2 Rough Diagram Preparation—An Overview

Objectives

Upon completion of this chapter, you should be able to:

- Enumerate project phases
- Decide which schedule format to use
- Determine schedule information needed
- Run schedule meetings
- Estimate activity durations

TYPES OF ACTIVITY RELATIONSHIPS

Logic refers to the entire network of relationships between and among activities. This network controls the scheduling of activities. When you prepare the schedule, you establish relationships between activities. These relationships describe which activities depend on others. The relationships between activities are defined as predecessor, successor, or concurrent relationships. *Concurrent activities* are logically independent of one another and can be performed at the same time. A *predecessor activity* is one that must be completed before a given activity can be started. A *successor activity* is one that cannot start until a given activity is completed. Relationships between a particular activity and its predecessor and successor activities can vary. The options, as shown in Figure 2–1, are:

- Finish to Start (FS)
- Start to Start (SS)
- Finish to Finish (FF)
- Start to Finish (SF)

The FS relationship means that the predecessor activity must finish before the successor activity can start. The SS relationship means that both activities can start at the same time. The FF relationship means that both activities can finish at the same time. The SF relationship means that the predecessor activity must start before the successor activity can finish. We will use Figure 2–2 and the information in Table 2–1 as an example throughout the chapter.

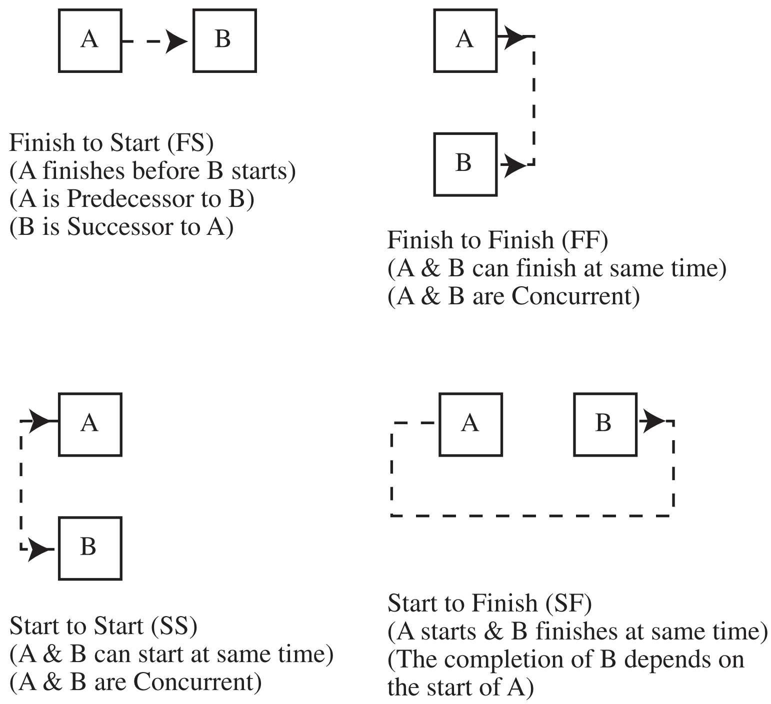

Figure 2–1 Activity Relationship Types

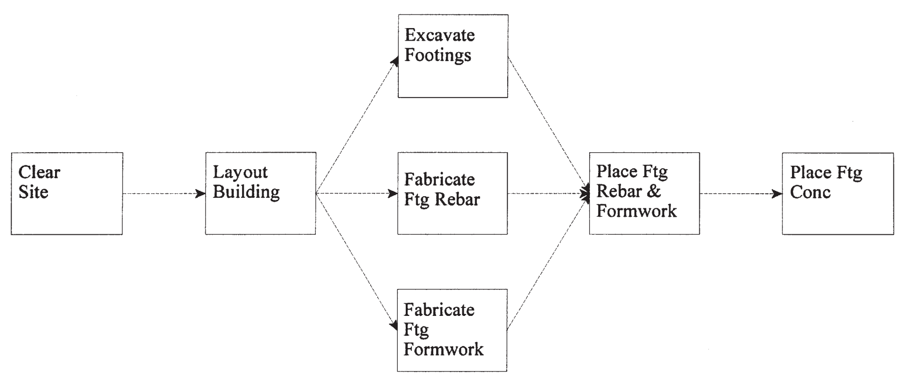

Figure 2–2 Logic Example

Clear Site	Predecessor to	Layout Building
Layout Building	Predecessor to	Excavate Footings Fabricate Ftg Rebar Fabricate Ftg Formwork
Excavate Footings Fabricate Ftg Rebar Fabricate Ftg Formwork	Predecessor to	Place Ftg Rebar
Fabricate Ftg Rebar	Predecessor to	Place Ftg Conc

Table 2–1 Logic Statements

ROUGH DIAGRAM

The four steps of project control are planning, scheduling, monitoring, and controlling. The very first step of the planning phase is the preparation of a rough diagram. A rough diagram builds the project on paper. It defines the activities and the relationships (logic) between them and the time to complete them. Once accepted, developed, and refined, the rough diagram becomes the project plan. Durations and resources are then applied in scheduling. During the rough diagram phase of the planning, the approach to placing the project takes shape. The planner should always remember that there should be a balance between the intricacy of the project and the number of activities scheduled. Too few activities in the rough diagram results in a schedule insufficient in detail to be worthwhile. Likewise, too many activities result in confusion and needless detail. In either case the schedule is likely to be ignored by those it is intended to benefit.

Construction decisions concern:

- Construction methods
- Flow of materials
- Prefab versus on-site assembly of materials
- Types of construction equipment
- Crew size and balance
- Productivity expectations
- Subcontractor definition

Management decisions include:

- Work breakdown structure (WBS)
- Division of responsibility
- Division of authority
- Software to be used
- Level and distribution of reports
- Interface with other functions (payroll, accounting, etc.)

