FOURTH EDITION

Project Scheduling and Management for Construction

David R. Pierce , Jr.

RSMeans

WILEY

Project Scheduling

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Fourth Edition

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Cover Design: Wiley
Cover Image: © 2012 Foreman Seeley Fountain Architecture

This book is printed on acid-free paper.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey

Published simultaneously in Canada

Library of Congress Cataloging-in-Publication Data

Pierce, David R.

Project scheduling and management for construction / David R. Pierce, PSP. — Fourth edition.
pages cm
Includes bibliographical references and index.
ISBN 978-1-118-36780-3 (pbk. : alk. paper)); ISBN 978-1-118-41717-1 (ebk);
ISBN 978-1-118-42056-0 (ebk); ISBN 978-1-118-77955-2 (ebk) 1. Construction industry—Management. 2. Critical path analysis. I. Title.
TH438.P464 2013
690.068'4—dc23

2013009450

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Philippians 4:13

To Dr. Bill Barnes 1930-2012, an honored colleague to so many who worked with him to create the profession of construction management, and a special friend and mentor to the author for over 25 years.

Contents

Preface

This text is the product of the author's 30 plus years of teaching and practicing the art of construction scheduling. The organization and content of the material is derived from experience in both teaching and practice, and is representative of what the author has learned about teaching scheduling in multiple classrooms and on many projects in several segments of the industry. More importantly, however, the content of the text contains much that the author has learned from colleagues throughout the country who have contributed so much the development of construction scheduling since its inception.

The book itself is aimed at two audiences. The first is those students in Construction Management and Construction Engineering programs who are taking a basic first course in the subject of CPM scheduling. The presentation and teaching materials in the various chapters come directly from what works in that environment. The second audience is practicing professionals who are interested in acquiring basic knowledge and skills in scheduling in order to improve their own job performance.

The teaching approach is built around an example project, which is representative of small-scale construction projects. The size of the project is deliberately such that it has some degree of complexity but is not so large that the level of detail detracts from learning basic principles.

Also the approach is designed as a step-by-step process that mimics the actual practice of scheduling as it should be done. Construction scheduling should be taught in a studio or laboratory class, so that students go through the decision processes that are essential for proper scheduling.

The project itself is a hypothetical vehicle maintenance garage, which services a small corporate vehicle fleet consisting of pickup trucks and light vans. The service bays contain standard vehicle-servicing equipment for that purpose. The building also contains office spaces and training rooms plus restrooms and other auxiliary spaces.

These features were designed into the building to allow a student to encounter see several different kinds of spaces, some semi-industrial, as well as finished commercial spaces. Also, the building contains a vertical element in the service pits, so that a student must think through the process of building upward as well as building horizontally.

The physical features of the building are “standard,” for example, there are no unusual materials or building techniques involved so as not to create distractions from the process of thinking about scheduling.

In the sample schedule, it is assumed that the project is being built under the terms of a lump sum fixed-price contract, and that all zoning and building department approvals have been obtained. Also, the contract has a start date of Jan 2, 2013, and a completion date of the end of September 2013. All work is assumed to be subcontracted, thus creating a need for the use of activity codes in the schedule. It is also assumed that the specifications call for a cost-loaded schedule.

The reader should note that the drawings are not totally complete, mainly because of printing limitations. The drawings are, however, sufficiently detailed to allow development of a complete schedule.

ACKNOWLEDGMENTS

The author would like to express grateful appreciation to all the individuals and companies who contributed to the writing of this book by sharing their experience and knowledge over the course of the author’s career in construction practice and teaching.

Particular appreciation is due to Jerry Fountain, Teri Huling, and Dan Cook of Foreman Seeley Fountain, Architects, all of whom helped with the CAD drafting of Vehicle Maintenance Facility (VMF) project used in the text; Jeff Casey of Reliable Hydraulics, who instructed the author in the fine points of automotive service facilities and equipment; Alan Ezell of Industrial Air Conditioning, who devised the HVAC system for the VMF; Mike Guinan, who reviewed and critiqued the sample schedule; Don Davidson and Mark Snashall, of Inglett and Stubbs, who helped with the electrical design and estimate; John Famer, of the Beck Group who contributed advice on the scheduling process; Brian Scheiber, of Jacobs Engineering, who developed the Microsoft Project schedule output, and Gerardo Barillas, who contributed to the estimate for the VMF.

Introduction

Scheduling and management of a construction project is a three-step process that requires the involvement of all the parties on a job site. It demands that the participants look ahead at the work to be done, plan strategies for getting it done, and then monitor the work to ensure completion according to plan. Each step requires the commitment and dedication of all project team members. All are essential to the successful outcome of a construction project and to the long-term success of a construction firm.

The first step is establishing a plan of action for carrying out the construction work. This involves breaking the job down into a series of manageable subparts, deciding on an order of placement, and determining the time and cost for each part and for the job as a whole. This early planning process provides a "road map" to be followed by all individuals and companies on the job to finish the project on time and within budget. There is no one best plan for each project, just as there is no single correct estimated cost. There are only choices among possible plans. The task of the project manager is to make the right choices to ensure that a reasonable and effective plan is devised, one that reflects the intentions and desires of those who will be responsible for its accomplishment.

After the plan has been developed and accepted, it must be communicated effectively to all those on the job. The quality and effectiveness of this plan and the degree to which management personnel are involved in its development set the tone for the work itself. Once the job is under way and the plan is being carried out, events inevitably occur that will force changes in the job. To cope effectively with these events, the project manager must ensure that the second management setup is carried out.

The second step in project scheduling and management is regular monitoring of the job. This includes comparing the progress of the work to the original plan to see which aspects of the job are going according to plan, and which are not. To check progress, individual parts of the job are tracked to determine if they are completed within the time limits of the schedule. With information gathered from this tracking and monitoring, the project manager must find out where the job is off track.

Finally, in the third step, the project manager must determine the causes of any delays that have occurred, and then follow through. This means working with the personnel responsible for the job's progress to ensure that corrective action is taken to bring the troubled parts of the job back into line. In order to do this, the project manager must involve all the working managers in the problem-solving process to determine causes and corrective actions. This process frequently involves replanning and aggressive follow-up. These actions are essential, however, if the job is to be properly controlled and a late and unprofitable finish avoided.

Construction projects are becoming more and more complicated, and a project manager's work is becoming increasingly difficult as a result. Every tool a project manager can find to help manage the hectic process of building is one more asset that can help bring the project in on time. This book is intended to give the project manager one of those key tools—a technique that helps the project team to effectively plan the schedule and keep track of progress. If used as described, the techniques given here will give any project manager a significant head start.

The scheduling techniques covered are all based on the Critical Path Method (CPM) of scheduling, which has become the standard means of planning and keeping track of construction progress. Too many works on this subject simply show that CPM schedules are made up of activities and that network calculations are done thus and so. This book is different in that it shows the project manager how to think through the details of a work sequence the way it is actually done by experienced construction personnel, and it discusses the "nuts and bolts" of the process as real-world people actually do it. In that sense, it is short on theory and long on practice. Also, the techniques are demonstrated using a straightforward sample project that provides an excellent learning tool. In addition, sample computer output is provided, which is in keeping with modern practice. Up-to-date scheduling practices include the use of microcomputer-based software. This text includes samples from Microsoft Project to illustrate how modern computer programs can be used display schedule information.

The first chapter lays out the basic concepts of project management and scheduling and explains how they can be used to develop a scheduling system and procedures for a construction project. Also, Chapter 1 introduces the primary tool for accomplishing this, the Critical Path Method. Finally, a sample building project is introduced at the end of Chapter 1, and this project is used throughout the book to illustrate the principles of scheduling and the actual steps necessary to build a full project schedule and control its progress.

Chapter 2 identifies key project team members and spells out the essential steps for getting a project schedule started out on the right foot. The chapter discusses preliminary investigation that must take place to ensure that all relevant information is uncovered so that the schedule as developed reflects the full scope of the project.

A primary key to good scheduling and control is a thoroughly thought-out initial plan. Chapter 3 covers the tasks of planning the project, for example, breaking the project down into its component elements and tasks, and deciding on a sequence of work. Chapter 4 follows up with how to schedule the tasks—determining how long each part should take and how to calculate the overall time for the project. Chapter 5 then covers how the project manager can best display and use the information found in the schedule.

Since all projects encounter difficulties and often changes in plans, a primary task of a project manager must be to identify these problems early and take corrective action, Chapter 6 deals with how a project's progress can be monitored and how action can be taken to bring the project back on track.

In addition to time and schedule, project managers must also be concerned with how to manage the resources used for the project. Chapters 7 is, therefore, included to show the basics of how a Critical Path schedule can be used to plan and track resources, as well as how to use the schedule to adjust workload to use resources more efficiently. Chapter 8 covers how a schedule can be used to plan, track, and control the procurement process and its inevitable paperwork.

Chapter 9 covers linear scheduling, which is used for projects that are long and continuous, and that are difficult to schedule using traditional CPM techniques. Chapter 10 covers the techniques used for dealing with construction costs, especially labor costs, which tend to be the most difficult for contractors to monitor and control.

Finally, the appendixes of the book include a drawings and other information about the sample project in Appendix A. Appendix has detailed information about the sample schedule, including Activity IDs, original durations, predecessors, activity codes and earned values. Appendix C includes additional sample schedule output, and Appendix D includes helpful hints about the realities of logic development.

1 PROJECT MANAGEMENT FUNDAMENTALS

1 Project Management Fundamentals

The goal of this book is to help the reader become a more effective construction project manager, or to help a construction company carry out more effective project management and control. A major element in the process of project management is scheduling the work of the project, and then keeping it on track and on time as the project unfolds. This book is devoted specifically to that part of the project management. However, if we are to schedule as effectively as possible, it is important for us to understand the underlying principles of management as they relate to project management generally and scheduling specifically. These general principles form the basis for specific tasks we must execute as we schedule and control a project. The following chapter is, therefore, aimed at helping the reader understand these principles as a starting point for subsequent chapters.

WHAT IS MANAGEMENT IN GENERAL?

The general principles of management are probably one of the most widely known subject areas in the modern world. The concepts involved in managing enterprises of all types, whether in business or government, are of intense interest to individuals working at all levels of organizations all over the world,

The question is: What are these principles and how can they be useful to those of us who manage construction projects? To develop a set of tools that can be useful for us, we should look at a basic general definition of management and work forward from basics to specifics.

To begin with, a basic definition: "management is the process of planning, organizing, directing, and controlling."

The concepts contained in this definition are so well known that a web search for these exact words yields over 4,750, 000 "hits"!

We can further extend this definition by looking at the specific concepts contained within it. The ideas that are most important to us for purposes of schedule and control construction project are these:

- Goals
- Process
- Planning
- Control

At the very beginning, we recognize that **goals** are always involved. In a philosophical sense, without a set of goals, there is no point in even taking actions. In practical terms, a construction company or manager must have profit as an overall goal, and completing the work on time is an essential part of meeting profit goals. Establishing smaller and more focused short-term goals is a very important part of the overall task of project management.

Process can be defined as a set of continuing systematic actions over time. The management process must be carried on continually throughout the life of the job or company. Management must be done in a **systematic** way, which means an orderly, regular, and dependable way, using a set of established procedures or methods.

Management also means that **decisions** must be made in order to achieve the goals of the project or company. These decisions must be made **rationally,** that is, based on facts, not hunches or inaccurate information. One of the primary reasons for setting up a systematic, orderly method of management is to deliver accurate, timely information to the decision makers on the job.

Once a sound project management system is in place, the project manager may use it to carry out the more specific functions of **planning** and **controlling.** *Planning* can be defined as deciding what tasks must be performed to accomplish the goals of the project. This means establishing realistic schedules and budgets, coordinating resources to get the work done, and most importantly, making sure everyone knows what the plan of action is.

Controlling is the final action in the management process. To achieve and maintain control, the project manager must monitor the progress of the job. When short-term goals are not being met, the project manager must take action to get everything back on track.

WHAT IS PROJECT MANAGEMENT?

While these fundamental ideas can form a basis for our management practices, we still have to translate them into more specific terms and actions. The tasks in the following list grow out of these concepts and are the focus of this book.

1. First, we must establish and focus on goals that will be general at first, then increasingly specific and job-oriented as we plan the work.
2. Second, we must establish an effective management process that will operate in a systematic manner.

3. Third, we must use this management process, or system, to make the best possible decisions coordinating the work of our project, and then continue planning and controlling the work throughout the life of the job.

Having defined the three major project management tasks, we can begin to focus on the more specific jobs of the project manager.

Setting Goals

The first task of the construction project manager is establishing goals. Many goals have already been set by the project estimate and contract documents. A primary purpose of the estimate is to arrive at a cost for the project, while the contract establishes the time required for completion. Neither of these goals—cost or time—can be altered in any significant way by the project manager. However, the project manager can set intermediate goals for the construction process, goals that meet the ultimate requirements of cost and time.

Creating a Project Management System

After setting goals for the project, the next task of the project manager is to establish control through an effective management system. There are two approaches to project management. They are: (1) proactive—aggressive management ensuring that the job proceeds as planned by the manager, or (2) reactive—spending money and reacting as events occur and letting circumstances run the job. The latter, reactive scenario tends to occur if the manager fails to set up a properly organized, thorough, and methodical management system. This approach almost certainly guarantees that a job will overrun time and budget allowances, and generally cause much grief to all concerned.

The management system should be designed to address the following elements:

Time: A plan of action must be established to ensure the work is done in the correct order or sequence and within the time allowed.

Cost: The work must be performed efficiently if the contractor's goals are to be met.

Resources: It must be determined in advance when and how much of each resource (such as particular categories of labor, equipment, or materials) is needed to do the work. One must then ensure that the resource is provided when and where needed. Resource management supports the effort to control time and cost. The information used by the project manager to perform this task is developed from the time and cost information data.

Finances: Ultimately, time and resources translate into dollars. Thus, the financial control function means accurately predicting the amount of cash needed to support all the work done on the job.

Managing the Project

The third task of the project manager is to manage the project as it proceeds, using the project control system to best advantage. In the simplest terms the project

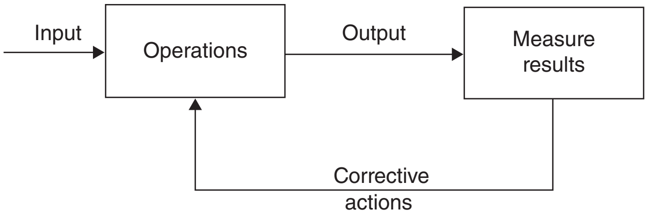


Figure 1.1 Basic feedback loop

manager must know if the project is heading in the right direction to meet its goals? Project control is best illustrated as a *feedback loop,* shown in Figure 1.1.

Managing the project begins with the input of data on labor, materials, and equipment—the resources used to build the project. As the work is performed, the output, or productivity, is measured to see if it is meeting the goals set for the project. If it is not, corrective action must be taken.

Project control can be illustrated by comparing it to a feedback loop used in machine control. For example, a cruise control on a car measures the speed of the car, compares it to the preset speed, and if there is a variation, either adds or reduces throttle to return the speed of the car to the preset limit. If the cruise control fails to function properly, the car either takes a long time to reach its destination or the driver gets a ticket. Using feedback to manage and control a construction project, however, requires a few more steps. The project manager must perform the following tasks.

Plan: Realistic, usable schedules and budgets must be established for all phases of the job. These guidelines will serve as a "blueprint" for building the job. The schedules and budgets should be based on the original estimate and contract requirements. They must reflect the commitment of the people who will have to carry them out.

Communicate: Once developed, the plans must be communicated clearly and effectively to the people who will be executing them. Emphasis must be placed on providing clear, usable visual displays, particularly for scheduling. It is also wise to recognize that the professionalism shown by the project manager in planning and communicating on the job site has a very real effect on employee morale and effectiveness. A sloppy plan, poorly organized and executed, gives employees the impression that they work for a slipshod organization. Pride in their work will be affected accordingly.

Monitor and control: After the plans have been developed and communicated, they must be carried out by project personnel. Realistically, some unexpected events could interfere with the original plan. If this occurs, the project manager must take steps to ensure that the project goals are met. This means taking action to bring the job back in line with the original plan, or revising the plan to fit the new situation.

If the project manager is to effectively deal with delays, the management system must provide him or her with the most current information. This monitoring function involves collecting data on time and cost, and comparing this information to original projections.

Once the project manager is aware of the current job status as compared to the original plan, actions can be taken to meet the original goals. These actions can range from adding more crews to speed up sheetrock installation to completely changing the installation sequence of complex formwork.

Two other points should be made about the feedback loop. First, construction job sites can be very busy places, with many activities going on at one time. Therefore, it is important that the management system be *exception-oriented*. That is to say, the system should be designed to specifically point out those items that are at variance with the plan, and to essentially ignore those that are proceeding on schedule. Without an *exception-oriented system*, the project manager is in danger of being overwhelmed with detail, while key areas may be overlooked.

Second, the information provided must be timely, so that problems are caught and recognized early in the game. Problems on a job tend to worsen at an accelerating rate. It is important to catch them before they have a chance to become major disasters.

The key to monitoring and control by project management is making frequent checks of job status and, if necessary, taking action to ensure that the project's goals are met. Failing in either checking or acting will result in a failure to meet the project goals.

WHY USE PROJECT MANAGEMENT?

In the previous sections, we have recommended an overall strategy for project management and control. There is still, however, some feeling in the construction industry that all these management procedures and paperwork is not really necessary—that one can monitor the job effectively enough by walking around the site to ensure on-time completion and a profit. After all, that has been the way superintendents have managed construction since the time of the pyramids. In reality, the current state of the construction industry is such that more effective techniques for control and management on the job are essential.

The recent history of some construction projects is sadly one of the reasons why old methods of project control are no longer effective. Today's construction projects are complex and very different than in the past. For example, building environmental control systems have replaced simple heating systems. Structures may now consist of high-, early-strength, post-tensioned concrete floor systems with shear walls, where we once had simple flat slabs and columns. Windows have become complete “exterior enclosure systems.” This means a greater variety of jobs to be done, and a greater percentage of subcontractors. Architects and owners have a much wider range of materials and systems to choose from; thus, very few projects are the same.

The increased variety of construction materials and methods has generated more detail than can be managed effectively by one person. In the past, one individual could carry out most of the management tasks since only the basic trades were involved, there was an architect and an owner, and the contract was straightforward. Today's project manager must coordinate specialized subcontractors and work with design specialists who are, in effect, subcontractors of the architect. Many regulatory agencies have also entered the picture. The total management work load has increased to the point that a team with a comprehensive, well-designed system of control is essential. Contractors who attempt to deal with this new situation in the same old ways have encountered enormous problems.

At the same time, owners who purchase construction services have found themselves operating in business environments that are more difficult than before. Many of them now face rapidly changing markets and have had to adopt new computer-based management systems. These companies now insist that contractors who build their projects adopt some of the same kinds of methods and show they can also operate effectively in a fast-paced environment. A contractor not using up-to-date methods is at serious competitive disadvantage. In some cases, owners have even dictated operating methods to contractors. The demands of clients provide yet one more good argument for good project controls.

Good project controls can help keep us out of the legal arena—first by making it more likely that we will perform better, thus reducing the reason for legal action—and second, by providing us with a better set of documents with which disputes may be more easily resolved.

THE BENEFITS

Having reviewed today's situation and having seen the need for an improvement in management, the question arises—why use scheduling? Above all, it should be used because it has proven effective on construction jobs. In particular, the use of critical path method (CPM) scheduling (and the implementation of this method using computers programs) is clearly both workable and cost-effective.

