation of construction operations may be accomplished by writing a simulation program using a conventional programming language or a simulation language or by utilizing a packaged simulation program. An example of the output of a scraper simulation program is shown in Figure 20–6. Packaged simulation programs are relatively simple to use but are usually limited in the type of operation and equipment which can be modeled. However, a programmer using a simulation language can quickly model almost any type of construction operation and any combination of equipment. Reference 10 describes several earthmoving simulation programs written in the GPSS simulation program.

In this day of rapid technological advance, one can never predict the exact impact of new technology on construction. As we have seen, the wide availability of the personal computer has placed a powerful tool at the disposal of the construction professional. In addition, computers have already begun to be applied to the control systems of earthmoving equipment and to the construction robots discussed in the following section.

Simulation Number 5

Type of Material	Loading Method	Project Conditions	Delay Option	Pushing Method
1-Common earth 2-Rock	1-Single pusher 2-Tandem pushers 3-Push-pull 4-Elevating	Length of haul road- 3000 ft Type of material-1 Total excavation-25000 LCY Total shift time-3.89 hrs Delay option-1	0-No delays used 1-Delays used	1-Single pusher 2-Tandem pushers

Scrapers

Scraper Number	Load Meth	No. Eng	Rated Load (LCY)	Ave. Load (LCY)	No. Loads	Load Time (sec)	Total Exc (LCY)	Travel Time (sec)	Cnst Time (sec)	Prod Time (sec)	Wait Time (sec)	Ext. Delay Time (sec)	Total Cycle Time (sec)	% Util	Prod LCY/ hr
1	3	2	31	26	26	107	676	319	52	478	9	72	559	85.5	168.15
2	3	2	31	26	25	106	650	347	49	502	26	48	576	87.2	161.71
3	3	2	31	26	26	108	676	339	54	501	18	29	548	91.4	168.15
4	3	2	31	26	26	106	676	321	54	481	25	43	549	87.6	168.18
5	3	2	31	26	27	107	702	324	56	487	31	41	559	87.1	174.65
6	3	2	31	26	25	103	650	337	52	492	48	33	573	85.9	161.71
7	3	2	31	26	25	119	650	321	49	489	14	56	559	87.5	161.71
8	3	2	31	26	26	106	676	307	53	466	26	51	543	85.6	168.18

Fleet

Overall production = 1332.52 LCY/HR = 1039.20 BCY/HR
Fleet cost per hour = $699.20
Overall cost per LCY = $0.525 – PER BCY $0.673
Total time of simulation = 4.02 HOURS
Total production = 5356 LCY = 4177 BCY

Figure 20–6 Scraper simulation program output.

20–5 ROBOTS IN CONSTRUCTION

Robots, or manipulator machines controlled by computer have been employed on industrial production lines for some years. As the technology has improved, robots have found increasing use in a number of industries, including the automobile manufacturing industry. Advantages of robots over human workers include higher speed, greater accuracy, absence of worker fatigue or boredom, and the ability to work under hazardous conditions without endangering worker health. While robots do displace some production workers, they increase the demand for skilled workers to design, manufacture, program, and maintain the robots.

Despite the advantages that robots can offer, robot manufacturers and construction firms have been slow to apply robots to construction tasks. Many argue that the field environment and unique characteristics of each construction project make the use of robots impractical for construction. Despite these obstacles, progress is being made in the application of robots and automated equipment to construction tasks.

Recent Developments

Considerable research and development work on the use of robots in construction is taking place in universities and construction research facilities, particularly in Japan. Some of the construction tasks to which automation and robotics have been successfully applied are described in references 6 and 12. These include:

Building Construction

- Finishing of concrete floor slabs.
- Fireproofing of structural steel after erection.
- Positioning steel members for steel erection.
- Spray linings for silos and similar structures.
- Surfacing of walls and other building components.

Heavy Construction

- Automated asphalt and concrete plants.
- Automated excavators.
- Automated tunnel boring machines.
- Concrete demolition in radioactive areas.
- Manufacture of precast concrete beams.

The automatic grade control of a dozer, excavator, and grader using a laser transmitter as a reference plane is illustrated in Figure 20–7. A pipe manipulator controlled by the excavator operator and using an integrated laser beam for pipe alignment is shown in Figure 20–8. The use of such a machine removes the hazards involved in having construction workers in the trench during pipe installation. The multipurpose interior robot shown