Approaches to Rough Diagramming

The four most common approaches to handling the rough diagramming meeting are using a tape recorder, making a list of activities, drawing the actual diagram, and using a software integrator.

Tape Recorder

Some schedulers prefer to record the initial meeting of key project participants on audiocassette. The participants verbally walk through the project from beginning to end, identifying the activities, their sequence, and their interrelationships. The scheduler then prepares the graphical schedule manually or by computer. The group meets again to review the first rough activity diagram. When agreement is reached on activities and logic, the scheduler obtains input that will affect the schedule from the owner, architect/engineer, subcontractors, equipment suppliers, and suppliers of long lead-time items. This information is incorporated into the rough diagram and reviewed again. If there are conflicts between the contractor's team and the information provided by the other parties, some negotiation or conflict resolution is in order. It is best to resolve any differences in opinion before the project starts. When all conflicts are resolved, the plan is accepted (signed-off). The rough diagram is ready for scheduling, which is the phase when durations, and possibly resources, are applied to the planned activities. During the scheduling stage, a certain amount of fine tuning is always necessary. Rough diagram planning must be reconciled with the estimate (cost and resource constraints) and time constraints (usually imposed by the contract documents).

List of Activities

In the second approach to the preparation of the rough diagram, the scheduler in the initial meeting makes a written list of activities instead of using a recording, remarking on the relationships between activities and other pertinent information.

Sketch for the Diagram

In the third approach, during the initial meeting the scheduler simply sketches the diagram (usually PERT) on a large, usually continuous, sheet of paper showing the activity names and logic. The disadvantage of this approach is that sometimes the scheduler gets so bogged down in diagramming that the flow of conversation and the effective use of meeting time are diminished. If the meeting has more than two people present, this method is usually not efficient.

Combination Approach. A combination approach that consists of listing the activities and simultaneously sketching a diagram is popular. After identifying the activities and discussing their relationships in the initial meeting, the planners write activity names on small stick-on notes. The notes can be moved around on a large sheet of paper by members of the scheduling team to refine the original logic in accordance with the accepted plan.

Reconciliation. In the first three approaches to creating a rough diagram, no reconciliation to the estimate is made until *after* the rough diagramming stage. Reconciliation is done during scheduling, when durations and resources are assigned to the project activities. All costs input to the estimate have to be input a second time if they are to be used in the schedule. This extra step of having to reenter all the information prohibits many contractors from using labor or resource profiles and detailed cost analysis by activity.

Software Integrator

The fourth approach—using a software integrator to produce the rough diagram—differs fundamentally from the others. This is the most efficient method for a number of reasons, primarily because it combines the estimate and the schedule simultaneously. The estimate is the document that defines the bottom line for a project—the budget for resources and costs. Unfortunately, the estimator and the scheduler look at the world differently. The estimator's goal is to turn out the greatest number of estimates with the best accuracy for the least cost. He or she will probably only get one out of every six to ten jobs estimated. The estimator is more concerned with defining cost than with providing a breakdown of cost for sequencing purposes. For example, an estimator will use one entry for concrete grade beams of a particular type with breakout by the different materials making up the grade beam (concrete, formwork, rebar, embeds, finishing, waterproofing, rubbing, etc.). This is the most efficient way to estimate cost. The scheduler, however, usually needs to relate the work by type of crew (carpentry, finishing, etc.) to individual pours or groups of pours. Since labor crews are commonly the resource to be maximized and kept working efficiently, the scheduler needs information sorted by type of crew.

Using an estimate/schedule software integrator for preparing the rough diagram avoids the problem of inputting the same information twice. Many of the best-selling estimating programs provide an interface program for the estimate to be "dumped" into the estimate/schedule integrator. While the information is in the integrator, individual line entries from the estimate can be either combined or split and attached to a named activity. The strength of the integrator is its ability to name the activities and move any associated cost and resources in the estimate to the named activity. The named activity retains the cost and resources when it is dumped to the scheduling software package without having to be reinputted, which ensures the correlation between the data in the estimate and in the schedule. The software integrator cannot be used to establish relationships, however. The relationships are established when the new file is brought up in *P3e*. This simplification process helps ensure that the contractor actually uses the management tools available through software packages such as *P3e* to control cost and resource functions.

Markup of the Estimate. When using a software integrator approach to produce the rough diagram, the first step is for the project team to mark up the hard-copy printout of the estimate and define the activities manually. In the integrator, line entries from the estimate are either combined or split to form activities. When complete, the computer estimate file is dumped into the scheduling software package. All associated cost and resource information identified by activity is brought into the scheduling software package automatically when the dump occurs. The scheduling software package establishes relationships among the activities and calculates the schedule. This version of the rough schedule is presented to all key project participants for fine tuning, as are rough diagrams in the first three approaches. This approach to producing the rough diagram offers the advantage of reconciling the estimate and the schedule without having to input information twice, but care must taken not to let reliance on the computer stifle the creativity and freedom of the planning stage.

Rough Diagram Preparation

There are five steps in the development of a rough diagram. The steps for preparation of a construction-only schedule are as follows:

1. **Contractor's Initial Meeting.** The contractor's project team members have an initial meeting to discuss the entire project from beginning to end. The members include the estimator, project manager, possibly the superintendent, and the person creating the schedule. The team builds the project on paper, starting from the estimate. Either a tape recorder is used or the scheduler takes notes. Some people prefer to simply list the activities. In any case, the estimate is the benchmark from which to start.
2. **Rough Diagram Creation.** The scheduler uses the information from the initial meeting to draw the rough diagram (usually PERT) on paper, showing interrelationships between the activities. Some schedulers prefer to go straight to the software at this stage rather than to manually draw the rough diagram on paper. Those who have software with an integrator function can also use it to estimate cost and resources needed for each activity at this stage.