While a computer and good control systems are not a panacea and will not do the manager's job, they are very helpful in providing a way to set up target plans, track events on the site, and examine alternate ways to correct the schedule of work in the event of deviation from the original plan. A good control system is especially helpful to the manager in pinpointing the problem areas and, therefore, helps to manage and reduce the information overload. While such an approach may not guarantee success in terms of cost and time, the intelligent use of control systems definitely increases the odds that success will follow the project manager's efforts.

Better Organization

One of the benefits of using good management systems is that they encourage, or even force, better organization and planning. This is a vital influence since one of the biggest failures of managers in the construction industry is a lack of planning.

Effective monitoring and control must start with a workable plan. It has even been said that 75% of the value of creating a CPM schedule is the initial planning that must accompany the process. This statement may be an exaggeration and probably reflects the fact that people in the field sometimes tend to be less rigorous about updating and monitoring a schedule as the project progresses. Nonetheless, a well organized initial plan starts the job off right.

Using control systems also forces the manager to look at how all of the available resources will be assembled and used. It encourages better purchasing and timing, and reduces wasted motion.

A Good Basis for Coordination

A major problem for many contractors is subcontractor scheduling and coordination. A big part of the solution is communication. If the project manager and superintendent maintain an up-to-date schedule and require the subs to attend regular job schedule meetings, all the parties on the job will be operating from a base of common agreement. Also, the regularly scheduled meetings encourage subcontractor participation in the scheduling process. This participation promotes a sense of commitment to the project.

In general, better coordination benefits all of the parties to a project—the owner, contractor, designer, and subcontractor. Delays are prevented rather than reacted to, costs are contained early, claims prevented or resolved earlier and more amicably. The result is a better profit for all.

Management by Exception

As noted, a major challenge for today's project manager is tracking vast amounts of detail. Computers provide an advantage as they are very good clerical and record-keeping devices. Most of the computer-based management systems used today take advantage of this capability, and promote the exception-based management approach. The systems can be set up to track all work but report only those elements of job progress that deviate significantly from the original plan. This leaves the project manager free to devote his or her construction knowledge and skill to the problem areas, leaving the on-schedule areas to proceed to completion.

Another key point in a computer-based management system is providing early detection of problem areas, thus helping to prevent unpleasant surprises. This early detection is critical to correction since, as we all know, problems on construction sites never get better without attention; they only get worse.

Better Decision Making

A good, up-to-date management system and the associated techniques will in all cases provide the basis for better decisions on the job. Accurate information is an absolute necessity for sound decisions. Such a system should be designed to display the essential data and to weigh the effects of alternate plans of action. Many experts suggest that a better term for *project control systems* is *management information systems.* Regardless of the name applied, a good system properly used should result in better decisions, and thus, better results.

VARIABLES THAT AFFECT THE PROJECT

While the benefits of project management are clear, it must be noted that a good project management system—whether manual or computerized—cannot be implemented without an investment of money and time on the part of corporate management. It is, however, an investment that brings a definite and positive return. It is certainly worthwhile to review some of the common problems associated with developing better project management. Forewarned, one can at least minimize these problems. Later chapters of this book will cover the procedures and possible pitfalls in more detail.

Personnel

In any change, people must be the first consideration. First, the installation or development of new project management techniques must directly involve the people who will be responsible for the results. Probably the worst possible approach is to simply choose a technique or system, and say, *"you will* use this system." The people involved should be recognized as knowledgeable, competent, and concerned about their job performance. Their professionalism will also be helpful in choosing and operating any new and better procedure. They must be brought into the decision making and changeover process.

Job-site personnel may be somewhat intimidated by new methods. For example, a superintendent may fear that a new scheduling or cost system will have the home office constantly looking over his shoulder. Or a project engineer may feel uncomfortable with a new, unfamiliar system, fearing failure due to lack of knowledge. The solution to these kinds of problems lies in: (1) dealing honestly with the persons involved, with an emphasis on team improvement and the removal of threatening elements, and (2) training, which will clearly demonstrate the company's commitment to improvement and willingness to continue investing in its employees.

Cost and Organizational Concerns

The project manager must recognize that implementation of better management techniques will cost real dollars and will require some organizational changes and adjustment. As previously noted, the benefits justify the investment of time and money, however.

Organizational changes clearly involve people. To begin with, any improvement in the system must start with the wholehearted commitment and backing of the company's management. Without it, it is difficult for a single project manager to undertake significant improvement in techniques.

It is also important that company management approach the problem professionally. If, for example, the company president's attitude toward installing and developing a new project control system seems sloppy and half-hearted, company personnel will perceive that the president does not really care about good project control. The development of a better project control system is probably doomed from the start in this circumstance, since the people who have to carry the work out will not devote anything like their best effort to a project that they feel the president will not reward.

Another organizational concern is inflexibility, or rather the fear of it, among construction people. The personalities who do well in the construction field are traditionally self reliant and individually competent. They prefer to work with little supervision and to be judged on results, not methods. Also, most field supervisors have more than a few good ideas themselves, which they are willing to share with upper management. A new technique or method should, therefore, be flexible enough to allow for this kind of individual approach in the field. The emphasis should be on making the burden as light as possible for the field, with the information as accessible and usable as possible.

One final note concerns the importance of communications. When new procedures are being discussed and changes are in the wind, rumors are inevitable and may hurt morale and cripple the effort to change for the better. Such rumors are best countered by full and open disclosure to project personnel whose lives and professions are directly affected.

THE PROJECT CONTROL CYCLE

So far, we have discussed planning, organizing, plus monitoring and controlling, functions that are at the heart of the project manager's job. These concepts can serve as a model for setting up the specifics of operating our project management system, including our most essential tool—the feedback loop (see Figure 1.1). This basic feedback loop does not, however, cover all of the details that must be dealt with on an actual project. The Project Control Cycle, shown in Figure 1.2 and discussed here, illustrates the practical workings of project management.

Step 1: Set Initial Goals

The first step in the project control cycle is setting initial goals. This step typically occurs before the job is even awarded to the contractor. The initial goal is generally no more than a profit goal for the project, in the form of an estimate. Regardless of whether that estimate is conceptual or fixed, or something in between, it serves as a limiting factor, along with the time allowed in the contract documents. Simply put, no future budget for construction should exceed the costs anticipated in the estimate, nor can the time planned in a schedule exceed the number of days permitted under the terms of a contract. The detailed development of estimates is not within the scope of this book. However, using the estimate and contract documents to develop the intermediate goals and job plans is covered in subsequent chapters.

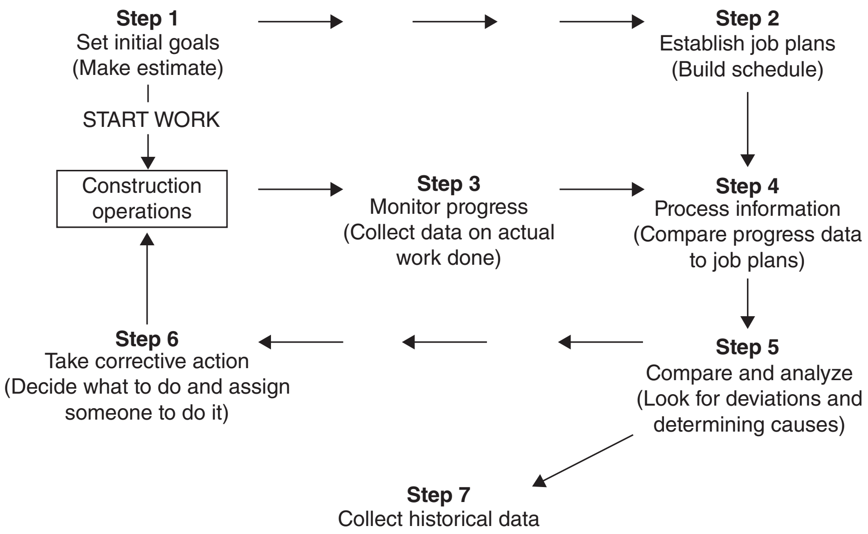


Figure 1.2 Construction Project Control Cycle

Step 2: Establish Job Plans

This second step, establishing job plans, typically occurs after the job has gotten under way, and crews and equipment have moved onto the site. It may not seem advisable to start without a control mechanism completely in place. However, initial conferences will typically have been held during the period right after contract award. Information gleaned during this time may provide a good basis for initial decisions. Such decisions are later developed into detailed job plans.

Establishing job plans for scheduling is done in a three-step process. First, the overall job is broken down into workable parts or *activities.* These activities can be analyzed and planned independently for maximum efficiency. Second, the activities are strung together in a realistic order of work, which is then converted into a *logic diagram*, or network. The third and final step involves *network calculations* to determine at what time and on what dates each activity should occur. The final result is a comprehensive plan which serves the following two functions: it is a guide to action by all those involved with building the job, and it can later be used to effectively cope with the inevitable changes that will occur.

Step 3: Monitor Progress

After the job is under way and detailed plans have been drawn up in the form of a budget and schedule, the job-monitoring system must be established and used by the project managers. The first part of this process is carried out on the construction site at regular intervals, and involves monitoring the actual events that occur on the project, to be compared with the schedule later in the cycle.

Schedule monitoring is done on an activity-by-activity basis, again reflecting the very important concept of dealing with workable-sized units of the job at all stages.

Typically, each activity is labeled with the following information: start time, duration of work, and anticipated final completion.

Step 4: Process Information

This activity occurs throughout the monitoring and control process. A computer or manual procedure is used to manipulate the data collected during the monitoring phase. The data is set up so that it can be compared with the plans developed earlier. This processed information enables the project manager to determine whether or not the project is deviating from the planned order or rate of progress, and if that deviation is significant enough to warrant action.

The key element in this information processing phase is the management of the project control *system,* as distinct from managing the project. The processing and use of the plans and monitoring of data depends in large part on having logical and workable coding systems. Also needed is a regular, efficient, and workable procedure for quickly and accurately developing comparison reports for management.

As projects grow larger, managing the project control system becomes more and more a full time job for a specialist. However, this does not mean that a project management system cannot be operated without specialized job site personnel. The key is having a system that is appropriate for the job at hand.

Step 5: Compare and Analyze

In Step 5, the project managers review the information developed by the system in the last stage in order to determine the actual state of the project. Report formats must be selected to best support typical job decisions, and other methods established for efficient exception reporting. The greater the efficiency, the more the project manager's efforts can be directed to those areas of the project that are most in need of management attention.

Step 6: Take Corrective Action

Taking corrective action represents the final step—acting to rectify an aspect of the job that is not going according to plan. A complete evaluation of Step 6 would include a wide range of topics, since the project manager must deal with technical questions relative to the actual delay or cost overrun.

It is fairly common in construction for deviations from plan to be noted but not followed up on by project personnel. This is equivalent to not monitoring the job at all, and it means that not only is the effort spent in developing a project management system wasted, but the job is also likely to end up behind schedule and over cost. The project management feedback cycle must have all its parts working in order for the job to be properly run.

Step 7: Collect Historical Data

Step 7 occurs on the expanded project control cycle but does not occur on the general feedback cycle. It involves collecting data on what has happened on the job.

Ideally, the results of the job are recorded for two purposes: first, to serve as a basis for planning future jobs, and second, to serve as a thorough record of actual events in case claims arise.

INTRODUCTION TO CPM SCHEDULING

It is essential that construction companies maintain and use good scheduling systems so that projects can be kept on track and can be completed on time. The best available method for doing this is the critical path method.

The Critical Path Method

The emphasis of this book is on how to use critical path method (CPM) techniques of construction scheduling. The following chapters emphasize the techniques available to a project manager, CPM has proven to be the most useful and effective means of developing and displaying the information needed to control the time variables on today's job sites. The basic CPM technique was developed in the late 1950s, primarily for the purpose of controlling large manufacturing and construction projects. It has been further developed and refined since, and has evolved into a tool that is well suited to the construction process.

Most people familiar with the construction process recognize the fact that a project is composed of tasks that are separate, yet interdependent. For example, in building a house, both foundation and stud wall are essential elements. The crew that forms and places the foundation is very different from the one that erects the stud walls. Nevertheless, these tasks are interdependent in that the walls cannot begin until the foundation is complete. The most difficult task in construction is keeping track of tasks and deciding on the correct order and timing, of a large number of these individual, yet interrelated tasks; the CPM of scheduling addresses this issue.

The CPM technique is simpler and more flexible than it might first appear. It takes the building process one step at a time and separates the project into workable subparts or activities. A plan is made for each activity to be performed in the correct sequence. The task of scheduling becomes a systematic, one-piece-at-a-time endeavor.

The basic steps, or phases, of scheduling are:

A. Planning
B. Scheduling
C. Monitoring and controlling

Each of these phases has substeps. The first phase, *planning*, involves:

1. Breaking the project down into workable subtasks, commonly called *activities*
2. Deciding the order in which these activities are to be performed

The result of the planning phase is a logic *diagram,* or *network,* which is an initial graphic representation of a plan of what to do and the order in which to do it. This phase of the process is illustrated in Chapter 3.

The second phase, *scheduling*, adds a time element to the planning phase; the substeps for this phase are:

1. Determining a reasonable duration for each individual activity
2. Calculating the duration of the project as a whole

The product of this second phase is a series of time plans, typically presented as *planning schedules*, or *bar charts*. This type of display is shown in Chapters 4 and 5.

The last phase, *monitoring* and *controlling*, consists of:

1. Measuring the progress of the project
2. Comparing the actual progress against the schedule developed during the scheduling phase
3. Taking corrective action if the actual progress deviates significantly from the schedule

The monitoring and controlling phase is covered in detail in Chapter 6.

Learning CPM Techniques

Many people who have tried to implement the critical path method have found it a difficult task. Most of this difficulty stems from not recognizing the basic simplicity of the process, and from being overwhelmed by the "gurus" of scheduling who have made the process seem far more complex than it really is. Much of this book is devoted to straightforward, workable techniques for CPM scheduling. As these techniques are presented, it is helpful to keep in mind the following general guidelines.

First, take the process one step at a time. The chapters of this book are presented in the same, step-by-step manner, outlining each of the major tasks that must be performed in order to achieve effective construction project management. These tasks and methods are discussed in the actual order in which they would occur on a project.

Second, recognize that the CPM technique is a way of representing what a manager intends to do; it does not require that the manager build in an unfamiliar way. Modern CPM techniques and software systems have more than enough flexibility to represent virtually any possible plan of action desired, so there is no reason to have the "tail wag the dog."

Third, the project manager and other project personnel should recognize that using CPM effectively will require an investment of time and energy on their part. Using CPM requires skill, and no skill can be developed without some effort in learning it. To use an analogy, no one in construction would expect to use a new laser surveying system without some training and practice. CPM is like the new laser surveying system in that it is a better productivity tool but requires an initial investment of time as well as money. CPM is also like the new surveying system in that no contractor is likely to continue with an old tool when his competitors are using a new and more productive one.

Fourth, developing schedules is a creative process. It is analogous to an architect developing a set of plans for a building. No one ever created a set of working drawings without first going through a lot of sketches on tracing paper, then schematic and design development drawings, and finally, working drawings. Those developing a CPM schedule should be prepared to do a lot of erasing and rewriting as decisions are made and altered, and the plan of action develops.

Potential Pitfalls of Using CPM

First and foremost among CPM's potential pitfalls are those related to the human element. It is very common, for example, for a contractor to require the use of CPM for scheduling projects, and to use schedules that are developed and presented by professional schedulers. These professional schedulers have no stake in the outcome of the project, and they may fail to consult the project manager and other project personnel. The result is a schedule that frequently does not reflect reality, and certainly not the project manager's reality. In this situation, those who are responsible for the performance of the project are, in effect, being told how to run the job, and may, quite understandably, be resentful. As a result, the schedule may be largely ignored by field personnel and become useless as a monitoring tool. In this case, the job as a whole suffers, and the management of the company is unable to monitor progress until it is too late to correct the overruns.

The best way to avoid an unrealistic schedule is to provide project management with the tools and training to develop and use CPM effectively, and for top management to require its use in tracking and reporting progress. This is the ideal, in which every field manager regards good scheduling as an essential part of his or her job, and has the skills to use it properly. In the real world, the company's management must be sure that any schedules developed by others reflect the thinking of the field personnel, and that field personnel see the schedulers and the schedule as serving them and not as an imposed duty. If the schedule does not reflect the thinking of the people who have to live with it, it will not have their commitment, and cannot be effective.

Second among potential pitfalls is too much complexity. This problem can usually be identified when the schedule reports tend to gather dust rather than fingerprints. The schedule may be particularly susceptible to this problem when a “sophisticated” computer system is used. The problem brought on by complexity is that the schedule does not serve the project managers, but rather becomes an end in itself, and is ultimately ignored. The computer's capacity for generating large amounts of paper seems to be very difficult to resist, and quite often one or more of the following occur.

- Huge volumes of reports are generated that are so complex and bulky that it is difficult to read them all, much less pick out the important ones.
- The reports are confusing or are in an inappropriate format, and do not concentrate on the problems at hand, that is, they do not promote management by exception.
- The project manager is flooded with detailed reports when, in fact, summary reports are needed, or vice versa.
- There is a severe lack of flexibility in the reports or in the schedule itself.

INTRODUCTION TO THE SAMPLE BUILDING PROJECT

Now that we have discussed—in general terms—the main steps that are performed in the scheduling and controlling process, we can begin to look at them in detail and explore techniques for actually running a project. Subsequent chapters develop these ideas and tools step by step, using a sample office building project, which is included in this chapter. The goal is to provide the reader with a demonstration of what real scheduling would be like. The reader is, therefore, invited to become familiar with the sample project, just as he or she would on a real project, and then follow the process through as the chapters unfold. Ideally, at the end of the book, the reader will then have some real skills in scheduling and a sense of how the process proceeds.

The sample project is a hypothetical corporate vehicle maintenance facility, and is "designed" to contain features that are typical in small-scale commercial buildings.

The contract itself is assumed to be a fixed-price, fixed-scope arrangement between an owner and a general contractor. All code and zoning approvals have been obtained, and construction can begin immediately upon receipt of the notice to proceed. Contract time allowed is 270 calendar days.

The site is located on a city street in an industrial park. The existing slope of the site is minimal, and bringing the site to finish grade does not require large amounts of excavation. The site plan contains a large parking lot to allow for vehicle parking and movement during servicing. The paving is asphalt over graded aggregate base with concrete curb and gutter, and runoff is handled by catch basins and 18-inch corrugated metal pipe storm drains.

The building itself contains two main areas, which are a high bay space for actual vehicle servicing, and an attached office and training area. The structure of both spaces consists of CMU walls with steel joist roof structures, with concrete floors.

The vehicle servicing area is designed for handling pickup trucks and light vans. It has four service bays with roll-up doors at both ends, and a service pit under two of the bays which allows easier access to the underside of vehicles. Also, the servicing area contains vehicle lifts, oil and lube, coolant and air conditioning service equipment, as well electrical and pneumatic power outlets. Heating of this space is done with suspended gas-fired heating units. Compressed air is provided by an air compressor located in a adjacent room

The office and training area is finished space, with steel studs and gypsum wall partitions, suspended ceilings, and varied floor finishes. In addition to finished office and classroom space, this area contains restrooms, a locker room, and an employee break room. All doors are hollow metal with standard commercial hardware, with the exception of the front entrance, which is commercial storefront.

The heating and cooling of the office areas is done using two systems, each consisting of exterior condenser unit, plus air handling units in a dedicated room, and ductwork mounted above the suspended ceiling. In addition to standard power and lighting, the building has modern voice and data systems, as well as a wired fire alarm system.