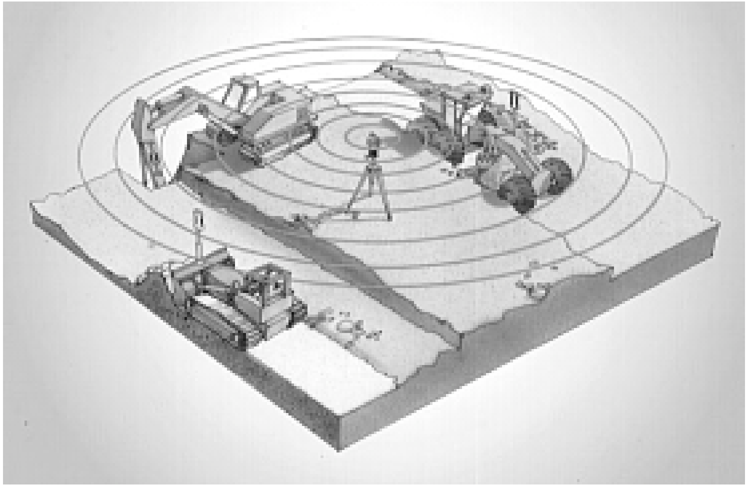


Figure 20–7 Automatic grade control of an excavation using a laser. (Courtesy of Trimble)

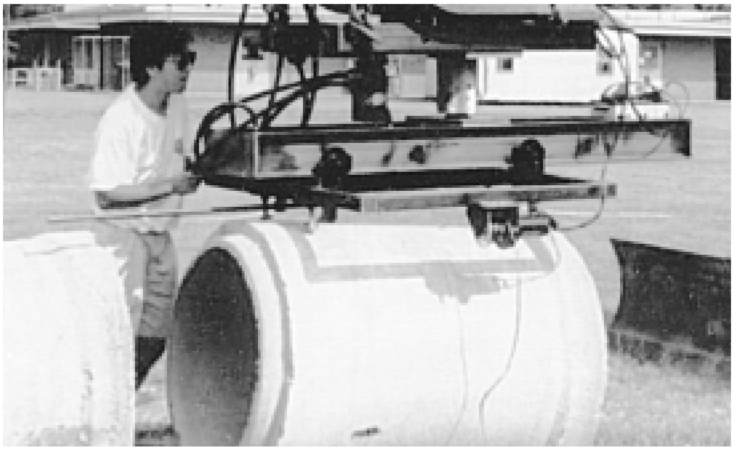


Figure 20–8 Remote-controlled pipe manipulator. (Courtesy of the Construction Automation and Robotics Laboratory, North Carolina State University)

in Figure 20–9 is capable of constructing block walls, setting tile, plastering, and painting inside buildings.

The availability of the Global Positioning System (GPS) has provided a new tool for surveying and mapping, site layout, and the automated control of earthmoving equipment. The GPS system consists of 24 satellites orbiting the earth at an altitude of 12,000 mi (19308 km). By using two GPS receivers operating together in a differential mode it is possible to obtain a location accuracy within less than 1 in. (25 mm) with GPS.

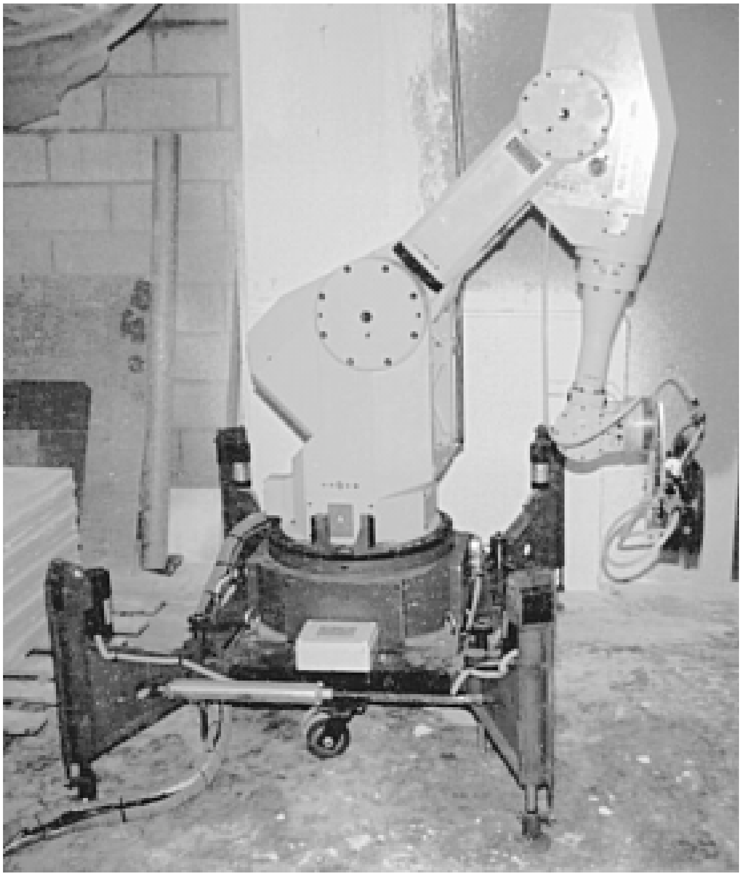


Figure 20–9 Robot for interior construction. (Courtesy of Prof. A.Warszawski)

20–6 THE FUTURE

As has been noted throughout this book, changes in the construction industry are occurring at an ever-increasing rate. Some recent trends in construction include increasing international competition, rapid changes in technology, the wide availability of information via the Internet, increasing ease and speed of communication, and increasing governmental regulation of the industry, particularly in the areas of safety and environmental protection.