3. **Review.** The entire project team must "buy into" the rough diagram so that it is "their" schedule. It is critical for each to agree as a team to the concept, methods, and procedures to be used in the construction of the project.
4. **Major Subcontractors and Suppliers Input.** Input from major subcontractors and suppliers of long lead-time material and/or equipment items is critical. With the contract documents, the general contractor or construction manager has overall responsibility for coordination and scheduling of the work. It is up to the contractor to coordinate all parties' work and to resolve any disputes. Input is usually required of the subcontractor in the contractor-subcontractor contract. Through discussions with the subcontractor/suppliers, the contractor modifies the plan to reconcile differences. Then the subcontractors/suppliers accept the contractor's plan as the project plan. Contractors need to make sure they have obtained information from any outside party that can impact the schedule.
5. **Project Schedule Acceptance.** Once the contractor has reviewed the revised rough schedule with the subcontractors/suppliers, it becomes the official project schedule.

Information Gathering for the Rough Diagram

During the prebid or estimating phase of the project life cycle, the estimate becomes the focal point in the gathering of information relating to the project. Information must be gathered from many sources and incorporated into the estimate. The following is typical of the information that must be collected:

- Owner time constraints and other input
- Scope definition
- Building methods and procedures to be used
- Productivity rates, crew balances, and crew sizes
- Labor availability and wage rates
- Construction equipment to be used
- Construction equipment availability and use rates
- Material availability and prices
- Subcontractor availability and prices
- Fabricator availability and prices
- Project organizational structure
- Rough preliminary schedule
- Temporary facilities requirements
- Permit and test requirements
- Tax requirements
- Insurance requirements

In-Depth Planning. If a contractor's bid wins the contract for a project, the estimate is used to generate the schedule. Now that the project is a real live job rather than just a proposal, more in-depth planning can take place. A logic diagram rather than a "quick and dirty" bar chart is used to fine-tune the information already gathered in the estimating stage.

Parties. The schedule becomes the focal point of project information that is received from the project manager, superintendent, foremen, estimator, subcontractors, fabricators, suppliers, vendors, owner, and architect/engineer.

Meetings Held for the Preparation of the Rough Diagram

There are five important considerations to remember when holding meetings to produce the rough diagram. They are using an agenda, making a list of action items, preparing the project schedule, team building, and brainstorming.

Agenda. To keep a meeting from degenerating into a general waste of time requires an agenda. Distribute the agenda prior to the meeting. It should document the date, time, and location of the meeting, information to be covered, what each participant should bring to the meeting, and points each participant should know before the meeting begins. Each member should already be familiar with the contract documents and the major parameters. It is a waste of everyone else's time if some project members come to the meeting unprepared.

Action Items. The immediate product of a scheduling meeting is a list of agreed-upon action items to be accomplished before the next meeting. The list should designate the person(s) responsible for each item and set a date for the next meeting. The way we schedule and carry out the scheduling says a lot about our management abilities in carrying out the project.

Project Schedule. It is frequently commented that the act of preparing the rough diagram is the most valuable part of the entire scheduling process. The reason is communications: Everyone is aware of the "plan"; everyone knows everyone else's point of view regarding project goals. The project schedule that is accepted after all discussion has taken place is the one used by all parties to organize their work.

Team. If all key parties feel that they are a part of the team with a chance to contribute their information and ideas, the project is more likely to succeed. Some of the suggestions for improving project efficiency or lopping time off the schedule may come from unexpected sources. Communication leads to evaluation and reevaluation of the plan to streamline construction.

Brainstorming Alternatives. When a decision has to be made to choose a particular system or technique for some portion of the work, brainstorming is a good way to look at the alternatives. For example, to decide on the most effective way to pour the concrete columns in a multistory building, the group would start by simply tossing out the question: "What is the most effective way to pour the concrete columns on this project?" Each member of the group replies by tossing out the first solution that comes to mind, no matter how ridiculous the solution might immediately sound. Try to get many possible solutions before any analysis of the solutions begins. After all proposed solutions have been introduced, discuss each one and eliminate those that obviously won't work. You should be able to narrow your list down to only two or three legitimate choices from which the group can make a final selection. The object of this brainstorming exercise is to break established patterns or mindsets and look for new and better ways to build the project. Many times you get stuck in a rut doing things in the same old way simply because "that's the way we have always done it and it has always worked." Only by looking for new and more effective ways to build the "mouse trap" can we improve construction operation.

The Construction Project Defined

Most construction companies look upon each project as a profit center. The project represents a unique set of activities or actions that must take place to produce a unique product. The lump-sum project is divided into actions that precede and follow the signing of the contract. Precontract relates to the bidding. The contractor wants to invest as little as possible in the project until the client has signed the contract. Once the contract is formalized detailed planning and scheduling proceed. Only after the contract is in hand should the constructor commit to the level of detail and resources needed to produce a "production schedule."At the end of the project, the owner takes possession of the structure to use it for its intended purpose, takes responsibility for utilities and insurances, and submits final payment to the contractor.

Criteria for Success

Each project has a definable start and end and a unique set of characteristics and activities that must be accomplished to fulfill a contract. Each project is judged as a success or failure in terms of a preset list of criteria. For example:

- Did the project come in under budget?
- Did the project make any money?
- Were changes controlled through change orders?
- Did the project come in on time?

- Did the project meet the requirements of the contract documents?
- Were both client and employee satisfaction achieved?
- What was the project safety record?
- Was this project an effective use of company resources?
- Did the project meet, or exceed, the company's short- and long-term goals?