Finally, the plans provided in the text are not fully detailed in part because of the limitations involved in printing what would typically be Architectural D or E size drawings in a 8-1/2 inch by 11 inch format. Some details must necessarily be left out in order for the drawings to be readable in the smaller format; however, the plans are sufficiently detailed to provide all the information needed for a complete CPM schedule.

In reality, such a building would require many more sheets of plans, though construction schedules are often developed from schematic or design development drawings of a similar level of detail as these sample drawings. A set of specifications would also be included with an actual set of plans. However, for purposes of illustrating scheduling principles, these drawings provide sufficient information. Assumptions have been made for items not shown in the sample drawings that would normally be included in the plans and specifications for a building of this type.

SUMMARY

In this first chapter, we outlined the underlying general management concepts, and the more specific project management ideas that we need to apply to run our construction projects. Also, we covered in some detail the specific steps of the Project Control Cycle, which is the underlying concept behind all the actions and steps a project manager must perform to properly control the schedule of a construction project. If, as the reader continues through the book, learning the actual tools and concepts of scheduling, he or she refers back to the appropriate step in the cycle, the logic behind the tool or action will be clearer. The reader can understand the total process, rather than simply learning to apply a series of steps in isolation. Also, we work with a sample project, which will serves as an illustrative device for teaching the specific tools. This hypothetical project will be introduced in the next chapter along with the beginning steps in the scheduling process. If the reader can become thoroughly familiar with this hypothetical building, he or she will more easily understand each step and can more easily translate the ideas to his or her own projects. In the next chapter, we will start describing the actual process of scheduling, beginning with the preliminary information gathering, which should precede any actual work planning.

REVIEW QUESTIONS

1. What are the four key functions of management? Define each one in your own words.
2. What is a "process" in management? Why is it important?
3. What is the difference between "management" and "project management"?
4. Diagram a feedback loop. Name a place other than in construction where you would use a feedback loop.

5. Why are goals important in project management?
6. What is a "system" in process management? Why is it important?
7. Why is communication so important in management?
8. Has the project management performance record of the construction industry been mainly good or mainly poor over the last 50 years? Cite examples and specifics of actual projects to make your case.
9. What is meant by "coordination" in project management?
10. What is "management by exception"?
11. Diagram the project control cycle, and describe each step.
12. Why is the CPM method so well suited to construction?
13. Who invented CPM? Why?

2 PREPLANNING INVESTIGATION

2 Preplanning Investigation

After the contract has been awarded and the notice to proceed has been issued, the project manager must develop a project management plan. The best place to start this process is with a phase most accurately described as *preschedule investigation* or *setting up for project control*. During this phase, the project manager establishes the basis for good job planning, and for efficient and effective monitoring as the job proceeds. Effective project control is an orderly process, which depends on accurate, reliable information distributed to project personnel. Setting the system up properly ensures effective performance from the beginning.

The project manager sets the tone for the job during this preplanning phase. The quality of the initial set-up of a construction job has a profound effect on the entire project. If project personnel perceive a professional, well-thought-out approach, the job is more likely to proceed in the same manner. It is the project manager who is responsible for the job as a whole, and the entire project team looks to him or her for direction.

One of the major tasks of the project manager is coordinating all of the parties in the management process, and this, too, begins in the early planning stage. All should be encouraged to participate and share information about the project and its processes. Participants should also be made aware of their responsibilities—both during the set-up part of the process, and for regular procedures once the job is under way. Communications with project personnel involve more than simply recording in a manual the various requirements. It must be an active process in which the responsibility is assigned and acknowledged, and the tasks monitored to see that they are accomplished. There is no room for assumptions.

The project manager takes on the leadership role at this early stage and maintains it throughout the job. He or she must communicate the requirements and, once the work is under way, perform follow-up procedures to ensure completion.

These early activities can be viewed as a twofold process and will be treated as such in this chapter. First is the task of information gathering. We will cover possible and desirable sources of data, how the information may be best obtained, and who should undertake this task. The second part of the process is management—including establishing procedures. We will focus primarily on the ongoing decision making, and on the record keeping needed to support project control. While other aspects of construction management, such as safety and personnel administration, are also very important, the emphasis of the discussion in this chapter is in keeping with the scope of this book: schedule control.

The recommended procedures and checklist included here are not comprehensive, as it is not possible to cover every construction situation in one book. It is recommended that the individual project manager use these guidelines as a starting point, then expand and modify these procedures based on experience and the direction of his or her career. For example, the recommended file classifications could be used on a first job. During the course of the job, these categories might be expanded and culled appropriately and the revised version used as the basis for starting the next, and presumably larger, job. Within a few years, a comprehensive file list will likely have been developed. The general guidelines presented here cover most project management situations.

IDENTIFYING KEY PERSONNEL

The first task that the project manager must undertake is to mobilize the company's resources. Part of this task is identifying key personnel. Depending on the size of the job, these individuals could range from a superintendent to a staff consisting of project manager, office engineer, scheduler, cost engineer, and secretary. Home office personnel who will not be assigned permanently to the job, but who will be responsible for specific tasks at particular stages of the project, may also be part of the project team.

PROVIDING DATA TO THE PROJECT TEAM

The next step is to note all sources of information for use by the project team. In these early stages, there are few sources of information that are available to everyone. Typically, these are all of the data is derived from the contract documents and estimate, plus the knowledge accumulated by the estimators during the bidding or procurement process. An excellent starting point is making sure that project personnel have access to the estimate data and contract documents. Ideally, copies of both would be issued to key team members. If this is too costly, copies of the documents should be provided in an easily accessible location and team members should be assigned the responsibility of familiarizing themselves with the contents of these documents.

CONTRACT DOCUMENT REVIEW

A review of the contract documents should provide each project team member with an overall understanding of the job. The project team has a further opportunity to question any unclear aspects during a later meeting with the estimators. It is essential that the members of the project team have a clear understanding of the project. This is accomplished by simply spending as much time as necessary reviewing the plans, specifications, and estimate. During this document review, project team members should be looking for the following:

- **The size and scope of the project, including physical features of the structure:** The point here is that no one would start building from a set of foundation plans without knowing what was to be erected above the foundation.
- **Required construction procedures:** Contract documents do not typically describe specific construction procedures; each team member should visualize the process and then agree on the actual plan in the team meeting.
- **Special conditions and features:** This element should also be considered by individual team members and agreed upon at the project team meeting.
- **Physical limits of the site:** This category includes special construction problems that might be caused by the character of the site, by virtue of remoteness or surrounding structures.
- **Unusual situations:** The reviewer should look over the contract documents, taking note of those items that may cause unusual problems.

In addition to reviewing the plans and specifications, the team members should also review the general and special conditions. Information in this section should include:

> **Contract time allowed:** This figure sets a limit on the duration of the initial schedule. Any intermediate milestone dates that must be met, or portions of the project that must be delivered to the owner prior to the project's completion should be noted, as they clearly affect the project plan.
>
> **Owner's schedule, payments, and other administrative requirements:** Some owners, particularly public owners such as the U. S. Army Corps of Engineers, have specific requirements that must be met during the building process. These stipulations may have little to do with the actual construction. For example, pay invoices may have to be based on a critical path schedule rather than a traditional schedule of values. If there are specific requirements for the submission of schedules, it may be that only certain software packages will provide this capability. If the company does not already own a suitable system, it might first have to be procured. Setting up a new system creates purchasing and training requirements which must be considered.
>
> **Inspection and notification requirements:** Some contracts require a minimum notice for all inspections. Failing to take note of this requirement can result in otherwise avoidable delays during which work stands idle while waiting for the inspector to appear.
>
> **General administrative requirements:** Many owners require contractors to attend to administrative matters relating to public laws, financial institutions, and the like. The contractor must set appropriate procedures for those needs on the job site.
>
> **Claims requirements:** In today's legal climate, many owners are establishing time limits for submitting claims for extra compensation. The team should pay particular attention to the notice requirements. Certainly no contractor wants to be in the position of losing an otherwise valid claim because of having failed to meet these requirements.

ESTIMATE REVIEW/ESTIMATOR MEETING

After reviewing the contract documents, the team members should review the estimate thoroughly. The project manager should then schedule and conduct a meeting with the estimators, allowing the team an opportunity to ask questions. This meeting should be one of the earliest and certainly occur before any meetings with "outsiders," such as subcontractors or owners.

In the early stages of a project, the estimators and their documents are probably the best and most complete source of information in the company about a given project. It is not enough, however, to simply read the estimate and look at the numbers. The information in an estimate is not arranged to help in the actual management of a project. It is arranged to help make the bid process accurate and efficient. Therefore, it may need some interpretation by the originating estimators to make it useful to project management. A meeting between the estimators and the project team ensures that the assumptions built into the estimate are reflected in the project plans.

In reviewing the estimate and questioning the estimators, the project team should look for the following.

Special Conditions and Features

In addition to the special conditions and features picked up by the project management personnel, the estimators may be aware of other situations that are not readily apparent in the estimate documentation. It should be the estimator's responsibility to pass this information on to the field personnel, but it cannot be assumed that this will be the case. The estimator may well be deeply involved in preparing another bid, so members of the field team must ask specific questions.

Assumptions and Limitations

Even in straightforward projects without special features, the estimator will have made assumptions about how the project is to be built. Typically, these assumptions are made in the interest of getting the bid put together on time. While such assumptions are usually valid, it should be noted that the project team is not obliged to assume that they are completely infallible. In fact, the management team should be encouraged to find a better solution to problems of production. Any improvement, after the bid is won, results in pure profit, not money left on the table. At a very minimum, questions should be asked about the following areas:

Weather: Weather can be thought of in terms of two different factors: location and time of year. Location is clearly not alterable, but the time of year may be flexible. For example, while the use of overtime is usually not a good idea, there may be cases where the shrewd application of overtime to structural work in good weather may permit indoor work to take place in winter weather in an enclosed building. A "normal" schedule, on the other hand, would simply mean waiting for the spring before resuming structural work.

Crew composition: The management team clearly needs to know what crew make-ups were assumed in planning both the unit costs and the scheduled time in the estimate. Initial crew assumptions serve as a starting point in the scheduling process, but they should not be taken as absolutely reliable without checking. It is possible that the estimator has allowed too few crews or crews that are too small.

Equipment: It is also necessary to determine what equipment has been assumed, particularly since equipment has such an impact on other parts of the job. Estimates often contain equipment assumptions based on a particular piece of gear being on the job for a period of time, rather than tying the equipment to the cost of specific tasks. This approach is especially common with large pieces of equipment such as tower cranes. Problems can arise if the equipment is either too small to handle all that is expected of it or the time allowed on the site is not adequate to do all the jobs for which it is intended. Equipment choices also have an impact on crew assumptions in that the time allowed for a piece of equipment on site may be predicated on a crew moving at a given rate; if the crew is too small to move at that rate, then clearly, the size of the crew or the time frame for the equipment must be altered. The estimator may also have made certain assumptions about renting, leasing, or buying. Such decisions may be governed by company policy (i.e., if the company owns it, we use it). Again, the project manager may not be obliged to use the estimator's plan, but it does serve as a starting point for the actual decisions as to equipment use.

Note: The project manager should be aware of any deals made by the estimator with the subcontractor regarding the use of general contractor-owned equipment. This issue can be very complex, particularly on high-rise jobs where only a limited amount of equipment can fit onto the site at any one time.

Location: As previously mentioned, the location of a site can have a great influence on construction cost and schedule. The two types of sites that tend to cause the greatest problems are those that are either isolated or tightly restricted. Both tend to increase production costs and schedule time, by virtue of the difficulty and expense associated with getting material and/or labor to the site.

Logistics and procurement: While site location is an important factor in logistics, it is not the only one. In general, any situation that requires materials or equipment that are subject to manufacturing and delivery problems requires special attention. The estimator should be questioned on this point since, hopefully during the process of compiling the bids, he or she will have identified the items to be installed which will take longer than normal to be delivered. Once these items have been identified by the project team, they can be properly factored into the schedule. Tracking these items during the job is also extremely important. Promised delivery dates are seldom moved up; they are much more likely to be put off, and during construction adjustments will have to be made.

Subcontractors: Of all the items that must be discussed with the estimator, subcontract arrangements are among the most important. The scope of work of each subcontractor is never clear immediately after a bid opening. The time pressures of bid day are simply too great to permit precise definition of scope at that time. Also, the documentation of the subcontractor bidding, including all the call-ins, bid alterations, and price cuts, are invariably confusing and require explanation by the estimator. In particular, the project manager will be responsible for executing the buy-out with the subcontractors as the job proceeds. He or she must know the conditions under which bids were tendered by the subs. The project manager must also know the identity of each subcontractor, the scope of work for which the subcontractor bid, and the price quoted. The project manager should also be made aware of any special contractual exclusions made by the subcontractors, and any long-lead-time items within the subcontractor's scope of work.

Quantity takeoffs: Finally, the project team should inquire as to the nature of the material takeoffs done by the estimators and should understand the format thoroughly. This part of the estimate serves as a handy source of information for the field production planning and scheduling that will occur as the job progresses. These original quantity surveys will probably have to be reworked in part, but they provide a good starting point.

INITIAL PROJECT TEAM MEETING

After reviewing the contract documents and the estimate, and after meeting with the estimators, the project manager should meet with the project team. The purpose of this meeting is to set goals for accomplishing the remainder of the prejob planning tasks, and to assign responsibility for getting those tasks done. Such a meeting also provides an opportunity to solicit ideas and comments from the project team members, both for building the job and for starting the ongoing project control procedures. Ideally, there should be a corporate operations manual in existence to guide new personnel. If there is no manual, one should be created and should include the above-mentioned planning procedures.

During the initial meeting, the team should consider the following:

Overall job approach: It is very rare that a company gets a job of a type that no one in the company has seen before. In fact, it makes sense to assign most of the personnel to a job on the basis of their having done that kind of work before. The team should, therefore, be able to decide fairly quickly on the primary methods of construction. In the event that several possibilities exist, a knowledgeable team member should be assigned the task of investigating alternatives and reporting the results to the project manager.

Most critical parts of the job: In most types of construction, the most difficult or likely trouble areas can be identified by the team members based on past experience. All members of the team should be made aware of these areas. By getting this information out onto the table, decisions can be made as to the best course of action, which will result in the most effective construction sequence.

Project control needs: Since the intent of the meetings is to set up the most effective project management process possible, the team will also be considering the control system to be implemented. While many of the systems, such as cost, may be dictated by company-wide requirements, some, such as scheduling, are up to the team. The size and character of scheduling systems to fit specific jobs are discussed later in this book, but it is worth noting here that during these initial meetings, the team and the project manager must start to consider how scheduling is to be implemented. Scheduling choices are based, primarily, on the degree of detail desired, the way in which the information is to be displayed, and how often that information is needed. Also, the responsibility must be assigned for maintaining the scheduling system.

Project administration: Complete coverage of this subject is beyond the scope of this book. However, project administration is an important topic that should be discussed in these early meetings when the project team sets up procedures. These procedures will be determined by such diverse needs as corporate policy, the owner's requirements, and local ordinances.

It is important at this point to assign the responsibility for creating rough drafts of major subcontracts. This is done in anticipation of the buy-out meeting which will fix the scope of work and the price, drafting the major material purchase orders for mailing to suppliers, and last but not least, identification of submittal data requirements by job items.

Remaining prejob planning: Finally, the team should plan the actions and assign the responsibilities for dealing with the prejob planning that must occur with agencies and parties outside the company. These parties and items will be discussed in the next section.

PREPLANNING WITH OTHER PARTIES

As is the case with employees, subcontractors and other "outsiders" respond well to professional management and respond poorly to sloppy procedures. The project team should use the same professional approach in dealing with these other parties to the contract. While there are many similarities, each outside party has its own peculiar set of requirements for the most effective construction process.

Subcontractors

According to some experts, the most challenging aspect of construction today is the effort to achieve effective, on-time use of subcontractors on job sites. While the subcontracting process does relieve the general or prime contractor of much of the risk stemming from labor cost overruns, the problems associated with scheduling and actually getting the work accomplished are, in some ways, worse. The reasons for this situation are many. One problem is that each subcontractor is a separate corporate entity with obligations beyond the job site; few are on the job site full-time. Early, effective preplanning can do much to prevent the problems associated with extensive subcontracting.

The general process for dealing with subcontractors can be described in the following three steps:

1. Setting up the contract, in a process which is known as "buy-out"
2. Involving the subcontractor extensively in the initial planning and scheduling process
3. Involving the subcontractor in the monitoring and any subsequent replanning processes that may occur

The first of these phases is discussed in the following paragraphs; the last two are covered in detail in subsequent chapters.

The buy-out is the process in which the general contractor makes the final subcontractor selections, negotiates scope of work and price, settles contractual terms, and signs the subcontract. Also considered at this time are initial scheduling concerns, meeting and notice requirements, subcontractor representation in dealings with the owner, and the submittal data and equipment delivery issues associated with the subcontractor's work.

The first of these concerns is the definition of scope of work and price. As previously noted, the bidding process leaves no time for adequate definition of scope of work. This task is best accomplished later in meetings between general and subcontractor, at which all of the items of work are very carefully defined. Defining scope of work and price is a task involving great amounts of detail; it is a job that is best done one piece at a time. A set of drawings and specifications is used, on which each item of work for which the subcontractor is responsible is marked in color. From the drawings and specifications, a list is developed, which both parties can keep as a part of the contract. This list should cover both included and excluded items, and it should be as specific as possible. While this method of marking up drawings and specifications is not the only way to conduct a buy-out meeting, the purpose of the process is to remove all possible ambiguity from the subcontract. One of the benefits of creating a well-defined set of contractual obligations for the subcontractor (which will in itself prevent future claims), is the fact that it is probably not possible to talk about *what* will be done without talking about *how* it will be done.

At this time, the project manager and subcontractor should also address scheduling issues. As the activities are defined, a commitment must be obtained from each sub regarding the duration of each activity. The submittal data is required before an activity can begin, and it must be known what material must be ordered and delivered prior to the start. These items should be included in the list of contractual obligations for the subcontractor. The information will be used in the development of the critical path scheduling sequence and times.

The subcontractor must also be made aware of the ongoing scheduling requirements for all parties on the job. The basic idea is that the project manager must conduct regularly scheduled meetings during the course of the work; attendance and participation will be required of all parties. Despite the fact that many contractors and subcontractors consider meetings a waste of time, experience in the industry has shown that well-conducted, regularly scheduled meetings are the most effective means of achieving the real coordination vital to job progress.

Suppliers

In addition to the subcontractors, the major material suppliers must also be contacted and the information they contribute worked into the planning process. During the bidding, suppliers, like subcontractors, are working under the pressures of time, and while their quotes typically contain terms and dates of delivery, it is always best to confirm that data. The project manager cannot assume that the estimate contains information on all items that have the potential to delay the schedule. For example, because of time pressures, the estimator may commonly use average, current prices for a bid submission, rather than specific quotes. There will also be no information gathered about delivery times at this stage.

The specifications and plans must be thoroughly reviewed for the following purposes: to identify all articles of material that must be ordered and delivered, identify and contact suppliers, confirm prices, and obtain delivery commitments. This information must then be incorporated into the budget and schedule.

Even materials that are not difficult to obtain must be reviewed in terms of their effect on the scheduling process. Many owners, especially public agencies, require submittal data on even the most common materials, such as lumber and concrete. These submittal data requirements can affect the project schedule if the submissions and subsequent approvals are not carried out on time.