Computers are playing a growing role in construction equipment design and operation. Automation has taken over many aspects of construction equipment control. When equipment control systems are integrated with wireless communication systems and GPS (Global Positioning System) systems, remote and even off-site control of construction equipment operations become highly feasible. In addition to requiring highly trained managers and operators, such developments will increasingly demand skilled technicians to maintain and repair the equipment involved.

In light of these developments, tomorrow's construction professional faces an exciting future.

PROBLEMS

1. What were the principal conclusions of the Business Roundtable CICE Study of the U.S. construction industry?
2. Using any Internet source, find the annual value (current dollars) of Total Construction Put in Place in the United States for the three most recent years as reported by the U.S. Census Bureau. Identify the Internet source used to obtain this data.
3. What is an electronic spreadsheet computer program?
4. Prepare a flow process chart for precutting the chords of the roof truss of Figure 20–2 using a single table-mounted power saw. Notice that two cuts at different angles (a vertical or plumb cut at one end and an angle cut at the other end) must be made on each chord. Two chords are required per truss. The steps in the process to be charted are as follows: A piece of raw material is removed from the storage pile, carried to the saw, and positioned on the saw table, one cut is made, and the partially precut piece is removed and placed in a temporary storage pile. After the pieces have all been cut, the saw is reset for the second cut angle, and the process is repeated for the second cut. However, after the second cut the piece is placed into a precut storage pile for use in truss assembly. Use the following job planning data in preparing your flow process chart. The subject to be charted is material.

   Hand transport rate, loaded = 2.5 ft/s (0.76 m/s)

   Hand transport rate, unloaded = 4.5 ft/s (1.37 m/s)

   Job efficiency = 50 min/h

   Make saw cut = 2 s

   Position piece at saw = 2 s

   Power saw to precut storage = 25 ft (7.6 m)

   Power saw to temporary storage = 15 ft (4.6 m)

   Raw material stack to saw = 15 ft (4.6 m)

   Remove cut piece from saw = 3 s

   Remove material from stack = 3 s

   Stack material = 3 s

5. Briefly discuss the influence of human factors on construction productivity.
6. What is the purpose of work sampling and how is it performed as applied to construction?
7. Explain the effect of sustained overtime on the labor cost per unit of construction production.

8. How could the process of precutting chords described in Problem 4 be made more efficient?
9. a. The control factor for the process of precutting the rafters of the truss of Figure 20–2 is 12 s based on the cutting rate of one saw. What is the maximum number of precut rafters that can be produced using one saw in a 40-min hour when labor supply is unlimited?
   b. Using a crew of two workers (1 worker carrying material and 1 saw operator) with one saw, the cycle time for precutting rafters is 54 s. Using this crew, how many 50-min hours would it take to precut the rafters for 200 trusses?
10. Use a linear programming computer program to solve the problem of Example 20–1.

REFERENCES

1. Abrid, Jorge, and David Arditi. "Time-Lapse Digital Photography Applied to Project Management," *ASCE Journal of Construction Engineering and Management,* vol. 128, no. 6 (2002), pp. 530–535.
2. Adrian, James J. *Construction Productivity Improvement.* New York: Elsevier, 1987.
3. Alfeld, Louis Edward. *Construction Productivity.* New York: McGraw-Hill, 1988.
4. Borcherding, John D., and Douglas F. Garner. "Work Force Motivation and Productivity on Large Jobs," *ASCE Journal of the Construction Division,* vol. 107, no. C03 (1981), pp. 443–453.
5. *Construction Labor Motivation,* CICE Report A-2. The Business Roundtable, Washington, DC, August 1982.
6. Cousineau, Leslie, and Nobuyasu Miura. *Construction Robots:The Search for New Building Technology in Japan.* Reston, VA: ASCE, 1998.
7. Drewin, F. J. *Construction Productivity.* New York: Elsevier, 1982.
8. Kangari, Roozbeh, and Tetsuji Yoshida. "Prototype Robotics in Construction Industry," *ASCE Journal of Construction Engineering and Management,* vol. 115, no. 2 (1989), pp. 284–301.
9. Myers, Fred E. *Motion and Time Study,* 2nd ed. Upper Saddle River, NJ: Prentice Hall, 1999.
10. Nunnally, S. W. *Managing Construction Equipment,* 2nd ed. Upper Saddle River, NJ: Prentice Hall, 2000.
11. Oglesby, C. H., Henry W. Parker, and Gregory A. Howell. *Productivity Improvement in Construction.* New York: McGraw-Hill, 1989.
12. Paulson, Boyd C., Jr. "Automation and Robotics for Construction," *ASCE Journal of Construction Engineering and Management,* vol. 111, no. 3 (1985), pp. 190–207.
13. *Scheduled Overtime Effect on Construction Projects,* CICE Report C-2. The Business Roundtable, Washington, DC, November 1980.
14. Stark, Robert M., and Robert H. Mayer, Jr. *Quantitative Construction Management.* New York: Wiley, 1983.