Uniqueness of Each Project

No two construction projects are quite the same. Even if the plans and specifications are almost identical, the projects' sites differ. The starting dates also differ, so each project is subject to different weather conditions. Environmental requirements, permits, and regulatory personnel differ from job to job. The project team that builds the project is usually also composed of different people. Each project is thus a learning experience. Lessons learned about productivity, project layout, flow of materials, crew sizing, and communications can help improve the quality of estimates and schedules in future projects.

Project Phases

Time and the control of time relates to all phases of the construction project life cycle. The construction project life cycle can be broken into eight phases:

1. Feasibility study
2. Conceptual design
3. Detailed design
4. Bidding
5. Construction
6. Commissioning
7. Closeout
8. Maintenance

1. **Feasibility Study.** The feasibility study usually involves evaluating different design scenarios from the standpoint of building cost, maintenance cost, and appearance. Contractors use cost studies to play "What if?" games in an effort to pick the best approach. Only sketches are drawn, and only general concepts are considered at this stage. The great expense of producing detailed documents is not incurred until all major concepts have been agreed upon. Much of the project's costs are fixed when the feasibility study is complete. The reason these costs are fixed is that by this stage the following cost-determining characteristics of the project have already been defined:

   - Size of the project (number of square feet, number of floors)
   - Type of building system (steel building versus concrete building, flat slab versus waffle slab)

- General arrangement showing bathrooms, etc.
- Geographical location

The feasibility study phase is also where the global, high-dollar decisions about the project are generally defined and refined. The costs for implementing ideas are estimated and compared to the owner's budget and calculations of return on invested capital. Thus, during the feasibility study phase decisions about the economic viability of the project are made, before the owner invests in detailed plans and specifications and concrete. When participants believe that a viable project is attainable, conceptual design can begin.

2. **Conceptual Design.** In the conceptual design phase, the design professional (architect/engineer) defines the owner's need in a conceptual project-scope document. This document defines the project in enough detail so that detailed design can begin. The conceptual design information needed varies by type of project. An office building differs from a refinery, for example, but the general idea is the same. The conceptual design of a new building would contain sketches of the following:

   - Site
   - Footprint of the building on site
   - General floor plan of the building by floor
   - Major wall sections
   - Major elevations
   - General definition of traffic flows
   - Major environmental considerations, such as type of HVAC system
   - Conceptual estimate (must include a projection of project duration)

3. **Detailed Design.** Detailed design involves applying the broad concepts as defined in the conceptual design and producing the detailed plans, specifications, and the rest of the contract documents. To make a lump-sum bid specifying cost value and duration in days, a contractor has to know the scope of the project. The purpose of the detailed design is to produce the contract documents in enough detail so that they can be used for three primary purposes: bidding the project, building the project, and settling of any claims. A clear, concise set of contract documents is a tremendous asset to the constructor during the bidding, construction, and closeout phases of the project.
4. **Bidding.** In the bidding phase of the project life cycle, the constructor prepares the estimate based on the contract documents prepared in the detailed design phase. The constructor quantifies the project in terms of material quantities, productivity rates, worker hours, wage rates, material dollars, subcontractor dollars, overheads, and indirect expenses. A rough schedule, usually a bar chart, is prepared for use in the bidding process.
5. **Construction.** During building, the constructor marshals at the job site all the management, expertise, manpower, materials, equipment, subcontractors, temporary facilities, and financial wherewithal

necessary to construct the project according to the contract documents. The goal is to complete the project within cost and time constraints in order to make money.

6. **Commissioning.** Commissioning is the process of testing and start-up of systems. It includes the final inspection and preparation of a punchlist of remaining items to be completed, modified, or repaired before final acceptance by the owner. It is very important at this stage that the project be as nearly complete as possible. An attempt to close out the project when obvious items are incomplete may produce frustration and mistrust on the part of the owner and designer.
7. **Closeout.** The closeout phase in the project life cycle involves completing the paperwork necessary for a contractor to receive final payment and be released from the project. Documents include:

    - Affidavit of release of liens from suppliers, vendors, and subcontractors
    - Maintenance/owner's manuals for equipment and systems
    - As-built drawings
    - Request for final payment/lien waiver
    - Consent of surety
    - Guarantees
    - Warranties

8. **Maintenance.** Construction projects are designed for 20, 30, 50, or more years of productive life. To last that long, they require continual maintenance. Even on a project with a 50-year anticipated life cycle, the roof may only have a 20-year anticipated life. The elevator and the HVAC system require constant attention. Some contract proposal forms require from the contractor not only a bid for construction of the building but also for maintenance for a certain number of years of the building's life. Maintenance, however, is usually an ownership function.

Project Team

No construction project of any size is ever built by an individual. It is constructed by a team. The concept of "team" crosses company boundaries. The makeup of the team preparing the rough diagram depends on the construction life cycle phases to be controlled with the schedule. Members of the lump-sum, construction-only scheduling team include the following:

Contractor's Organization

Project team

- Project manager
- Superintendent
- Foremen/craftspersons

Home office support
- Estimator
- Scheduler
- Cost accountant
- Purchaser
- Accountant
- Equipment manager
- Lawyer

Subcontractor's Organization
Field team
- Project manager
- Foremen/craftspersons

Home office support
- Estimator
- Scheduler
- Cost accountant
- Purchaser
- Accountant
- Equipment manager

Vendors'/Suppliers' Organizations
Fabrication/storage yard team
- Project manager
- Foremen/craftspersons

Home office support
- Estimator
- Purchaser
- Accountant
- Equipment manager

Owner
Construction representative

Architect/Engineer
Project representative

- Engineering consultants

Government
Inspector
Labor law enforcement official
Safety law enforcement official
Tax enforcement official

Successful projects require a mindset of teamwork and problem solving. The goal is to work together to settle disputes at the lowest level for the mutual benefit of the entire group, rather than engaging in fighting, finger pointing, and litigation. Once again the modern concepts of "partnering" and "team" cross company boundaries. Looking at the project from the perspective of a team rather than one dominated by company boundaries helps control time and project duration. The contractor is not solely in control of all the variables required for successful project completion. Only through teamwork can the project schedule be successfully met. One of the best ways to ensure that teamwork is effective during the entire construction process is through thorough and accurate written project documentation. Many decisions made during the project and sealed with a handshake are forgotten later on unless written documentation formalizes the decisions reached.