The purpose of the preplanning process is to identify and assign responsibility for the activities of the job. Effective preplanning prevents the problems associated with making purchases just as installation is due to begin. The administrative task of setting up logs and continually tracking the status of these items must also begin at this point.

Owners and Their Representatives

One of the universal characteristics of construction owners is their desire to monitor how their project is being built and how their money is being spent. Most of the owner's attention is, understandably, directed toward ensuring good quality in the finished product. Owner involvement frequently creates administrative work for the contractor in the form of progress reports and additional record keeping requirements at the site, such as insurance confirmations and lien releases. The vast majority of these requirements are clearly designed to protect the owner's interests.

Many owner requirements are covered in the contract documents and will, therefore, have been discovered during the document review. However, a prejob meeting between owner and contractor will almost always be required. It is at this meeting that the contractor can discover the "unwritten rules" and clarify issues that may not be totally clear in the contract documents. This meeting will also be the start of personal working relationships between the owner's and contractor's representatives. These contacts can sometimes degenerate in an atmosphere of acrimony and distrust. It is, therefore, important to begin and remain on as positive and professional a footing as possible. A contractor must recognize the fact that the owner's concerns and fears are legitimate, since a large amount of money is typically at stake. The contractor should be properly organized for the initial meeting with the project team and display a cooperative attitude toward the information needs of the owner's representatives.

During the initial meeting, the following topics are of primary concern to the project manager. First, make sure that any items not clearly expressed in the contract documents now become known and understood. Very often a few words in a contract document will not even begin to describe a potentially complex situation. For example, it is common for a contractor to perform work while an owner continues to operate a business in the same structure. Under these circumstances, the contractor must know how to avoid damage to existing equipment and work, and the procedure for coordinating the various activities of construction with the closing or opening of various parts of the building. There may even be other contractors who have been hired by the owner and who are working at the facility at the same time. This situation usually requires frequent and effective communication among all concerned parties for the life of the project. First meetings with the owner set the tone for this aspect of the project as well.

There are many other issues that must be coordinated with the owner in the initial stages. For example, most construction projects require temporary utilities. These are often coordinated with the utility companies through the owner. Frequently, there is also the matter of owner-furnished materials or equipment which must be identified, delivery dates verified, and installation details confirmed. It should also be noted that the contractor must inform the owner of the specific, potential impacts on the schedule if delivery of owner-furnished materials or equipment are not made on time.

Public and Government Agencies

Almost all construction projects must meet the requirements of a regulatory government body. It has traditionally been the contractor's responsibility to acquire permits for the construction process, but that requirement has become much more complex in recent years. For example, many permits, such as environmental approvals, must be obtained by the owner prior to the start of design, with an additional permit for actual construction obtained by the contractor at the start of work. Some permits are predicated on the issuance of other permits; this whole issue has the potential to become a complex and difficult business.

There are several actions that the project manager can take in order to cope effectively with permits. First, a comprehensive list of required permits and the parties involved should be made. This list must include: all parties involved with individual permits, identification of those responsible for obtaining and paying for each permit, and the requirements for obtaining each permit. This list should be carefully cross-checked and coordinated with the owner and subcontractors.

Most construction contracts assign the contractor the responsibility of complying with local laws without specifying what those laws are. The project team must, therefore, do some careful research in order to determine exactly which local laws and ordinances require the contractor's compliance. The project team can get this information by going to the local building department and environmental agencies and obtaining literature on local requirements. It may be helpful to establish personal contact with the officials involved after reading the department's literature.

Unions and Labor Suppliers

Finally, the contractor and project manager must be aware of the procedures, problems, and pitfalls of obtaining labor in the location of the job. Basic information about labor availability and rates should have been known at the time of the bid. The project manager will, however, have to follow up in order to find out what the actual procedures are for hiring in a designated area. Aside from the more obvious source—local business agents and other union officials—it is a good idea to contact local contractor associations and government employment development agencies. Establishing Scheduling Procedures

Concurrent with the information-gathering process, the project manager must also begin to think about procedures for the managing the scheduling process. Clearly, some of these procedures will be influenced by the specific requirements of a particular project, for example, the owner may require specific reports or meeting schedules.. Most, however, will be similar in nature from project to project, especially for a series of projects performed for the same owner or in the same local area. Some basic guidelines for these procedures follow.

Assigning Responsibility

The assignment of responsibility is a task that continues throughout the project. It is, however, often neglected in the early stages. As a result, many important tasks do not start off as regular, monitored events, and they are consequently discovered not done at a critical time.

The basic concerns in assigning responsibility are as follows: First, make sure that every ongoing scheduling task is identified. Second, a competent individual must be assigned to monitor each task on a regular basis. For example, in scheduling, who is to track the progress of each activity on a periodic basis, and how is the tracking to be done? Or, who performs the tasks related to computer scheduling? Some scheduling tasks required skills in using a specific computer program for that purpose and it is important to be sure that the persson assigned is fully trained and competent in the use of the program. The project manager must follow up to see that the responsibility assigned is in fact assumed by the assigned individual.

Coordination on the Job Site

Construction projects are complex endeavors, and procedures must be established to ensure effective communication among all parties involved in the project. Communication requires both informing and listening to all participants. For example, schedule obligations should be clearly explained to subcontractors. In fairness and in the interest of maintaining productive harmony on the job, the subcontractors' concerns must also be heard prior to decisions being made about their assignments. The means of communication can take many forms, but consist primarily of: (1) regular meetings with concerned participants, and (2) recording and distributing the results of the meetings in written form.

The first element, regular meetings, must be made productive by the project manager. Otherwise, the other parties will simply come to regard the meetings as a farce, with no attention being paid to the results. To use scheduling as an example, a regular meeting should be held every week. In this meeting, the schedule for the previous week and upcoming two weeks would be discussed. The project manager must ensure that an up-to-date schedule and agenda are provided to all parties required to attend, and that the discussion is productive and to the point.

Following the discussion, the project manager should announce his or her decisions, basing the schedule he proposes on the commitments given publicly by each subcontractor. The new schedule should then be distributed in written form within one day.

By holding schedule meetings this way, the project manager invites participation by the subs, which helps to establish an overall team commitment. He also obtains "public" commitment from the subs, which is more likely to be met than a privately made promise. By distributing the results promptly, the project manager provides written documentation for the job, and reconfirms in everyone's mind the decisions made. Effective use of the project meeting is one of the project manager's most powerful tools.

SUMMARY

As we have noted in this chapter on preconstruction planning, early information gathering and preparation are key to building a complete and comprehensive schedule that covers all aspects and parts of a project. The reader will have no doubt noted that these preparations are what good project managers usually do anyway. This chapter simply put those preparations in the context of scheduling, plus provided some tools to help a project manager make the process even more effective. Once this preparation has been done, a project manager must get into the "nuts and bolts" of scheduling, which may be new ground for some readers. The next chapter, therefore, provides an introduction to the specific steps for scheduling and provides the reader with some background to help him or her understand the details.

REVIEW QUESTIONS

1. The three primary managers on a construction project are: (1) project manager, (2) superintendent, and (3) project engineer. Interview a construction professional to determine what these three jobs consist of.
2. Review a set of construction plans and specifications to determine the following:
   a. Are there any special or unusual construction procedures required by the owner?
   b. What are the physical limits of the site than can be used by the contractor? How are limits shown on the plans?

   c. What is the allowed contract time?
   d. Is a CPM schedule required for the project?
   e. Does the contract require the use of any particular scheduling software?
   f. Must the schedule be cost loaded?
   g. Is the project located in an area that requires special weather precautions?
   h. Is the project located in an area that will make it difficult to procure construction materials?
3. Interview a project manager or superintendent about how he or she schedules subcontractors. In particular, ask about (1) initial planning, and (2) how he or she works with subs to stay on schedule.

3 PLANNING THE PROJECT

3 Planning the Project

As noted in Chapter 1, the first major step in the scheduling process is planning, which consists of:

1. Breaking the job down into "subtasks"
2. Establishing the sequence of work

This chapter describes each of these parts of the process in detail and shows how the two are linked.

BREAKING THE JOB DOWN INTO ACTIVITIES

The first part of the scheduling process, breaking the job down into subtask, is probably the easiest. In fact, anyone who has worked in construction is probably aware that a foreman, superintendent, or project manager performs this task, either intuitively or deliberately, as a normal part of managing. Project managers typically think of a job as a series of distinct steps, separate from one another. This separation process begins in the estimating stage, and it continues through the hiring and scheduling of subcontractors, and in the setting up and directing of construction crews.

Using critical path method (CPM) techniques, the separation of the work into subtask is more formal and complete. There is no absolute way to go about this subdividing process, but the following guidelines can help to ensure that activities are not overlooked or ignored.

Activity Types

Listing the parts of the job can begin very early in the life of a project. For example, during the reviews of plans and specifications, a construction manager will probably already be thinking of the different tasks that have to be performed. The subdivision process is best begun using the basic construction drawings, the plans, and the specifications, and then expanding based on additional information from other sources.

General Activity Types

The easiest and most general way to view the task breakdown is by recognizing that all activities as fall into one or more of the following categories.

1. **Production Activities:** Directly related to construction, involving crews, materials, and installing elements of the building. Examples are, "erect steel studs" and "place foundation concrete."
2. **Procurement activities:** Required to order, purchase, and ensure delivery of the materials and equipment that are to be used in erecting the project. Examples are, "order air handling units," "fabricate storefront frames and glass," and "deliver hollow metal door frames."
3. **Administrative and support activities:** "Secondary" to the construction process but vitally important in the complex and litigious environment that exists today. Examples are, "submit water fountain shop drawings" and "approve steel shop drawings."

For many element installed in a project, there is an administrative process that must take place before actual construction can begin. To illustrate this idea, visualize the steps that must be performed in order to get structural steel for the vehicle maintenance facility project in place. These steps might include:

- Issue structural steel subcontract
- Prepare structural steel shop drawings
- Review structural steel shop drawings
- Fabricate structural steel
- Deliver structural steel
- Erect structural steel

The first two steps are administrative in nature, the next three involve procurement, and the last is the actual construction. The reader will note that of these six steps, only one actually involves crews and construction on the job site. Nevertheless, all are necessary for the installation of structural steel.

Not all elements of a building project involve all types of activities, however. For example, work involving ordinary masonry walls often do not require procurement or administrative activities in the schedule. The project specifications may not call for submittal data approval, and procurement of masonry materials is a simple matter of calling a local building supply dealer.

Specific Activity Types

After breaking the job down into general activities, a manager or scheduler developing a construction schedule further divides these categories into more specific items. This classification process might be based on the following features.

Physical elements of the project: This is the most basic of the groupings and the one that comes to mind most readily. In fact, anyone who works in construction tends naturally to view a project in these terms. In looking at the sample vehicle maintenance facility project, it would be logical to think in terms of footings, foundation walls, or structural steel. Clearly, each of these three parts of the building must be scheduled with different crews, and in all likelihood, the work will be done using different equipment. Also, it is clear that the foundation walls rest on the footings and must, therefore, be installed after the footings are complete. All of these factors make it necessary to separate the activities.

Trade, skill, or crew involved: The various trades used to erect the parts of the building must be directed by different foremen and must, therefore, be kept separate in any schedule. Again, looking at the vehicle maintenance facility project, typical activities might be, "form concrete retaining walls," "erect masonry walls," "erect structural steel," and "erect metal stud walls." Each of these activities involves a different trade or skill. Each activity is managed and directed separately and should, therefore, be kept separate in the schedule.

Contractual divisions: In today's construction projects, most work is subcontracted. Each subcontractor is a separate corporate entity, with its own set of contractual obligations to the general contractor. There are several reasons why each subcontractor should be kept separate on the schedule, if possible. First, each subcontractor is managed and scheduled for work individually. The electrical subcontractor will probably be scheduled to perform the rough-in after the heating, ventilating, and air-conditioning subcontractor. Examples of this type of subdivision on the vehicle maintenance facility project might be:

- Rough-in electrical – service bay
- Rough-in ductwork – office area
- Install storefront – front entrance

The second reason for keeping the subcontractors separate is that payment to each depends on progress. It is generally regarded as good practice to clearly separate one subcontractor's documented progress from that of another. In this way, disputes over responsibility for lack of progress can be more easily identified. In the event that a dispute does occur, separation of the subcontractors helps the general contractor accurately assess who is at fault. The process of claims resolution is also greatly simplified if the schedule keeps all contractors separate—an important consideration.

Organizational responsibility: This idea of subdividing also applies to the organizational subdivisions set up by the general contractor. For example, if a project is large enough to require two field superintendents, the activities for which each is responsible should be separately listed. Or, if a different part of the company is involved (such as a separate formwork design department which was part of the home office), then the task of "design formwork-foundation walls" should be kept and tracked separately from the field work.

Physical or geographic area: Often, if a job is large enough, it might be organized along what could be called geographic lines. This practice is very common in such projects as petroleum process plants, which are spread out horizontally over large tracts of land. In these cases, it is important to be able to track progress across the site. The principle can be applied to a project as small as the vehicle maintenance facility project. For instance, the two roof areas might well be installed at separate times, leading to two separate activities, such as:

- Install roofing–service bays
- Install roofing–office area

In the case of vertically oriented buildings, it is important to be able to track progress up the building by area. A manager needs to see activities organized in this way, since it is very likely that similar crews could end up working at several levels at the same time, for example:

- Install metal studs – main
- Install metal studs – 2nd floor
- Install metal studs – 3rd floor

System for Description

In developing a list of activities, it is recommended that a consistent system be used to describe them. A system that works well in practice describes each activity in terms of:

1. An action being taken
2. The building element involved in this action
3. A location identifier for the element

Such a system results in the following kinds of activity descriptions:

- Place concrete – service bay footings
- Erect masonry wall – office area
- Install ceiling grid – office area

The following examples show the kind of flexibility a classification system may offer.

Separating Actions

- Form footings – service bays
- Place footings – service bays

In this case, the types of work are kept separate, even though the element being worked on and the area are both the same.

Separating the Work Items

- Form footings – service bays
- Form foundation walls – service bays

In this case, foundations are kept separate from columns, even though both are in the same physical area.

Separating Areas

- Form foundations – service bay area
- Form foundations – office area

In this case, the garage area work is clearly kept separate from the dining/kitchen area, even though both are foundation work.

While this system may seem somewhat rigid, it points out some important distinctions in the activity lists. These issues are often ignored, only to find out later (after several hundred activities have been listed) that the listing, "concrete," has left the user of the schedule with no idea where the concrete is or what phase of the concrete work is being done.

The Concept of Level of Detail

So far, we have discussed how to divide work into activities and how to describe them in such a way as to prevent confusion later in the scheduling process. It is relatively easy to describe individual activities. After all, a footing or a wall is a simple element of the building, and anyone experienced in construction can probably visualize the work necessary to build one of these elements. However, when we are faced with the job of developing an entire list of activities for a large project, the task is somewhat more complicated by the fact that we rapidly find our lists becoming so large as to be unmanageable. If this occurs, it becomes difficult to use a schedule effectively, and in a worst case scenario, we may lose control of the schedule altogether because our information is not organized enough to be of any use.

The level of detail concept is one of the tools available that helps avoid this problem. In basic terms, it works as follows. All projects can be visualized in terms of a series of general phases that usually occur on projects of a like type. Within each of these phases, there is usually a similar set of physical elements or parts of the job, and for each element, there is a similar set of tasks that must be performed in order for that part to be built successfully. In a nutshell, we break the project down into its component parts by going from the general to the specific to the detailed.

The General Phase List

Using the vehicle maintenance facility building project as an example, we can illustrate how the level of detail concept is applied. First, any commercial building can be divided into several major phases, listed below.

- Site preparation
- Foundations
- Structure
- Envelope
- Rough-ins
- Finishes
- Final site work

This is, of course, not the only set of phases that could be used for a commercial building. Also, if we are working with a different type of project, the phases would be different. For instance, industrial projects are often broken down along the lines of engineering disciplines, and civil projects might be broken down along the lines of major structural features. Any scheme is acceptable as long as it is appropriate to the type of work and can be understood by the scheduler and by project personnel.

In the specific case of the vehicle maintenance facility project, a phase might be as follows:

- Project management
- Initial site work
- Structure and envelope
- Interiors – office area
- Service bay buildout
- Final sitework
- Project closeout

A key point about this first phase of activity list development and organization is that the scheme used should be based on how the project manager and superintendent of the project see the work as proceeding, and how they want the schedule information displayed.

The Specific Physical Element List

As we continue to break down the project into phases, we can use the foundation phase as an example of the next step in the process. Each phase is made up of actual physical elements of the building, all of which involve actual construction work. Materials must be purchased and installed, crews assigned to do the work, and inspections conducted. The final schedule must include every part of the building, and every one of these elements must be shown in one of the phases developed in the previous step. As an example, we can look at the project estimate and plans, and can see that the foundation of the vehicle maintenance facility project work consists of the following physical elements:

- Building excavation
- Footings – service pit
- Foundation walls – service pit
- Support steel – service pit
- Concrete topping – service pit
- Slab on grade – service pit
- Footings – service bays
- Foundation walls – service bays
- Slab on grade – service bays
- Footings – office area
- Foundation walls – office area
- Underground plumbing – office area
- Underground electrical – office area
- Slab on grade – office area

The Detailed Task List

Again, continuing with the process, we can develop a task list for construction footings, which is as follows:

- Form footings – service pit
- Reinforce footings – service pit
- Place footings – service pit
- Strip footings – service pit

The overall concept is illustrated in Figure 3.1, where each phase is shown to be the "sum" of its elements, and each element is the "sum" of its tasks.

This "downward" detail technique allows us to do a number of things that make our schedule better and more effective. First, it helps us ensure that nothing is left out. Second, it keeps our data organized and prevents us from being overloaded with pieces of paper listing unknown and untraceable activities. Third, it allows us to proceed in a methodical and orderly manner and will probably speed up our work in the long run.

We should note, however, that it is not necessary to develop every schedule to its maximum possible level of detail, down to individual tasks. Many schedules need be developed only to the level of physical elements, for example, and some may only need the major phases outlined. Each project and project manager has different requirements, but the basic technique of going from the general to the specific should be followed.

The following features show sample activity lists of the vehicle maintenance facility project projects. These lists contain both high and low levels of detail as illustrative examples.