Design-Bid-Build Construction

Design-bid-build construction carries out the construction life cycle phases in consecutive rather than concurrent, order—each phase is completed before the next begins. Building the project with this constraint takes longer. Since each step of the process is defined, finished, and usually paid for before the next begins, and since this process is usually based on lump-sum contracts, the owner transfers the risk of cost overruns to other parties. The owner knows the cost of each phase before committing to paying for it. The owner also knows that because the project can be canceled at any time, he or she is only at risk for the work that has been released.

No Contractor Input

In a lump-sum contract (design-bid-build construction), the contractor's contract typically includes the construction, commissioning, and closeout phases of the construction life cycle but no input during the conceptual or detailed design phases. This is unfortunate, since who knows more about minimizing construction cost by efficient design, constructibility, materials selection, and the use of prefabricated materials than someone who is involved in the actual building process every day? Many times the designers operate in a vacuum during the design phase relying only on their own past experience to select materials and methods of construction. Significant savings can usually be realized by involving contractors, subcontractors, and material suppliers at this stage of the project. The use of construction management professional services may be a good solution, as it incorporates the construction experience in the design process, before a contractor is available.

Steps in the Lump-Sum Project

The following is a sequential listing of the steps typically followed with lump-sum construction in the United States:

1. Owner determines a need.
2. Owner contacts architect/engineer for conceptual design.
3. Conceptual design is completed.
4. Owner approves conceptual design or sends it back for modification.
5. Owner contracts architect/engineer for detailed design contract documents.
6. Detailed design is completed.
7. Owner approves detailed design or sends it back for modification.
8. Owner puts contract documents out for bid.
9. Bids are received from contractors and negotiated.
10. Owner and contractor sign contract.
11. Construction proceeds.
12. Project is commissioned.
13. Project is closed out.

Negotiated, Fast-Track Construction

With a fast-track type project, the constructor (construction manager) is typically involved in all construction life-cycle phases except possibly maintenance. The constructor has a negotiated contract with the owner and acts as the owner's agent in a fiduciary relationship. He or she is looking out for the owner's best interest. The constructor has input in defining the owner's needs during both the conceptual and detailed design phases. The contractor is primarily concerned with minimizing construction cost by efficient design, constructibility, materials selection, and the use of prefabricated materials while the critical decisions about these factors are being made. The constructor will produce the conceptual estimate and cost studies of different design scenarios. Having a member of the design team who is a cost-conscious, knowledgeable constructor can be a tremendous advantage to the owner in producing a successful project.

Steps in Fast-Track Construction

The following set of steps is typical of fast-track construction in the United States using the agency construction management type contract:

1. Owner has a need.
2. Owner contacts construction manager for services, which include control of design, estimating, and scheduling. The construction manager may be the architect or engineer as well as the contractor.

3. Construction manager works with architect/engineer to produce conceptual design.
4. Construction manager estimates costs to fine tune conceptual design until it meets the owner's return-on-investment requirements.
5. Owner/construction manager approves conceptual design.
6. Owner/construction manager contracts with architect/engineer for detailed design contract documents, then breaks down design into packages or phases that can be completed and put out for construction bid.
7. Owner/construction manager approves detailed design one package at a time.
8. Owner/construction manager puts contract documents out for bid, one package at a time.
9. Owner and successful package contractor sign contract for single package.
10. Owner/construction manager brings all the packages through the steps of detailed design, bid, award, and construction.
11. Construction progresses simultaneously with further detailed design. The construction manager monitors the schedule, controls multiple contractors, and approves pay requests. The construction manager acts as the general contractor at the job site.
12. Project commissioning is usually handled one package or system at a time.
13. Project closeout is handled by the construction manager in much the same way as the general contractor would handle it.

With the fast-track approach to construction services, the owner assumes more of the risk, since construction is proceeding before the design documents are completed. The construction manager is the owner's agent, and therefore typically does not sign a lump-sum contract with the owner., unless it is a CM (Construction Management) at risk contract. The real advantage to the owner is the time savings of producing the detailed design and construction concurrently rather than consecutively. This approach can cut in half the overall time needed to bring a project "on line," thus saving not only time but money.

Use of Schedules

A critical part of any scheduling effort is in deciding how the schedule will be used to control a project. The following issues should be defined before the rough diagram is prepared:

- Type of project
- Purpose of the schedule
- Software requirements

- Parties involved: owner, construction manager, architect/engineer, contractors, major subcontractors, minor subcontractors and sub-subcontractors, suppliers of long lead-time items
- Authority/responsibility of involved parties (Who is "keeper of the schedule"?); responsibility for resolving disputes and interferences
- Needs of the involved parties from a scheduling point of view
- Type, frequency, and depth of reports to be provided
- Schedule update requirements (What is the time frame for providing updated information in what format, and who is to provide the information?)
- Project change requirements
- Resources to be controlled: labor, materials, subcontractors, construction equipment
- Cash flow requirements
- Payment (schedule of values) requirements

TIME UNITS

The Day

The time unit used for most construction schedules is the day. *P3e* does not have a concept of time units. Units are strictly for display purposes only.

The determination of the minimum planning unit depends on the total expended duration of the project, as well as the required level of detail. In the typical construction schedule with days as the unit of measure, when activities are being defined, no block of work is assigned a duration of less than a day to complete. If the activity takes less than a day, it is either rounded up to a day or combined with another task/activity.