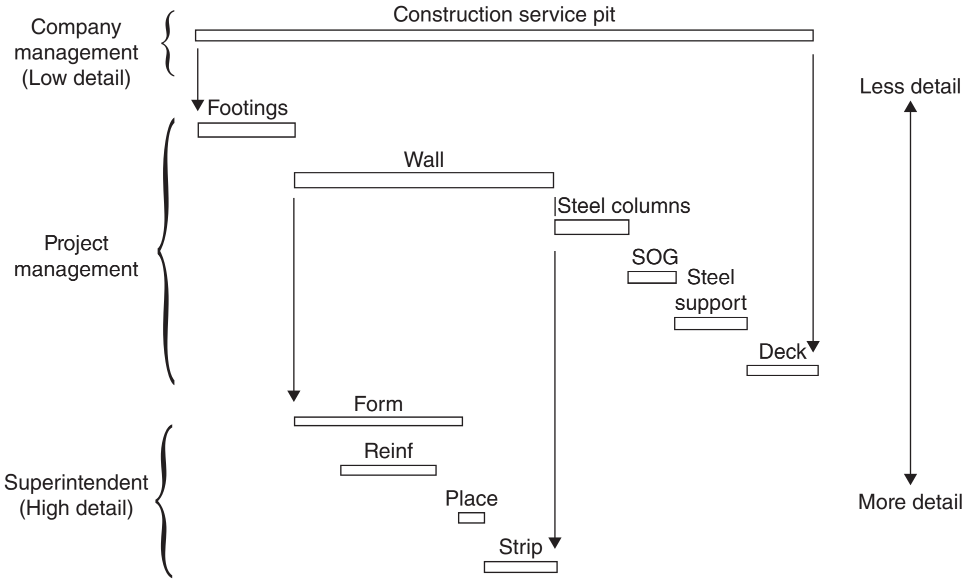


Figure 3.1 Level of detail in scheduling

Vehicle Maintenance Garage Activity List – High Detail

Project Management

- Receive NTP
- Set up erosion control
- Mobilize

Initial Sitework

- Clear and grub
- Rough grade
- Install storm drain system

Foundation

- Service bays
  - Excavate for foundation – service bays
  - Footings – service bays
    - Form
    - Reinforce
    - Place
    - Strip
  - Foundation walls – service bays
    - Form
    - Reinforce
    - Place
    - Strip
  - Slab on grade – service bays
    - Prep
    - Place
- Office area
  - Excavate for foundation – office area
  - Footings – office area
    - Form
    - Reinforce
    - Place
    - Strip
  - Foundation walls – office area
    - Form
    - Reinforce
    - Place
    - Strip
  - Underground utilities – office area
    - U/G electrical
    - U/G plumbing
  - Slab on grade – office area
    - Prep
    - Place
- Service pit
  - Excavate for service pit
  - Footings – service pit
    - Form
    - Reinforce
    - Place
    - Strip

  - Foundation walls – service pit
    - Form
    - Reinforce
    - Place
    - Strip
  - Backfill around pit
  - Install steel columns in pit
  - SOG – service pit
    - Prep
    - Place
  - Install work platform – service pit
  - Install access stairs – service pit
  - Install WF support beams – service pit
  - Corrugated steel decking over service pit
  - Concrete topping over service pit
    - Prep
    - Place
    - Structure and envelope
- Erect roll-up door frames
- Erect HM door frames – service bays
- Erect 12" CMU walls – service bays
- Erect 8" CMU walls – office area
- Erect brick veneer – service bays
- Erect brick veneer – office area
- Erect exterior HM door frames – office area
- Erect structural steel and joists – all areas
- Lay corrugated roof decking – all areas
- Lay rigid roof insulation – all areas
- Install cold process roofing and flashing – all areas
- Install precast coping at parapets – all areas
- Hang roll-up doors – service bays
- Hang exterior doors and hardware – office area
- Install windows – office area
- Install storefront – office area

Interiors – office area

- Rough-ins
  - Hang ductwork and install AHUs
  - Erect interior HM door frames
  - Erect steel studs
  - Install furring and insulation on exterior walls
  - Rough-in panels, conduit and wiring
  - Rough-in plumbing
  - Rough-in HVAC control system
  - Rough-in fire alarm system
  - Rough-in voice/data system
  - Hang and tape GWB
  - Rough paint
- Finishes
  - Hang ceiling grid
  - Install light fixtures in ceiling grid
  - Install ceiling tiles in grid

  - Lay ceramic tile – restrooms
  - Install plumbing fixtures – restrooms
  - Install toilet accessories – restrooms
  - Install wash basin – locker room
  - Install lockers and benches – locker room
  - Install casework – breakroom
  - Install appliances – breakroom
  - Install projectors – training and meeting rooms
  - Hang screens and whiteboards – training and meeting rooms
  - Finish mechanical
  - Finish electrical
  - Install VCT and base
  - Install carpet and base
  - Hang interior doors and hardware

Interior buildout—service bays

  - Paint interior walls
  - Seal concrete floors
  - Install main electrical panels
  - Rough-in electrical
  - Install lighting fixtures
  - Install piping for heating fixtures
  - Install heating fixtures
  - Install air compressors and piping
  - Install vehicle lifts
  - Install lube oil system
  - Install waste oil collection system
  - Install ATF system
  - Install coolant system
  - Install battery charger
  - Install workbenches and other furniture

Final sitework

- Lay concrete pads for electrical and AC equipment
- Set external transformer
- Set external AC units
- Dumpster enclosure
  - Place concrete pad
  - Install bollards
  - Erect masonry walls
  - Install gate
- Parking lot
  - Fine grade
  - Place curb and gutter
  - Spread and compact GAB
  - Lay AC base course
  - Lay AC wearing course
  - Stripe parking lot
  - Install signage
- Erect main entrance sign
- Lay sidewalks at building entrance
- Landscaping

Project closeout

- Test and balance AC system
- Test all building systems
- Final cleanup
- Final inspection
- Punchlist work
- Substantial completion
- Obtain Certificate of Occupancy

Vehicle Maintenance Garage Activity List – Low Detail

Project Management

- Receive NTP
- Set up erosion control
- Mobilize

Initial Sitework

- Clear and grub
- Rough grade
- Install storm drain system

Foundation

- Service bays
  - Excavate for foundation – service bays
  - FRPS Footings – service bays
  - FRPS Foundation walls – service bays
  - Slab on grade – service bays
- Office area
  - Excavate for foundation – office area
  - FRPS Footings – office area
  - FRPS Foundation walls –office area
  - U/G electrical – office area
  - U/G plumbing – office area
  - Slab on grade – office area
- Service pit
  - Excavate for service pit
  - FRPS Footings – service pit
  - FRPS Foundation walls – service pit
  - Backfill around pit
  - Install steel columns in pit
  - SOG – service pit
  - Install work platform and stair – service pit
  - Install WF support beams & decking – service pit
  - Concrete topping over service pit
  - Structure and Envelope
- Erect roll-up door frames
- Erect HM door frames – service bays
- Erect CMU walls – all areas
- Erect brick veneer – all areas
- Erect structural steel and joists – all areas
- Lay corrugated roof decking – all areas
- Lay insulation and roofing – all areas

- Install precast coping at parapets – all areas
- Hang roll-up doors – service bays
- Hang exterior doors and hardware – office area
- Install windows – office area
- Install storefront – office area

Interiors—office area

- Rough-ins
  - Rough-in mechanical
  - Erect HM door frames and studs
  - Install insulation on exterior walls
  - Rough-in electrical
  - Rough-in plumbing
  - Rough-in HVAC control system
  - Rough-in fire alarm system
  - Rough-in voice/data system
  - Hang and tape GWB
  - Rough paint
- Finishes
  - Hang ceiling grid
  - Install light fixtures in ceiling grid
  - Install registers and grilles in ceiling grid
  - Install ceiling tiles in grid
  - Lay ceramic tile—restrooms
  - Finish plumbing and accessories
  - Install lockers and benches
  - Install casework and appliances
  - Install furnishings – training and meeting rooms
  - Finish mechanical
  - Finish electrical
  - Finish paint
  - Lay flooring
  - Hang interior doors and hardware

Interior buildout – service bays

- Paint interior walls
- Seal concrete floors
- Install panels and rough-in electrical
- Install lighting fixtures
- Install heating fixtures and piping
- Install air compressors and piping
- Install vehicle lifts
- Install vehicle oil and lube equipment
- Install battery charger
- Install workbenches and furniture

Final sitework

- Hardscape
- Set external transformer
- Set external AC units
- Erect dumpster enclosure

- Parking lot
  - Fine grade
  - Place curb and gutter
  - Spread and compact GAB
  - Lay AC base course
  - Lay AC wearing course
  - Stripe parking lot
  - Install signage
- Erect main entrance sign
- Landscaping

Project closeout

- Test and balance AC system
- Test all building systems
- Final cleanup
- Final inspection
- Punchlist work
- Substantial Completion
- Obtain Certificate of Occupancy

Tips on Activity List Development

The following guidelines may be helpful in quickly putting together a good activity list.

- "Brainstorming" can sometimes help. A group of project personnel may meet and, together, record the list on a chalkboard.
- It is generally better to come up with a large list and then cull it, rather than the other way around.
- One of the best ways to get a sense of required building activities is to look at the wall sections and read upward.
- Procurement and administrative activity lists can often be gleaned from a careful reading of the specifications, taking note of submittal data requirements.
- The estimate is typically a good source of information about subcontractor work activities and identifies the responsibilities of each.
- Interviewing subcontractors to determine how they see their work as being subdivided is always a good idea.
- One should be prepared to go through a series of lists. The first one never has everything right.

ESTABLISHING THE SEQUENCE OF WORK

After the activity list for the project has been developed, the scheduler or project manager must decide the order in which the activities will be performed and communicate the information to those responsible for carrying out the work. The construction plan is normally represented by a *logic diagram*, or *network*, which is the basis for the CPM system of scheduling. The diagram is both a tool for making scheduling decisions and a means of representing the outcome. The diagram will always evolve through a series of versions as the schedule develops and as the project proceeds.

Diagramming Systems

Two methods for representing job logic are in use today. They are commonly known as the *Precedence Diagramming Method (PDM)* and the *Arrow Diagramming Method (ADM)*. Either system can be used effectively on construction projects. There is, however, some debate over the relative merits of these systems, as well as some misunderstanding about the nature of each. Of the two, the arrow system (ADM) is older, and many people in the industry have used it for during most of their careers. It has, however, been largely replaced by the precedence system (PDM), which has certain advantages. PDM offers greater ease of use and understanding, and the capacity to represent a wide variety of job situations. It is for these reasons that PDM is used for all presentations in this book.

Diagramming Formats

Basically, any diagramming technique or format will work in the PDM system as long as it roughly resembles Figure 3.2, in which the activity being represented is shown as a node (typically a rectangle or circle), and the relationship between two or more activities is shown as an arrow between the activities, or nodes. For drawing rough diagrams, a wide range of formats can be used. One option is a worksheet that has predrawn nodes; only activity titles and arrows need to be added. The opposite extreme is a blank sheet of drafting paper. Refinement of the diagram as the plan develops typically results in better and more clearly drafted successive versions.

Key Questions to Ask When Establishing Logic

In order to develop the construction plan, the scheduler or manager need only take each activity in turn and answer the following questions about that activity and related work activities:

1. What other work must be completed before the activity can begin?
2. What other work cannot begin before the activity is completed?
3. What other work can be performed at the same time as the activity and not interfere with the activity?

To illustrate this concept, visualize the process of placing the foundation for the vehicle maintenance facility project. The following general activities would be included:

- Excavate
- Install footings
- Erect foundation walls

The first activity, "excavate," is not preceded by any other activity. The next activity is "install footings." None of the other activities can take place at the same time as this one, and it must follow excavation, since the footings are below grade. Looking ahead to "erect foundation walls," the scheduler could see that this activity must be preceded by "install footings," since the walls must rest on the footings. The basic relationships between these three activities are illustrated in Figure 3.2.

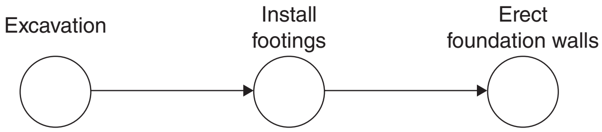


Figure 3.2 Network – three sample activities

Priority of Relationships

For a scheduler developing the logic, it is helpful to think in terms of which activity relationships are most important. In addition to the obvious physical relationships between activities, there are others that should logically be considered. Among them are the order of use of various pieces of equipment, weather-related scheduling problems, and the priority of labor. These factors involve more complex decision-making techniques. The general principle is that the relationships should be treated in order from the least to the most flexible. The following order of treatment has been proven a most effective approach.

1. **Deal with the physical relationships first.** These are by far the least flexible. For example, if a specific foundation wall rests on top of the footing underneath, the relationship between these two activities cannot be altered. Most of the relationships between activities fall into this category, and the scheduler should plan the construction based on this before considering any other type of relationship.
2. Deal with the contractual or external relationships next. If there are weather considerations or contractual obligations that must be reflected in the order of activities, must be factored into the schedule, but cannot override the physical relationships. For example, contract for renovation of a school may call for the work to be done in specific areas in a required sequence.
3. Deal with the managerial and equipment relationships last. Once the previous relationships between activities have been established, the manager can then start to make decisions about the order of equipment and labor assignments among various physical construction tasks and within phases.

Complex Relationships between Activities

As noted earlier in this chapter, the relationships between activities depend on what must be finished prior to starting an activity, and what may begin when an activity is complete. This basic idea is at the heart of the CPM concept. One of the advantages of the PDM system of notation is that it permits the construction manager to vary the relationship between activities in order to more fully represent the actual events on a job site.

To consider these advanced forms of activity relationships, a system of definitions must first be established. The standard relationship shown in all the figures of this chapter so far can be defined as a finish-to-start relationship (FS). The finish-to-start relationship is again illustrated in Figure 3.3, showing the node notation format and a time-scaled bar chart of the relationship between “erect studs” and “hang drywall.”

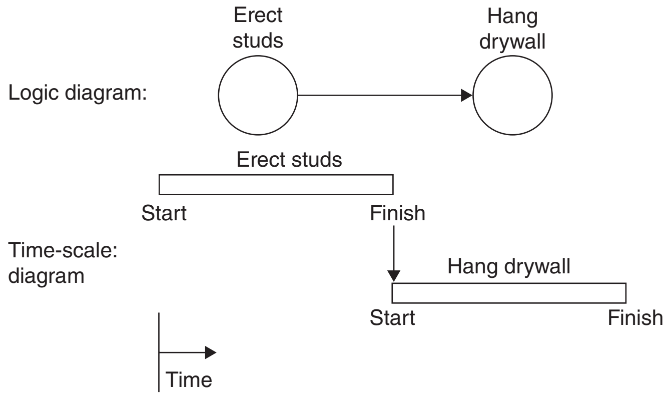


Figure 3.3 Finish-to-start relationship

This standard relationship says that if erecting studs precedes the hanging of drywall, then the studs must be finished before drywall can start.

While this basic relationship applies to many, if not most, activities on a project, there are also many cases where more complex relationships exist, or where the construction manager scheduling the job may want to represent the relationship more realistically. For example, consider the case in which studs and drywall are being installed in a very large building, and there is no point in waiting until all studs are erected before hanging any drywall. It is quite often possible under these circumstances to erect some portion of the studs, say 20% or so, then begin the drywall while stud work proceeds.

This kind of relationship between activities can be shown as *lag relationships*, or *overlapping activities*. Instead of showing the relationship between studs and drywall as *finish to start (FS)*, it can be shown as a *start to start (SS lag)*. A notation is typically made on the relationship arrow. (See Figure 3.4, which also shows the time relationships between the studs and drywall.) Another type of lag is the finish-to-finish relationship, sometimes called an *FF lag*, or *FF relationship*. The FF lag shows a relationship in the finishing times of activities. (See Figure 3.5.)

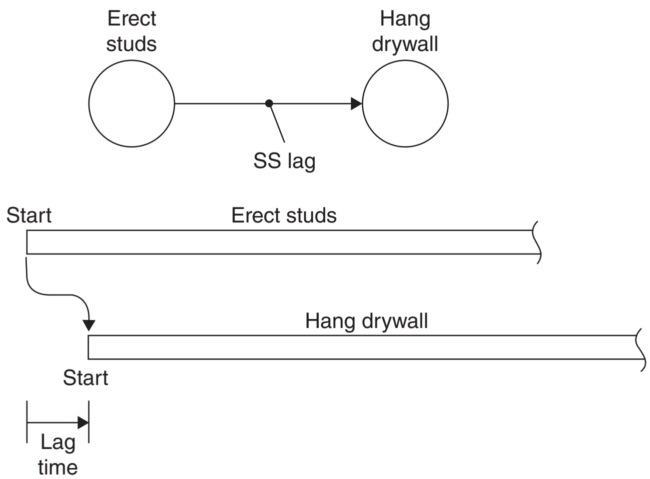


Figure 3.4 Start-to-start relationship

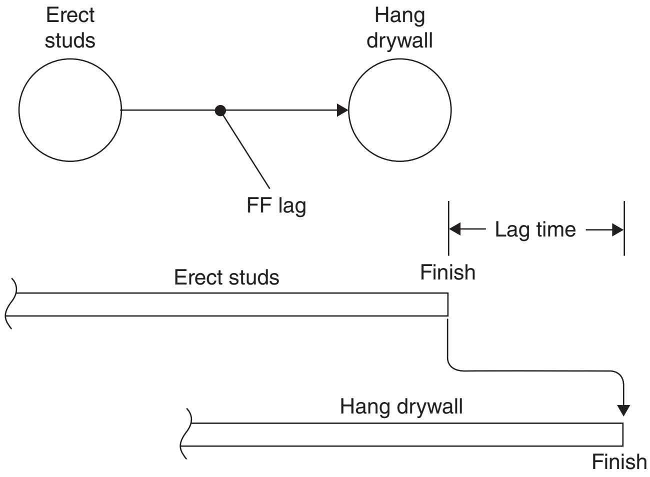


Figure 3.5 Finish-to-finish relationship

Lag relationships can be used anywhere in a network to represent all kinds of situations. It is even possible to have different kinds of lag relationships between the same two activities, if the construction situation requires this arrangement. The most common use of SS and FF relationships is in situations where crews are planned to proceed along a job at different rates of production. In this case, the lags are used to establish the correct starting times. The objective is to prevent too great of an initial spacing, which would be inefficient, or overrunning of crews, which would cause interference. Specifically, SS lags are typically used where the succeeding activity is slower than the leading activity, and FF lags are used where the succeeding activity is faster than the leading activity. This point is illustrated in Figure 3.6 where different times are applied to erecting studs and hanging drywall. SS and FF lags are used to show the necessary spacing. In Case 1, it can be seen from the relative times of the two crews that the succeeding drywall crew proceeds more slowly than the stud crew. Consequently, there is no danger of the drywall crew catching up with the stud crew and causing interference. In Case 2, the succeeding drywall crew is faster than the stud crew, and there is a danger of interference if the drywall crew starts too soon. The effect of the FF lag is to delay the start of the drywall crew until such time as interference will not occur.

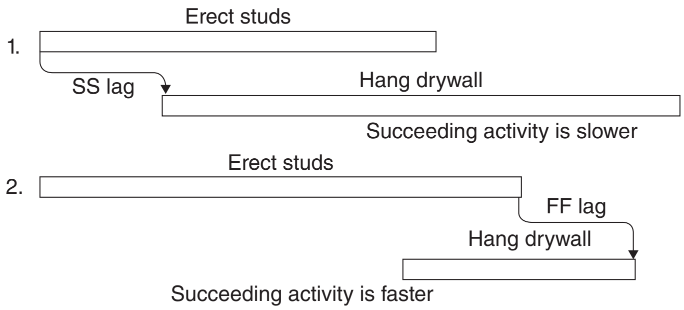


Figure 3.6 Use of SS & FF lags

Step-by-Step Development of the Overall Logic Diagram

Developing a logic diagram is a relatively simple task at one level, yet can be a difficult task at another level. For example, most construction people can easily create logic diagrams for relatively small portions of a building, even if they have very little experience in formal scheduling. A superintendent can readily visualize the sequence for a set of footings, and perhaps even an entire foundation without much difficulty. A set of activities which would cover the work of the foundation on the vehicle maintenance facility project might consist of less than two dozen individual activities and is, therefore, quite easy to diagram.

Consider, however, the task of developing all the activities of the vehicle maintenance facility project or an even larger structure. In this case, hundreds of activities may be required, and it is impossible for a scheduler or superintendent to visualize the entire sequence. Also, a scheduler must deal with keeping the information in some kind of order and thus creating a total schedule which can be used effectively.