The Hour

Sometimes the hour is a more convenient unit than the day. This is the usual unit of choice for a "turnaround" schedule as used in a paper mill, chemical plant, refinery, or other facility in operation. The facility must be brought down or "off-line" for maintenance or to add or modify plant systems. Typically, the owner loses thousands of dollars per day while the plant is out of operation. Making the modifications as quickly as possible and getting the plant going again is essential to the owner. Each hour is critical.

CONCURRENT RATHER THAN CONSECUTIVE LOGIC

Besides trying to improve efficiencies, schedulers also need to improve the logic of activity interrelationships and sequences when putting the rough diagram together. Instead of having just one thing at a time happen at the job site, as many things, crews, or work functions as possible need to be happening, without their interfering with each other and without risking exposure or damage by project components being in place too early. What is the shortest and most efficient way to accomplish the work?

ESTIMATING ACTIVITY DURATION

The duration of an activity is a function of the quantity of work to be done by the activity and the rate of production at which the work can be accomplished. The formula is:

$$\text{Activity Duration} = \frac{\text{Quantity of Work}}{\text{Productivity Rate}}$$

Take, for example, a masonry activity with a quantity of work of 10,000 regular masonry blocks to be placed by a crew of three masons, two laborers, and a mixer. The crew can place 800 blocks per day. Thus, duration = 10,000 blocks/800 blocks per day = 12.5 or 13 days.

RESOURCE AVAILABILITY

Critical to estimating activity duration is the availability of resources needed, including labor, materials, equipment, subcontractors, and suppliers/fabricators.

Driving Resources

Most activities have certain driving resources that control activity duration. For example, in the preceding masonry activity, the three masons are the driving resource. Their craft determines activity duration. Once the ratio of laborers and mixers has reached maximum efficiency for three masons, no matter how many more laborers and mixers are added, the performance of the three masons will not be increased.

Reduction of Duration

There are three ways to reduce the duration of 13 days for the masonry activity. The first is, by increasing the productivity rate of the three masons to better than 800 blocks per day. This could be accomplished by an improved method or system for placing the block. The second way would be to add more masons, with enough laborers and mixers to ensure full production. The third way would be to have the masons work overtime (more hours per day).

Extended Scheduled Overtime

Extended scheduled overtime can ultimately have a negative impact because of lost productivity. It is also important to consider the higher cost of overtime pay. Studies have shown that consistent reliance on overtime by the same crew actually results in less productivity than that normally achieved in an eight-hour day.

As a rule, the more resources that are available to put the activity in place, the less time it takes to place the activity. If any of the resources necessary to place the activity are missing or are not handled properly, the activity duration calculation is impacted.

Quantity of Work

The contract documents define the scope of the project. Using the plans and specifications, the estimators survey quantities of materials necessary to complete the project. The estimate may not provide a bill of materials in enough detail to enable purchasing of all materials for the project, but it will provide enough detail to bid the project. The estimate prepared at this stage relies solely on the contract documents. If insufficient detail or ambiguity exists in the contract documents, the estimate will usually be overly conservative to account for uncertainties.

To produce a *quantity survey*, the estimators organize by type of work. Building contractors usually use Construction Specifications Institute (CSI) cost code structure. The estimators assign work definition by spec division, by phase, then by the item or unit of work within the phase.

Contractors usually produce a quantity survey only for work to be completed by the contractor's own forces. For subcontracted work, contractors usually depend on the market for the best price.

A code of accounts is a coding/numbering system to categorize work for controlling/tracking purposes. The contractor organizes the code of accounts and quantity survey that each type of crew will accomplish into identifiable areas or phases, usually organized according to CSI format. The major CSI phase headings are:

01000	General Requirements	09000	Finishes
02000	Sitework	10000	Specialties
03000	Concrete	11000	Equipment
04000	Masonry	12000	Furnishings
05000	Metals	13000	Special Construction
06000	Wood and Plastics	14000	Conveying Systems
07000	Thermal and Moisture Protection	15000	Mechanical
08000	Doors and Windows	16000	Electrical

The cost code structure is organized by craft designation so that work boundaries are understood by all parties involved. For example, all masonry-related work is categorized in the 04000s.

Productivity Rate

Productivity Rate by Activity

The quantity survey defines the amount of materials for a particular type of work, such as the square footage of a slab to be finished. The next step is to assign a productivity rate to determine the duration and resources necessary for the activity. The rate is the quantity of work accomplished per work hour (e.g., 30 square feet of concrete finished per work hour, or 30 SF/WH), or quantity of work accomplished per crew hour (e.g., 120 square feet/crew hour based on a four-person crew, or 120 SF/CH). The rate per man-hour (work hour) has to be adjusted for the size of the crew to determine duration.

Sources of Productivity Information

Sometimes if no formal estimate is prepared, the scheduler may have to come up with the productivity rate. The following sources may be useful:

- Company records for producing the same type of work on previous projects (historical data)
- Published information in reference text
- Observation and measurement of work performance as it is being put in place on another project
- Qualified expert opinion

Factors Affecting Productivity

The amount of time it takes to accomplish a unit of work can vary appreciably for the same type of work from project to project and is the reason for unpredictability of construction labor costs. This variability in performance results from differences in communications, supervision/proper preplanning, layout of the work, crew balance, skill/craftsmanship, mental attitude of workers, purchasing practices, working conditions, environmental factors, continuously scheduled overtime, safety practices, work rules, and availability of work.

Communications

Good communications—in writing—cannot be stressed enough when discussing productivity. It is common practice for the superintendent to communicate orally with the foreman about the work to be accomplished, referring to the plans, specs, and shop drawings. The foreman in turn communicates orally to craftspersons the direction, methods, and layout for accomplishing the work. This chain of oral communication leads to a great deal of rework, exemplified by the comment "I built what I thought you wanted."