The solution to handling this kind of situation lies in working in a manner opposite to that of developing the list of activities. In that case, the answer was to work from the general to the specific, that is, going from large scale to small scale. By contrast, to develop the total logic diagram for a project, we should proceed from small, manageable subunits to larger and larger overall units of work. We can see how this process works by using the building foundation as an example.

Looking at the activity lists shown earlier in this chapter, we can see that the foundation consists for three different main sections or elements:

Service bay foundation

Office area foundation

Service pit foundation

First, we treat each section or element in turn. Beginning with the service bay foundation, we can see that it is composed of five basic steps, as follows:

Excavate

FRPS footings

FRPS walls

Backfill

Slab on grade

After reviewing the building drawings, we can see that the most logical sequence of work is to perform each of these steps in turn. If we express this sequence using our system of displaying construction logic, we get the diagram shown in Figure 3.7.

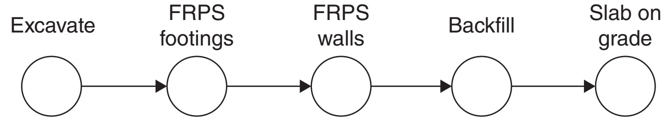


Figure 3.7 Logic diagram—service bay foundation

Next we can work on the office area foundation, which consists of the following steps:

Excavate

FRPS footings

FRPS walls

Backfill

Slab on grade

U/G plumbing

U/G electrical

The logic diagram for this work is shown in Figure 3.8. The logic is similar to the sequence for the service bay, but is slightly more complex. The basic concrete subelements use the same sequence, however, the underground plumbing and electrical work can be done at the same time as the wall and backfill.

After creating a logic diagram for the office area, we can develop a logic diagram for the service pit foundation, which consists of the following:

Excavate

FRPS footings

FRPS foundation walls

Backfill

Steel columns

SOG in pit

Upper platform

Access stairs

Support beams

Steel decking

Concrete topping

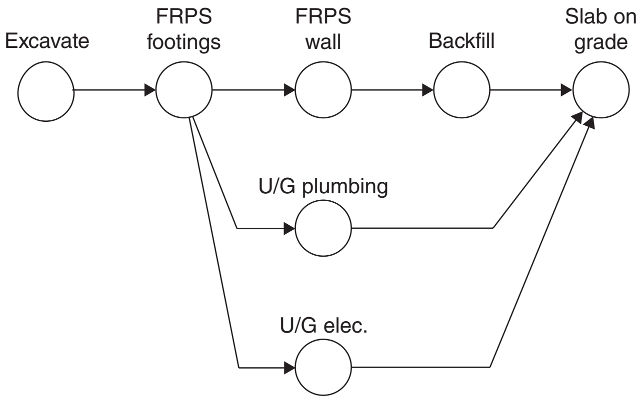


Figure 3.8 Logic diagram—office area foundation

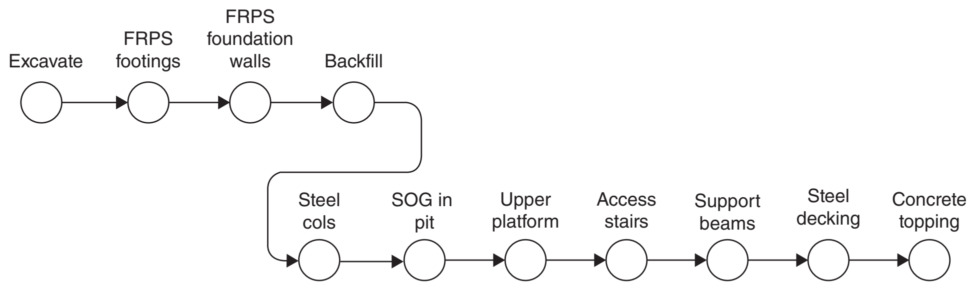


Figure 3.9 Logic diagram—service pit foundation steel

The logic diagram for this work is shown in Figure 3.9. Note that although there are more individual elements in this part of the foundation, the work has to be done one step at a time, and there is no opportunity to do any work concurrently.

Once we have completed these networks for the various subelements, we can then connect them as shown in Figure 3.10. The resulting logic diagram gives us a sequence for all the work needed to build the overall foundation.

The key point is that the best approach to logic development is to create small networks of each element and then progressively combine them into larger and larger diagrams for the project as a whole.

There are definite advantages to using this approach to logic development. One is that visualizing work sequences in a series of small segments is much efficient than trying to visualize a schedule for an entire building. Even small buildings may contain a surprising number of activities, and even experienced schedulers and project managers can quickly get lost in the details. If this happens, the odds

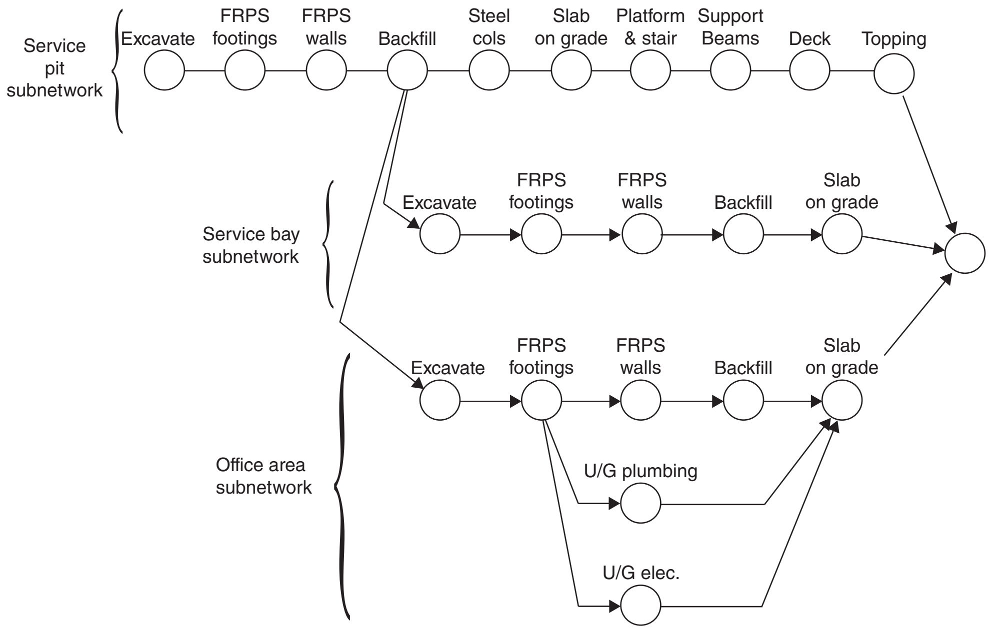


Figure 3.10 Overall logic diagram—foundation

are very high that something will be left out of the schedule, or that some part of the sequence of work will not reflect reality.

Another is that schedule information has to be organized in such way that presentations for the project team are clear and easily understood. This means that the schedule activities have to be coded according a work breakdown structure or activity codes so that barcharts and other displays can be easily created. This aspect of scheduling is covered in Chapter 5, but the important point at this stage is that developing activity lists and logic diagrams in an orderly and organized way makes the later task of coding much easier.

Finally attempts to shortcut the scheduling process are almost always counterproductive. All too often, those individuals who are higher up in a construction company will want to see a complete schedule yesterday, but the project will be better served is the scheduler and project manager work in a methodical and orderly way to create a well thought out and organized schedule.

Tips for Establishing Work Sequences

The following tips may be helpful in working up an effective and realistic network.

1. Make absolutely sure that the plan reflects what the field construction managers want to do with the job. If the people who have to carry out the plan are not committed to it, the chances for success are minimal. Although it is probably best to have the actual managers develop the plan, it is not essential, so long as they are regularly consulted and their ideas are incorporated into the plan.
2. When developing the construction plan, or network, remember that the diagram only represents what is to be done on the job, and that the schedule is not an end in itself. Under no circumstances should scheduling or computer considerations ever dictate construction operations.
3. Remember that developing a construction plan is a creative process and that the first pass is never the final solution. Be prepared to erase, redraw, and use lots of paper if necessary.
4. There are no hard and fast rules about how the network should be drawn. Some schedulers claim that an arrow should never be drawn in a backward direction, for example, for a statement that is not really valid. What counts is that the diagram is understandable, and while neat drawings are more legible than sloppy ones, anything that works is acceptable practice.
5. Some networks can be developed without sketching a logic diagram on paper by creating logic directly as one puts activities into a computer scheduling program. Realistically, however, this practice is probably limited to small networks, or to networks for projects that are quite similar to previous work.

SUMMARY

In this chapter, you have seen how a scheduler or project manager can develop an overall plan for a project by breaking the job down into its component parts and tasks and then working out a sequence best suited to completing the job quickly and efficiently. In the next chapter, we will look at how the results of this process of analysis can be used to determine how long each activity will take to perform and then determine the likely overall time for the project as a whole.

PRACTICE LOGIC PROBLEMS

Draw a logic diagram for each of the problems given below. Use circles or rectangles to indicate activities and arrows to indicate precedence.

1.

Activity	**Precedes**
A	B
B	C
C	D, E, F
D	G
E	G
F	G

2.

Activity	**Precedes**
A	B, C, D
B	E
C	E
D	E
E	F

3.

Activity	**Precedes**
A	B, C
B, C	D

4.

Activity	**Precedes**
A	C, D
B	C, D

5.

Activity	**Precedes**
A	B, C
B	D

6.

Activity	**Precedes**
Z	G, F
G	B, C
F	C, D, E
B	A
C	A
D	A
E	A

7.

Activity	Precedes
M	G, H, K
G	A
H	B
J	C, D
A	E
B	E, L, F
C	F
D	F, K
E	L
F	L
K	L

8.

Activity	Precedes
H	D, E, F
D	C
E	C
F	B, A
C	G
B	G
A	G

9. Draw a logic diagram for a project that is broken down into five consecutive segments, A through E, which must be done in sequence, beginning with Segment A then B, and on through Segment E. Each segment has four steps, 1 through 4. Each segment uses a different crew, and when a crew finishes its work on a segment, it must move on to the next segment. Number your activities within each segment thusly, A1, A2, and so on, then B1, B2, and so on, where the letter corresponds to the segment being worked on and the number corresponds to the crew.

10. Draw a logic diagram for the following foundation construction sequence.

Activity	Condition
Excavate	First activity
Footings	Excavation must be complete
Foundation Walls	Footings must be complete
Underslab Plumbing	Can go on during Foundation Walls
Slab on Grade	Foundation Walls and Underslab Plumbing must be complete

11. Draw a logic diagram for finishing a commercial restroom, using the activities listed in the following table.

Activity	Condition
Ceramic tile	First activity
Ceiling grid	Cannot go on while any other work is underway. Ceramic tile must be in.
Light fixtures	Ceiling grid must be in.
HVAC registers & grilles	Ceiling grid must be in.
Ceiling tiles	Light fixtures and HVAC equipment must be in.
Wall coverings	Ceramic tile must be in.
Countertops	Must come before wall coverings and plumbing fixtures.
Toilet partitions	Plumbing fixtures must be in.
Bath accessories	Countertops and wall covering must be in.
Complete bathroom	Milestone activity—all work must be complete.

12. Draw a logic diagram for the following commercial office interior buildout. Note particularly the concurrencies that can happen.

Activity	Conditions
Rough in mechanical	First activity
Rough in electrical	Studs and door frames must be in.
Rough in plumbing	Ditto
Rough in sprinklers	Ditto
Studs and door frames	Rough in mechanical must be finished.
Rough paint	GWB must be hung, taped, and dried.
Install ceiling grid	Rough paint must be complete.
Hang and tape GWB	Studs must be up and all rough-ins complete.
Install lighting fixtures	Ceiling grid must be hung.
Install grilles and registers	Ditto
Install sprinkler heads	Must be done after ceiling tiles are done.
Lay in ceiling tiles	All other work in ceiling must be done.
Lay ceramic tiles	Ceiling work, including tiles, must be done.
Finish plumbing	Toilet fixture must rest on ceramic tile.
Hang toilet partitions	Toilet fixtures must be installed.
Finish paint	Can be done after ceiling work is done but must be complete before doors are hung.
Install toilet accessories	Cabinetry and plumbing fixtures must be finished.
Cabinetry	Ceramic tile must be finished.

Install signage	Can be done anytime after ceiling work is complete but before carpet is laid.
Install doors and hardware	Should be done just before carpet and after all other work is done.
Install carpet	All other work must be done.
Complete interior buildout	All work must be done.

13. Lay out a logic sequence for ordering hollow metal door frames, preparing shop drawings, reviewing and approving shop drawings, fabricating and assembling door frames, delivering door frames, and installing door frames.

4 SCHEDULING THE PROJECT

4 Scheduling the Project

The previous chapter provides guidelines for initial job planning, including the processes of breaking the project down into workable subparts, or activities, and then determining the sequence of work that will be used to accomplish those activities. Once these two tasks are complete, the project manager has created some "tools" to help finish the job. This organized approach must be carried further, however, since no time information has yet been developed. This chapter addresses time issues, specifically:

1. Estimating the times of individual activities
2. Calculating the length of the job as a whole

We will describe techniques for accomplishing these two tasks and for relating work times to calendar times.

ESTIMATING DURATIONS

A number of specific methods can be used to arrive at reasonably accurate estimates of the time required to perform a given activity or piece of work on a job. Before getting into the details of these methods, however, some general rules should be noted. These rules can help to arrive at realistic times and avoid serious errors, and they should be observed by anyone developing a construction schedule.

Assume Each Activity Will Be Done Normally

First, the time estimates should initially assume a normal or ideal set of working conditions. The reason for using this assumption can be seen in Figure 4.1, which relates efficiency, or unit cost, to activity time. For most activities, there is a most efficient rate of production, which results in the lowest possible unit cost. Because all jobs vary somewhat, this rate of production is not a precise number. Instead, it represents a range of production rates, which, experience has shown, result in the lowest unit cost. Figure 4.1 also shows that if the production rate is significantly higher or lower, the unit cost changes accordingly.

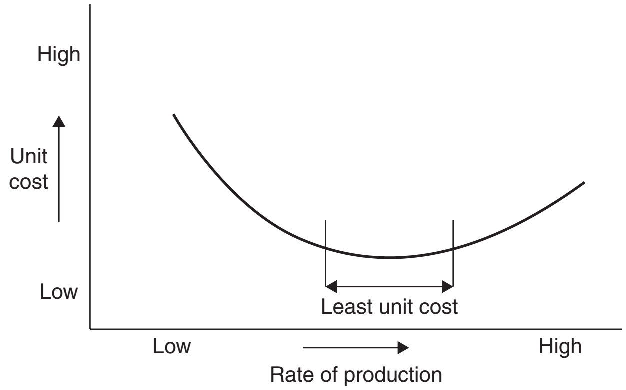


Figure 4.1 Unit cost versus rate of production

In the best of all possible worlds, a construction manager would expect all the activities on a job to be carried out at a rate close to the ideal. In the real world, the ideal rate is actually possible for most activities. However, those that do not proceed on schedule may be critical to the job, or hold up the progress of other activities in some way. The best procedure, therefore, is to plan all activities initially in terms of ideal time and then change only those that must be changed for valid reasons, such as overall time.

Evaluate Each Activity Independently

In addition to initially assuming an ideal time for each activity, the scheduler should compute individual activity times as if no other work existed. Clearly, this is not realistic in the long run, but practice has shown that much of the work of a project does in fact proceed without being affected very much by other work. It is also true that if a person drawing up a schedule tries at the start to consider every constraint affecting an activity, the number of variables may rapidly become overwhelming. Further, many of the factors that will affect a given activity cannot be known until the overall project time has been determined. Thus, it is better to plan each activity independently and then account for constraints as necessary and as they become known in the scheduling process.

Use Consistent Time Units

Throughout this book, the time units used to describe activity and project durations are *work days.* These work days are converted to calendar days through the calendar definition process, covered later in this chapter. Days are by far the most common unit of time measure in the construction industry, although hours or weeks can be used appropriately in many circumstances.

Regardless of the time unit used, it is important to be consistent in order to prevent confusion and misunderstanding over the scheduled times for various parts of the job. Calculated times for work activities are usually in work days; the quoted times for delivery of materials are often in calendar days. The person preparing the schedule must be certain that one is converted, if necessary, to be consistent with the other.

Keep Records as the Schedule Is Developed

It is often helpful during the schedule development process to be able to refer to previous assumptions, calculations, and "trial balloons." For example, in trying to decide how much to speed up various activities, it is helpful if one knows what is the assumed normal rate. With this information, it is possible to gauge the effect of one activity's acceleration on the various other activities, so as to decide on the most efficient mix. Toward this end, most good schedulers maintain analysis and record sheets on each activity as the schedule develops. Figure 4.2 is a sample sheet used for this purpose.

Typically, any given activity may have several sheets worked out over the course of the job. Dating and keeping each subsequent sheet in order is important. The sheets

Activity Analysis Sheet

Activity No.: ________ CSI Number: ____________________

Estimate Page Number: ____________________

Date: ____________________

Revision Number: ____________________

Activity Definition:

Action: ____________________

Object: ____________________

Location: ____________________

General Description: ____________________

Codes Involved:

Cost Code: ____________________

Schedule Code: ____________________

Limiting Factors: ____________________

Total Units of Work: ____________________

Productivity: LH/Unit: __________ EH/Unit: __________

Calculations:

$$\frac{\text{LH}}{\text{Units}} \times \underline{\quad\quad}\text{Total Units} = \underline{\quad\quad}\text{Total LH}$$

$$\frac{\text{Total LH}}{\text{LH/Crew Day}} = \underline{\quad\quad}\text{Total days}$$

Equipment Used: Type: __________ Qty: __________

____

Crew Description: ____________________

____

____

Comments and Assumptions: ____________________

____

____

Figure 4.2 Activity analysis sheet

might be kept in a loose-leaf notebook, catalogued by a classification system, such as the CSI MasterFormat or by phase within the project. An organized approach makes referring back to previous data much easier.

ACTUAL CALCULATION OF ACTIVITY DURATIONS

Several methods can be used for determining an accurate activity duration, depending on the situation. The emphasis in this book is on *labor-hour productivity*, or *daily production rate-based* methods. These methods have proven to be the most flexible and have the additional advantage that they are based on readily available data from a variety of sources. Possible sources include a company's own historical data, or published information such as *Means Building Construction Cost Data (BCCD)*.

Our vehicle maintenance facility project is used to illustrate the productivity-based techniques and methods. The calculation examples are from the network for the foundation of the vehicle maintenance facility project (developed in the previous chapter).

Labor-Hour Productivity Method

Traditionally, cost and productivity data within the construction industry have been collected and recorded using the *basic dollars per unit of work in place* (e.g., $/SF, $/CY) method. However, there has been a growing trend toward the use of labor-hours per unit of work placed (e.g., LH/SF, LH/CY) as a basis for cost estimating and work planning. There are several reasons for this change, including the fact that payroll systems must collect data on a labor-hour basis anyway, and inflation has made the traditional use of dollars per unit less reliable and subject to frequent change. The *labor-hours per unit measure* approach has proven in practice to be easier to use and more accurate—in both estimating and work planning.

Basic Calculations

The use of labor-hour productivity data in estimating activity duration is based on the following formulas:

1. Total labor-hours required for an activity = labor-hours/unit × units of work for the activity; which can be stated mathematically as:

$$\text{Total Labor-Hours} = \text{Labor-Hours/Unit} \times \text{No. of Units}$$

2. Total days required to finish an activity =

   Total labor-hours/labor-hours worked per day, which can be stated mathematically as:

$$\text{Total Days} = \frac{\text{Total Labor-Hours}}{\text{Labor-Hours/day}}$$

For the standard eight-hour workday, the above formula can be restated as:

$$\text{Total Days} = \frac{\text{Total Labor-Hours}}{\text{Crew Size} \times 8\ \text{hrs/day}}$$

To show how these formulas work, we will use the service pit wall activity of the sample foundation network. The total number of square feet of contact area (SFCA) in the wall footings is 2,814, a figure that would typically be obtained from the company's estimate.