Some supervisory personnel seem to almost take pride in not communicating information to their subordinates. This attitude of "I'm the only one who knows all the answers" promotes distrust and low morale among employees. The effective supervisor, however, has learned that open and effective communications with everyone involved in the construction process makes his or her job much easier and cuts down on needless finger pointing. A good subconscious thought for this manager to constantly ask is "If the owner of this project came onto the job site and asked any one individual what they were working on (and why), would that person know the answer?"

Many contractors now put communications in writing, using 10-day look-ahead and job-assignment sheets for in-depth planning and scheduling. An emphasis on sketches and drawings further reduces dependency on oral communications. The improved documentation improves productivity.

Supervision and Preplanning

Good supervision and proper preplanning also improve productivity. Commitment to cost and schedule control by top management leads to improvements in training, safety, scheduling, estimating, and purchasing and to an emphasis on quality on all projects.

Efficient Layout of the Work

Of critical importance in the proper execution of the work is efficient layout. These include:

- Storage of materials so they can be located quickly and easily when necessary

- Minimal handling of materials (on many work items, more time is spent handling the materials than actually putting the materials in place)
- Use of the right equipment for the job
- Efficient access to tools, utilities, drinking water, and sanitary facilities
- Where possible, working at waist level to reduce unnecessary motion and fatigue

Proper Crew Balance

A construction crew has a proper balance of workers for various aspects of each activity. In a masonry crew, for example, the ratio of the workers mixing the mortar to the laborers transporting the mortar and stacking the block for placement and to masons actually placing the block must be balanced properly to efficiently accomplish the work. The ratio of highly paid skilled workers to the lower paid helpers is important for peak efficiency.

Skill/Craftsmanship

Training construction craftspersons to improve their skills is necessary because of the ever-changing technology. Improvements in construction equipment are changing the way work is accomplished and increasing productivity. Since a construction company's primary asset is its employees, nurturing and training them to increase performance is a wise investment.

Mental Attitude of Workers

People are not machines. The mental attitude of workers seriously affects productivity. Management should strive to promote worker feelings of pride in the company, faith in a secure future, confidence in good management, the company's respect for employees, the company's regard for employee's opinions, company growth, and the potential for individual growth. When employees get satisfaction from working with a company and their individual needs are being met, they are more productive at the job site.

One way that many construction companies have discovered to improve the attitude of their workers is by adoption of a "Total Quality Management" (TQM) philosophy. This organizational and operational approach, originally implemented in the manufacturing sector, has proven to be beneficial for the construction industry as well. The Construction Industry Institute in a study of 17 major contractors who had developed a TQM operating philosophy found they had four major things in common:

- Greater productivity
- Increased customer satisfaction

- More profits
- Higher employee morale

As well as the obvious benefits of increased morale, many construction companies have documented savings in the form of better safety records and a significant reduction in "reworks."

Purchasing Practices

A construction company's purchasing practices can have a tremendous impact on job site productivity. The use of prefabricated assemblies or preassembled units or taking labor off-site to a manufacturing-type controlled environment can have great impact on worker hours spent at the job site. A lower average wage rate, lower-level craft skills required, increased availability of specialized tools and jigs, the ability to work under a roof in a controlled environment, and availability of local labor can all be great advantages. A scheduling advantage is that the fabrication can be concurrent with work at the job site, reducing the overall time for the project to be completed. Prefabricating materials in a controlled environment rather than at the job site can also have a huge impact on cost.

Working Conditions

In construction, the worker is typically exposed to the elements. Extremes can slow productivity. Conditions that influence job site productivity include some that cannot be controlled—heat, cold, rain, humidity, dust, wind, odor, and acts of God—and some that can be controlled— noise, climbing up or down, bending low or reaching high, and the number of people on site.

Some companies have taken innovative approaches to address the day-to-day working conditions of their employees. Texas Instruments Corporation (TI), for example, initiated radical changes to the way construction was carried out during the building of many of their newer facilities. Texas Instruments implemented a TQM policy to be followed by all of the general contractors and subcontractors working on TI projects. One of the requirements was the construction of a clean, air-conditioned lunchroom for the workers at every one of their job sites. The only stipulation was that no food or drink (other than water) was allowed on the actual construction site. This one change, along with other elements of the TQM philosophy, resulted in higher employee morale, increased profits reported by all of the contractors involved, and a reduction in "reworks" from 10% to 2%.

Continuously Scheduled Overtime

Many studies have shown that continuously scheduled overtime has a disastrous impact on productivity. The construction industry Business

Round Table study entitled "Cost Effectiveness Study C-3" (November, 1980) showed that workers putting in 60-hour weeks for nine straight weeks accomplished the same amount of work in the ninth week as in a normal 40-hour workweek without the overtime. This means that paying for the extra 20 hours accomplished nothing. Compounding this false economy is the enormous cost of paying overtime for work in excess of 40 hours per week. Spot overtime can be effective, but continuously scheduled overtime is decidedly ineffective from an economic point of view.

Safety Practices

Safety practices have direct and indirect influences on productivity. The direct influence is that when someone is hurt, work at the job site usually stops or is at least impacted by the disturbance. It is the topic of conversation. Everyone is concerned. The company has at least temporarily lost the services of an employee. The loss also affects the crew balance and hence the productivity of a work unit.

The indirect impact relates to the effect accidents have on workers' morale and feelings of personal safety and security. Accidents affect the way employees think of the quality of the company's management and ability to manage the job site. Accidents also affect the employee's pride in the company and desire to stay with the company.

Work Rules

Sometimes, labor constraints can have a negative impact on productivity. Union constraints that may limit management's ability to organize for maximum productivity include jurisdictional disputes, production guidelines, limits on time studies, limits on piecework, and limits on prefabrication.