From R.S. Means *Building Construction Cost Data, 2012* Edition we can determine that the labor-hour productivity for concrete pit walls of the type shown in the vehicle maintenance facility is .171 labor-hours per SFCA installed. We can also determine from experience that a crew of 6 carpenters would be applied to wall formwork of this type. Applying these numbers to the basic formulas, we obtain the following results.

> Total Labor-Hours = 2,814 SFCA × .0171 Labor-Hours/SFCA = 481 Total Labor-Hours
>
> Total days = 481 ÷ 48 (6 Carpenters × 8 hrs) = 10.012 Days

This calculated time of 10.02 days can then be used in work planning, and in the later calculation of overall project time.

Daily Production Rate Method

In addition to keeping production information in a labor-hour/unit format, many companies have traditionally kept the information in the form of a daily rate of production for a given crew. Publications such as *Means Building Construction Cost Data* also provide this kind of information. The daily crew productivity method is somewhat simpler than using the labor-hour productivity method, but it is probably not as flexible, particularly when it comes to varying the crew size by a few workers either way in order to adjust times. The following example is based on the same sample activity used to illustrate the labor-hour productivity method.

Basic Calculations

The use of daily output or production rate data in estimating activity times is based on this simple formula:

> Total Days Required for an Activity = Units of Work for the Activity/Daily Output or, stated mathematically:

$$\text{Total Days} = \frac{\text{Total Units}}{\text{Daily Output}}$$

To illustrate this method, we will again use the first activity of the foundation. The total number of square feet of contact area is 2,814. Using *Means Building Construction Cost Data, 2012 Edition*, we can determine that the daily output for the type of footing called for is 280 SFCA per day for a crew of six, which consists of five carpenters and one laborer. With these numbers applied to the basic formula, the following results are obtained:

Total Days = 2814 SFCA/280 SFCA per Day = 10.05 Days

This duration is the same as was calculated using the labor-hour productivity method, which is to be expected. By examining the relationship between the two methods, one can see why the results are the same. Our crew consists of six individuals, which means that 4 × 8 labor-hours = 48 labor-hours/day are invested in accomplishing the work. Dividing 48 labor-hours by 280 SFCA installed per day means that the labor-hours/SFCA is .171, which coincides with the value used in the labor-hour productivity method.

Adjustment of Calculated Times

While the two calculation methods just presented are the best basis for finding accurate times, we must recognize that productivity numbers usually reflect average or ideal conditions and, thus, may not apply to our specific project. We should, therefore, adjust our calculated times, if necessary, to reflect the complexity and peculiarities of our own situation. There are many factors involved in these adjustments; some examples follow.

Rounding up All Times

First of all, it should be a standard rule to never use optimistic times in a schedule. In practice, always round up at least to the next higher number of days. For example, if we calculated a time of 4.2 days for a set of footings, we should put a duration of five days into the schedule. The reality of doing work in the field is that we must always set up the work, get up to speed with our technique, do the actual work, and then take down the equipment. Providing the small cushion of rounding up will help accommodate these necessities.

Ensuring Productivity Data Is Used Correctly and Appropriately

To illustrate this point, consider the case of forming foundation walls for the service pit of the vehicle maintenance facility project. Ideally, best industry practice calls for using plywood forms more than once because the cost of formwork goes down considerably when we can use it more than once. There are several reasons for this. One is that the plywood and other materials are used more than once, which reduces the unit cost for that factor. Also, crews become more efficient as they repeat similar work.

However, we know from an examination of the drawings for the vehicle maintenance facility project that the only tall concrete walls the ones in the service pit, thereby preventing using the plywood more than once. But if we were to use values that were based on multiple uses of the formwork, or on repetitive work on the same project, we would introduce a significant error in our calculations.

Also, if we were planning a schedule with a high level of detail, the installation might be broken down into forming, reinforcing, placing, and stripping, rather than simply forming. Unfortunately, cost or productivity data from many industry is relative board in nature, and the overall forming productivity might be reported as a single figure and we would need to break the data down into finer detail.

When using any data from a reference source, it pays to determine exactly what that data includes by consulting any explanatory sections to ensure that the data does in fact fit our specific situation.

In any case, whenever we select time or productivity data for application to our schedule, it is better to err on the side of being conservative rather than over-optimistic. This is just another way of saying that there is a definite practical and psychological value to building small amounts of "cushion time" into schedules.

More Than One Type of Work in the Activity

Not all productivity reference materials contain data in exactly the same format as the work breakdown in the scheduler's activity list. As an example, the installation of bathroom accessories in the vehicle maintenance facility project is included as a single activity for each floor, in part because listing every single towel bar and soap dispenser is not a practical level of detail, and because it is logical to assign all the items in a bathroom to one or two carpenters anyway.

Typically, when we look up productivity information, we do not see items such as Install Toilet Accessories. Instead, we see items that are listed individually. So to determine the overall activity time, we simply lump the total calculated labor-hours together and calculate the work based on how long it would take a single carpenter to install all the items. The total man-hours and duration can be then be built up by creating a table similar to Table 4.1. All the restroom accessories in the building are listed, along with the man-hours required to install each type of accessory. The total man-hours for all the accessories can then be summed and used to calculate an overall duration for installation.

Also, this can be caused by the way we define activities. For example, many of the concrete activities in the Vehicle Maintenance Facility are given as FRPS Footings, or something similar. This means that dissimilar work is lumped together, and a scheduler needs to apply some judgment to the activity that he or she calculated. In the case of concrete work, the scheduler should visual the activity as a sequence of work, rather than as a lump sum. An entire concrete element always consists of

Table 4.1 Calculation of Activity Duration – Restroom Accessories (Labor-Hours)

Item	Quantity	LH/each	Total LH
42″ Grab bars	2	0.400	0.80
36″ Grab bars	2	0.400	0.80
Toilet Tissue Dispenser	6	0.333	2.00
Sanitary Napkin Disposal	3	1.231	3.69
Paper Towel Dispenser	4	0.500	2.00
Soap Dish	4	0.400	1.60
Mirror	4	0.400	1.60
Total Labor-Hours – Both Restrooms			12.49
Total Activity Duration		1 carpenter 2 carpenters	2 days 1 day

forming, reinforcing, placement, and stripping. These activities are always more or less sequential and the duration is the sum of consecutive events, not a sum of totally concurrent work.

Not All Scheduled Work Time Is Production Time

Looking at the activity in the vehicle maintenance facility project for gypsum wallboard installation, we can determine from our R.S. Means source again that hanging, taping, and drying are included in their labor-hour productivity number of .017 LH/SF. The time required to install the wallboard is therefore:

170 Labor-Hours / 3 Crews x 2 People x 8 hrs/day = 3.5 Days

The allowance does not, however, take into account time required to dry the mud used in the taping process. This drying time will not show up in any references on labor-hour productivity, as it does not involve actual work, but it must be added by the scheduler when the overall activity time is established. In this case, it would be reasonable to add three days of drying time, resulting in a total activity time of 6.5 days. This value should be rounded up to 7 days, which would be used as the scheduled time

Labor-Hour Productivity Does Not Govern Activity Time

Some types of work are not purely a function of the number of labor-hours required per unit of work. This fact must be taken into account when scheduling extra crews or workers. This point can be illustrated in the previous example of installing bathroom accessories. Increasing the number of carpenters decreases the activity time proportionally. In this case, one carpenter is essentially independent of the others and work proceeds according to the basic productivity rate. Not all types of work fit this situation. An example is the placement of structural steel. A raising crew typically consists of a fixed number of workers according to the complexity and height of the work, and the work always involves the use of a crane. Experience tells us that the rate of production is dependent on the machine rather than the number of workers. Adding one or two persons to the crew is unlikely to speed up the rate at which the crane can lift and place steel members. Changes in scheduled time would have to be planned on the basis of adding whole crews of three persons each, rather than individual workers, as was the case with bathroom accessories.

Taking Learning Curves into Account

Frequently, work is scheduled as a series of similar activities. For example, a concrete structural frame on a large building would probably be scheduled as a series of placements of repetitive structural elements, for example, columns, shear walls, elevated slabs, and the like. If this were the case, crews assigned to forming the slab would probably produce the last segment more efficiently than they would the first. This rising productivity or production rate, that is, the learning curve, should be reflected in the times provided by establishing slower times for the earlier activities and shorter times for the later activities which are performed more quickly.

Determining Subcontractor Activity Times

Frequently, a scheduler or project manager is faced with the task of having to put together a schedule with little or no information on some of the activities. A prime example is when a general contractor is building a schedule that contains a lot of mechanical or electrical work, yet there is little or no expertise within the general contractor's firm in these fields. Under these conditions, the general contractor should take the following actions.

First, consult the subcontractors in question as soon and as often as possible. The subcontractor should be encouraged to supply activity time determinations based on the same methodology used by the general contractor to determine time for other activities. Obtaining such information from subcontractors helps the scheduler set a more accurate activity time, providing information on the manning levels needed by the subcontractors to complete the work.

Second, the general contractor must look at the role of each subcontractor in the overall picture. As the calculations for the project are developed, the mechanical and electrical work durations will have to be assigned even if the subcontractor has not calculated them. These times must be based on average times for other activities and the sound assumption that the mechanical and electrical subs must fit the overall sequence like everyone else. In this situation, it is a common and effective practice to determine an overall timing for each phase based on experience and judgment, then go to the subs and say, “This is the sequence and these are the time limits we all must meet. Can you do it, and what will it take?” The emphasis must be on consultation and cooperation with all parties if the schedule is to work effectively in a real job environment.

Applying Experience to the Final Result

When all is said and done, and activities times have been calculated “rationally,” a final step remains. All activities times should be checked by experienced field personnel, (superintendents and foremen), preferably those who will actually manage the work in the field, to see if the times are in fact reasonable for the work and conditions expected. Historical data can be misapplied, calculation mistakes can be made, and a good field supervisor can often catch these mistakes in work and judgment. This step also serves to further involve and gain the acceptance of the superintendent and others in the CPM schedule development process.

CALCULATING OVERALL JOB DURATION

After the times have been calculated for the individual activities, the scheduler or project manager is then in a position to determine how long the entire project should take to accomplish. This is done by applying the times or durations for the activities to the logic diagram, which determines the order in which the activities are performed. We will use the sample foundation network to illustrate this procedure. Included are activities from the beginning of *Excavate Footings* to *Complete Foundation*, as shown in Figure 4.3.

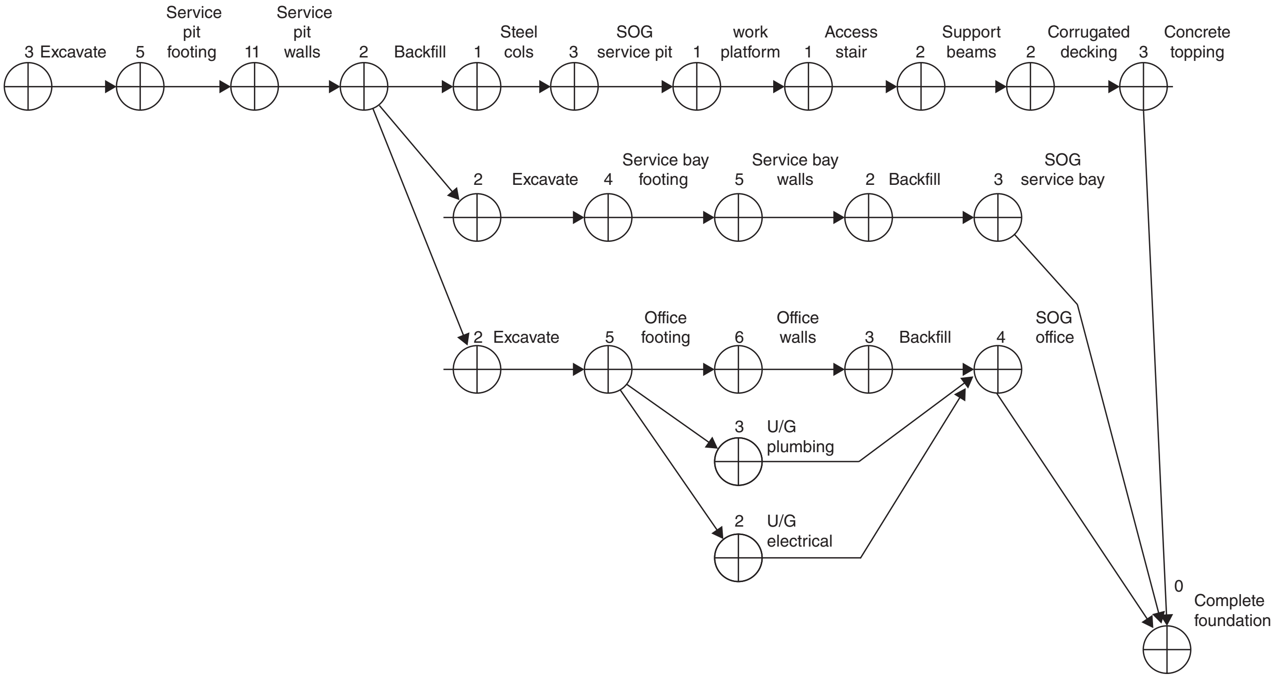


Figure 4.3 Overall logic network – foundation

It should also be noted that the scheduling procedures are fairly straightforward and can be performed manually. The calculations can, however, be tedious, and it is easy to make detail errors. It is, therefore, recommended that anyone involved in scheduling construction projects understand the calculation procedures and perform them using a good CPM computer scheduling program.

Goals of the Project Calculation Procedure

The last of the basic steps in the planning and scheduling process is determining several facts about the upcoming work, based on the assumptions and plans built into the logic diagram and activity times. These goals are:

1. To determine the desired or possible starting times for each of the activities that have been identified and established as necessary for getting the whole job done.
2. To determine the finishing times for these activities.
3. To determine how much flexibility is possible in these start and finish times, given the constraints that have been identified as affecting the project.
4. To determine the activities that are crucial to the success of on-time performance, that is, the critical path.

Once the preceding information is known, the project management team can effectively control the work of all the parties to get the entire job done.

Definitions

To determine the preceding information, it is necessary to understand the following terms that are commonly used in the calculation process.

Succeeding activity/preceding activity: Activity A precedes Activity B. Activity B is the succeeding activity. In logic terms, a preceding activity must be completed before a succeeding activity can begin.

Duration (DUR): The calculated or estimated time for an individual activity (determined in the previous section of this chapter).

Early start (ES): The earliest possible time an activity can start, assuming all previous activities have been completed. The early start of an activity is also the early finish of the preceding activity.

Early finish (EF): The earliest possible time an activity can be completed, assuming again that all previous work has been completed. In practice, the EF is equal to the activity time added to the early start time.

Late finish (LF): The latest time an activity can finish, and still not delay the completion of the project as a whole. The late finish of an activity is equal to the late start of the succeeding activity.

Late start (LS): The latest time an activity can begin, and still not delay the final completion. In practice, LS is equal to the activity time subtracted from the late finish.

Total float (TF): The difference between the early and late times on an activity; it is the allowable delay in starting the activity.

Critical path (CP): The set of activities, or path in which the early times are equal to their late times, that is, total float equals 0. In other words, the critical path represents the group of activities that must start on time in order to keep the project as a whole on time.

Milestone activity: An activity with zero duration, which marks the end of a particular phase of work.

The Actual Calculation Procedure

The actual process used to determine early times, late times, and floats consists of three individual steps, which must proceed in order. None of the steps can be bypassed in order to obtain the information on the next one, as each depends upon its predecessor. Working through these steps can be tedious, but each is essential. Specifically, they are:

1. **Forward pass:** The procedure whereby the early times for a project are calculated. It is called *the forward pass* because it proceeds "forward" along the logic diagram from left to right.
2. **Backward pass:** The procedure in which the late times of a project are determined. It is called the *backward pass* because it proceeds "backward" along the logic diagram from right to left.
3. **Calculation of floats and critical path:** The procedure in which the difference between the allowable starting times is calculated and the activities which have no slack are identified.

Table 4.2 Activity Durations and Float for Foundation Network

Activity Name	Original Duration	Total Float
Foundation	41d	0d
Service Pit		7d
Excavate for Service Pit	3d	0d
FRPS Service Pit Footings	5d	0d
FRPS Service Pit Walls	11d	0d
Backfill around Service Pit	2d	0d
Install Steel Columns in Service Pit	1d	7d
Prep and Place OSG in Service Pit	3d	7d
Install Work Platform in Service Pit	1d	7d
Install Access Stair in Service Pit	1d	7d
Install WF Support Beams in Service Pit	2d	7d
Lay Corrugated Steel Decking over Service Pit	2d	7d
Prep and Place concrete Topping over Service Pit	3d	7d
Service Bays		0d
Excavate for Footings – Office Area	2d	4d
FRPS Footings – Service Bays	4d	4d
FRPS foundation walls – Service Bays	5d	4d
Backfill around Foundation Walls – Service Bays	2d	4d
Prep and Place SOG – Service Bays 3 & 4	3d	4d
Office Area		
Excavate for Footings – Office Area	2d	0d
FRPS Footings – Office Area	5d	0d
FRPS Foundation Walls – Office Area	6d	0d
Backfill Foundation Walls – Office Area	3d	0d
Install U/G Plumbing – Office area	3d	6d
Install U/G Electrical Conduit – Office Area	2d	7d
Prep and Place SOG – Office Area	4d	0d
Complete Foundation	0d	0d

Demonstration of the Actual Procedure

The entire project calculation procedure is demonstrated step-by-step in the following figures. Table 4.2 shows the duration for each activity in the foundation, Figure 4.3 shows the logic diagram for constructing the foundation, and Figure 4.4 shows the notation system for a single node.

Forward Pass

The forward pass is illustrated in Figure 4.5. It begins on the left side of the sample logic diagram, Good scheduling practice calls for each network to have a single starting activity, which is in this case is *Excavate for Service Pit*.

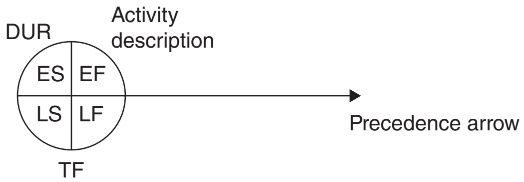


Figure 4.4 Notation system

To start the process, the first activity, *Excavate for Service Pit* is assigned an early start time of Day 0. The early finish of this activity can then be calculated as ES + DUR = EF, 0 + 3 = 3. These numbers are then written in the appropriate quadrants of the node, according to the notation system shown in Figure 4.4.

Since the starting time (ES) for any activity is the earliest time that activity can begin assuming all previous work has been completed, it can be deduced that the early start time for the next activity, *FRPS Service Pit Footings*, is *Day* 3.

Using the same logic as that applied to *Excavate for Service Pit*, it can be seen that *FRPS Service Pit Footing* can finish on Day 8 (3 + 5 = 8). Continuing along the top chain of activities in Figure 4.7, we can see that *FRPS Service Pit Walls* has an ES of Day 8 and finishes on Day 19, and *Backfill around Service Pit* has values of ES = Day 19 and EF = Day 21.

In the next step, we must deal with a different situation, however. Unlike the previous four activities, which proceed one right after another, Backfill around Service Pit is succeeded by three separate activities.