Availability of Work

If times are good and there is plenty of construction work available, employees know that other jobs are readily available. There is not as much pressure to produce at the existing job. Conversely, if things are tight, there is much more pressure to keep the existing job, or possibly to draw out the current work as long as possible. Work availability can be a double-edged sword, depending on how it is perceived by the workers.

Accuracy of Estimating Activity Duration

Schedulers sometimes make subjective judgments about the duration of activities rather than taking the time to refer back to the estimate and perform an actual calculation based on productivity rates and quantity of work. Since time is money, the accuracy of a contractor's schedule depends directly on the reliability of estimates of activity durations.

Example Problem: Rough Manual Logic Diagram

Table 2–2 is a list of 28 activities (activity ID and description) for a house put together as an example for student use (see the wood-framed house drawings in the Appendix). The rough manual logic diagram (Figures 2–3a and 2–3b) was constructed using the list provided in Table 2-2.

Act ID	Act Description
A1000	Clear Site
A1010	Building Layout
A1020	Form/Pour Footings
A1030	Pier Masonry
A1040	Wood Floor System
A1050	Rough Framing Walls
A1060	Rough Framing Roof
A1070	Doors and Windows
A1080	Ext Wall Board
A1090	Ext Wall Insulation
A1100	Rough Plumbing
A1110	Rough HVAC
A1120	Rough Elect
A1130	Shingles
A1140	Ext Siding
A1150	Ext Finish Carpentry
A1160	Hang Drywall
A1170	Finish Drywall
A1180	Cabinets
A1190	Ext Paint
A1200	Int Finish Carpentry
A1210	Int Paint
A1220	Finish Plumbing
A1230	Finish HVAC
A1240	Finish Elect
A1250	Flooring
A1260	Grading & Landscaping
A1270	Punch List

Table 2–2 Activity List—Wood-Framed House

Exercises

Exercises 1 to 6 contain logic statements. Complete a logic diagram for these statements.

1.

1.	A	Must Precede	B, C, D
2.	B	Must Precede	E
3.	C, D	Must Precede	F
4.	E	Must Precede	G, H
5.	F	Must Precede	H
6.	G, H	Must Precede	I

Figure 2–3 Exercise 1—Logic Statements

2.

1.	A	Must Precede	B, C
2.	B	Must Precede	D, E
3.	C	Must Precede	F
4.	D	Must Precede	G
5.	E, F	Must Precede	H
6.	G	Must Precede	I, J
7.	H	Must Precede	J
8.	I, J	Must Precede	K

Figure 2–4 Exercise 2—Logic Statements

3.

1.	A	Must Precede	B, C, D
2.	B, C	Must Precede	E
3.	C, D	Must Precede	F
4.	D	Must Precede	G
5.	E, F	Must Precede	H
6.	G, F	Must Precede	I
7.	H, I	Must Precede	J
8.	I	Must Precede	K
9.	J, K	Must Precede	L

Figure 2–5 Exercise 3—Logic Statements

4.

1.	A	Must Precede	C, D
2.	B	Must Precede	D, E
3.	C	Must Precede	F
4.	D	Must Precede	G
5.	E	Must Precede	H, I
6.	F, G	Must Precede	J
7.	G, H	Must Precede	K
8.	I	Must Precede	L
9.	J, K	Must Precede	M
10.	K	Must Precede	N
11.	K, L	Must Precede	O
12.	M, N	Must Precede	P
13.	O	Must Precede	Q
14.	P, Q	Must Precede	R

Figure 2–6 Exercise 4—Logic Statements

5.

1.	A	Must Precede	B, C
2.	B	Must Precede	D, E
3.	C	Must Precede	F
4.	D	Must Precede	G, H
5.	E, F	Must Precede	I
6.	F	Must Precede	J, K
7.	G, H, I	Must Precede	L
8.	I	Must Precede	M
9.	J, K	Must Precede	N
10.	L, M	Must Precede	O
11.	M, N	Must Precede	P
12.	O, P	Must Precede	Q
13.	P	Must Precede	R

Figure 2–7 Exercise 5—Logic Statements

6.

1.	A	Must Precede	C, D
2.	B	Must Precede	E
3.	C	Must Precede	F, G
4.	D	Must Precede	G, H
5.	E	Must Precede	H, I, J
6.	F	Must Precede	K
7.	G	Must Precede	K, L, M
8.	H	Must Precede	L, M, N
9.	I	Must Precede	M, N
10.	J	Must Precede	O
11.	K	Must Precede	P, Q
12.	L	Must Precede	R
13.	M	Must Precede	Q, R
14.	N	Must Precede	R, S, T
15.	O	Must Precede	S, T
16.	P	Must Precede	U
17.	Q	Must Precede	V
18.	R	Must Precede	V, W
19.	S, T	Must Precede	W, X
20.	U	Must Precede	Y
21.	V	Must Precede	Y, Z
22.	W	Must Precede	Z
23.	X	Must Precede	A’
24.	Y, Z	Must Precede	B’
25.	A’	Must Precede	C’

Figure 2–8 Exercise 6—Logic Statements

7. Small Commercial Concrete Block Building
Prepare a rough manual logic diagram for the small commercial concrete block building located in the Appendix. Follow these steps:
- **a.** Prepare a list of activity descriptions (minimum of 60 activities).
- **b.** Establish activity relationships.
- **c.** Create the rough manual logic diagram.

8. Large Commercial Building
Prepare a rough manual logic diagram for the following large commercial building located in the Appendix. Follow these steps:
- **a.** Prepare a list of activity descriptions (minimum of 150 activities).
- **b.** Establish activity relationships.
- **c.** Create the rough manual logic diagram.