This situation is shown in the logic diagram. *Install Steel Columns in Service Pit, Excavate for Footings – Service Bays*, and *Excavate for Footings – Office Area* are all shown as following *Backfill around Service Pit*.

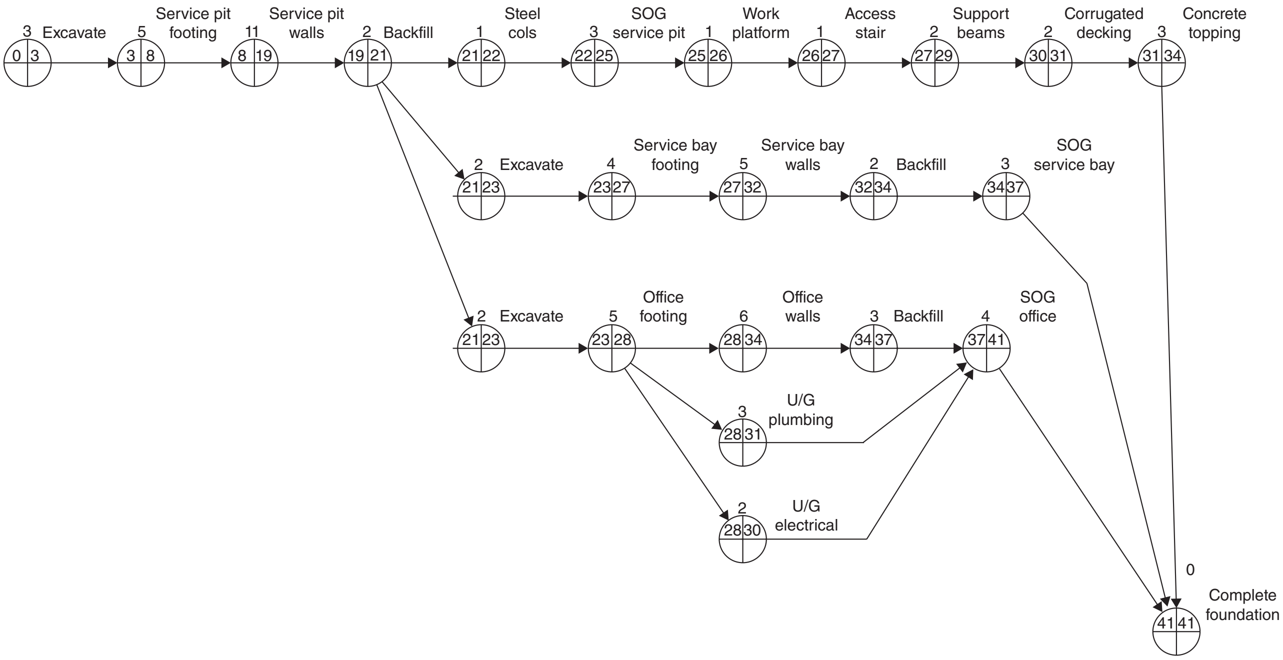


Figure 4.5 Foundation network – forward pass calculations

Our rule that the EF of a preceding activity equals the ES of a succeeding activity still holds true. All three activities in the diagram that follow *Backfill around Service Pit* have an ES start of Day 21, which is equals the EF of *Backfill around Service Pit*. This result is true no matter how many activities follow a single activity.

Also, in looking at the logic in Figure 4.5 we can see that work on the three segment of the foundation can now proceed independently of each other. Work can go on at the same time as work in the service bays and the office area at the same time. This can be seen in the logic diagram as three separate chains of activities going from left to right.

The top chain, work in the service pit consists of seven more activities, all of which continue one right after the other, ending in *Prep and Place Concrete Topping over Service Pit*, which has an ES of Day 31 and an EF of Day 34.

A similar situation exists in the service bays, where work consists of five more activities, ending with *Prep and Place Slab on Grade – Service Bays 3 & 4*, with an ES = Day 34, and an EF = 37.

The last chain of activities, the work in the office area is somewhat more complicated, however. It begins with *Excavate for Footings – Office Area*, which begins on Day 21, as noted earlier. With an ES = Day 21 plus a Duration of 2 days, the EF = Day 23. Looking ahead, we can see that *FRPS Footings – Office Area* has an ES = Day 23 and an EF = Day 28.

Once we reach this point, we are again faced with a situation where three activities all follow immediately after one activity. If we follow the same rules as before, we can see that *FRPS Foundation Walls – Office Area* starts on Day 28 and ends of Day 34, then *Backfill Foundation Walls – Office Area* starts on Day 34 and ends on Day 37.

Unlike the situation in the service pit and the service bays, the office area calls for plumbing and electrical to be installed underneath a slab on grade. These two activities, *Install UG Plumbing – Office Area* and *Install UG Electrical – Office Area* can go on at the same time as *FRPS Foundation Walls – Office area*, since this underground work occurs within the confines of the building at this point, while the walls are installed around the perimeter.

Our rules concerning ES and EF times still hold true, so that the plumbing work starts on Day 28 and ends on Day 31, while the electrical work starts on Day 28 and ends on Day 30.

Our next step as we proceed across the diagram is to calculate times for *FRPS Slab on Grade – Office Area*. Our rule about ES times says that the activity can start only after all previous work has been completed; however, in this case, *FRPS Slab on Grade – Office Area* is preceded by three separate activities. The questions then is: Which preceding activity governs the ES date of the slab on grade.

The answer is: We use the preceding activity that has the latest EF. In this specific case, it is *Backfill Foundation Walls – Office Area*, which has an EF of Day 37, which now becomes the ES of *FRPS Slab on Grade – Office Area*. If we had used the EF of either of the underground activities, which finish on Day 30 and 31, the *Backfill Foundation Walls – Office Area* would not have finished yet, and we would violate the rule that all previous must be finished.

Using Day 37 as our ES of *FRPS Slab on Grade – Office Area*, we can then calculate the EF as Day 41.

Now that we have calculated the early times for the activities for all three chains in the foundation work, we can calculate the last activity, which is a milestone activity called *Complete Foundation*.

To determine which of its three preceding activities governs its starting time, we fall back on the same rule that we used for *FRPS Slab on Grade – Office Area*. Looking at the three preceding activities, we can see that the work done in the office area has the latest finish, Day 38, so we can use that value as the ES of *Complete Foundation*.

Since this completion activity is a milestone and has a duration of zero, we can calculate the EF as Day 38 plus 0 = Day 38, which is our overall duration for the foundation work in total.

Backward Pass

The backward pass is illustrated in Figure 4.6. It begins on the right side of the logic diagram, in this case with the last activity of *Complete Foundation*. Following the definition of late finish, this last activity can be assigned a late finish of Day 41.

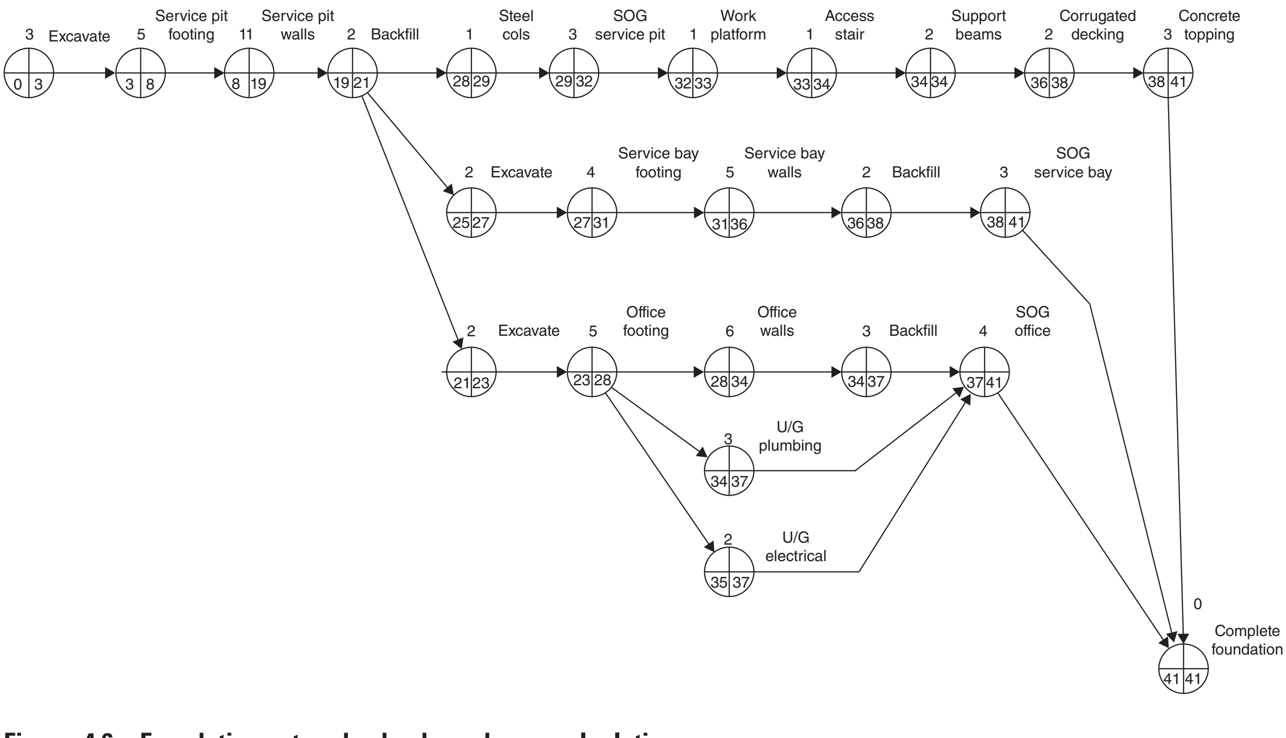


Figure 4.6 Foundation network – backward pass calculations

Logically, this judgment is based on the fact that if it finishes any later than day 41, the project as a whole finishes late. A simple rule of thumb is that in the single ending node for a network, the late finish must be equal to the early finish.

To determine the late start for *Complete Foundation,* we refer again to the definitions. In this case, the late start (LS) of the last activity is equal to the late finish (LF) minus the activity duration (41 – 0 = 41).

Looking back across the diagram, the activities that precede *Complete Foundation are Prep and Place Concrete Topping over Service Pit*, *Prep and Place SOG – Service Bays 3 & 4, and Prep and Place Slab on Grade – Office Area*. To continue the backward pass across the diagram, we must answer the question: How late these activities can finish and still not delay the start of the *Complete Foundation activity*. The answer is that they must finish by the time of the latest start of the *Complete Foundation activity*, Day 41. So, the rule for establishing late finish of any activity is that it equals the LS start of the following activity. In this case, all three activities that precede Complete Foundation must finish no later than the LS of Complete Foundation, Day 41.

To continue the backward pass, we continue toward the left side of the diagram, using the following formula: LS = LF – Duration.

When we do this for the chain of activities that make up the service pit work, we end up at *Install Steel Columns – Service Pit* which has a LF = Day 28 and a LS = Day 29.

At this point, note that there is a difference between the early times and the late times on each node. For example, *Install Work Platform in Service Pit* has an ES/EF of 25/26 and a LS/LF of 32/33. This difference constitutes total float, which will explain in detail in a later section.

When we do the backward pass in the chain of activities that make up the work on the office area, we run into another dilemma, however. Once we have finished calculating the LS/LF times for *FRPS Foundation Walls – Office Area*, *Install UG Plumbing*, and *Install UG Electrical*, we are faced with the question: How do we calculate the LF of *FRPS Footing – Office Area*?

The answer in dealing with multiple succeeding activities is to take the lowest late start among the succeeding activities as the late finish for the preceding activity. In this case, it is the late start of Day 28, which is the LF for *FRPS Foundation Walls – Office Area*, the lowest LF of the three succeeding activities.

To illustrate the logic of this choice, consider what would happen if we used the LF of Day 35 for *Install UG Electrical – Office Area.* If we did this, and *FRPS Footings – Office Area* was allowed to complete as late as Day 32, the work on the foundation walls could not begin until Day 35, which is seven days later than the Day 28 value we have already calculated, which would then push the overall completion of the foundation out by an equal amount, thus delaying the overall completion of the foundation.

Once we have determined the late dates for the *FRPS Footings – Office Area*, we can then calculate late times for *Excavate for Footings – Office Area.*

Since we have previously calculated the late times for the pit work and the service bay work, we are now faced with calculating the late times for *Backfill around Service Pit*, which is another case of calculating a LF for an activity which has three successors.

Using our rule of choosing the lowest LS of all our successor activities as the LF of the, we establish the LF as Day 21.

Again, continuing to the left on the diagram, the backward pass is completed at the beginning node of *Excavate for Service Pit* with a LS of Day 0. This determination is consistent with the logic that the late start is the latest time that the activity can begin without delaying any other activity.

This last calculation also serves as a check on our work. In networks with single beginning and ending nodes and no advanced calculations techniques involved, the calculation of the backward pass must result in a late start of 0; otherwise, there is an error in the calculation.

Floats and Critical Path

Now that the forward and backward passes have been completed, and the early and late times determined, the total float for all activities can be calculated. This part of the procedure is much simpler than the last two steps and consists of simply subtracting the early start time from the late start time (or early finish from late finish) for each activity in turn.

Looking at Figure 4.7 it can be seen that the TF (total float) for *Excavate for Service Pit* 0 – 0 = 0; for FRPS Footing – Service Pit, it is 3 – 3 = 0. Looking at

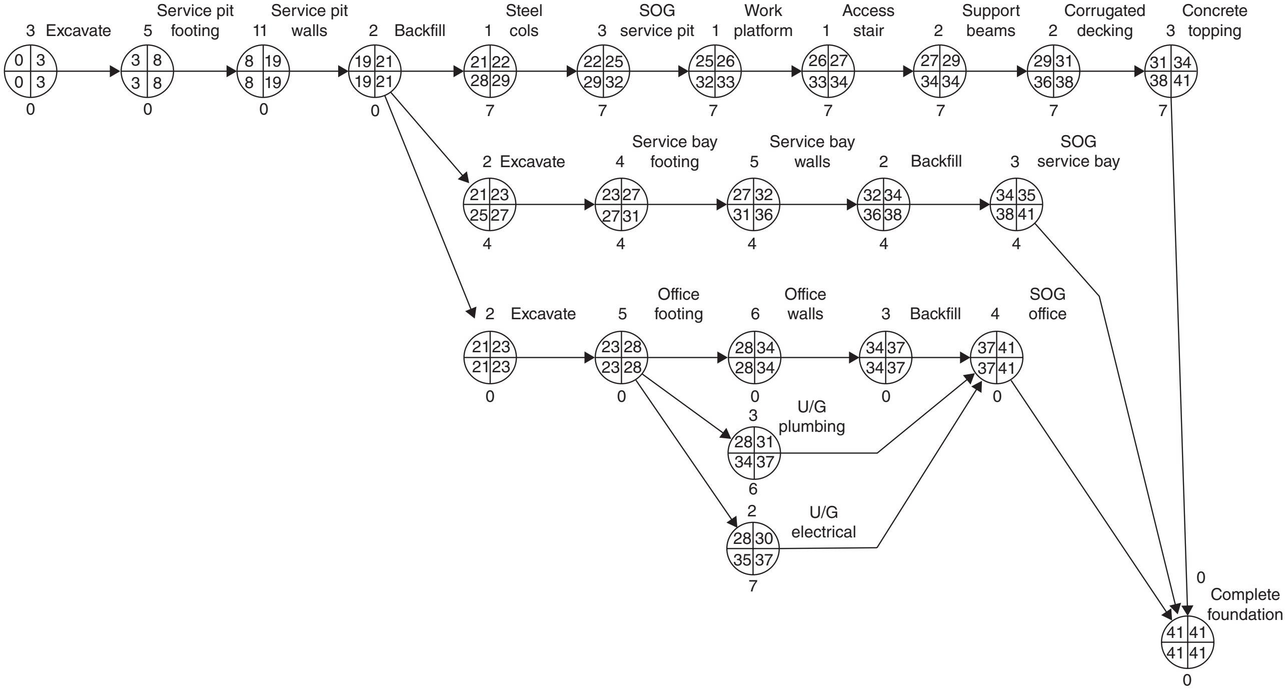


Figure 4.7 Foundation nNetwork – total float calculations

Install Steel Columns in Service Pit, however, it can be seen the value is 28 – 21 = 7. A value of more than 0 means that these activities have some "slack" or permissible delay built into the times they can start. In other words, *Install Steel Columns in Service Pit* has a "window" of Day 21 to Day 28; it can start any time during this period and still meet the requirements for the project as a whole.

Further, it can be seen that the activities that have a float value of 0 constitute the critical path for the project. These activities must start at their scheduled early start times; otherwise, the project will be delayed beyond the calculated completion time of Day 41.

ADVANCED CALCULATIONS

Lagged Relationships

As noted earlier, the basic relationship between activities is the *finish to start*, or *FS*, relationship. This relationship is by far the most common type used in networks, and it was used in the previous section, covering basic forward pass and backward pass calculations. The other relationships, *start to start (SS)* and *finish to finish (FF)*, are also very valuable. Their calculation is as follows.

Start to Start

In calculating the SS relationship, rather than basing the start time of the succeeding activity on the finish of the preceding one, each start time is based on the start time of the preceding activity. This concept is best shown in Figure 4.8, which also shows the notation system and time scale of this relationship. In this diagram, two activities, A & B, have times of 10 days and 20 days, respectively, and they are connected by an SS 5 relationship. In order to calculate the start time of the succeeding activity B, the lag value of 5 is added to the start time of 0 for the preceding activity A, to arrive at a start time of 5 for the succeeding activity B.

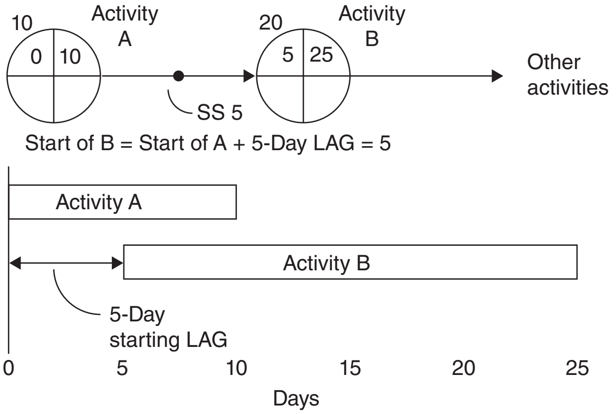


Figure 4.8 Start-to-start relationship

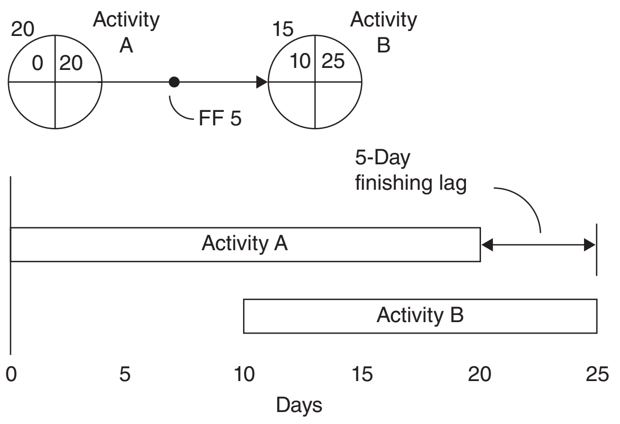


Figure 4.9 Finish-to-finish relationship

Finish to Finish

The calculation of the FF (Finish to Finish) relationship is similar in concept, although it is slightly more complex. To illustrate this point, Figure 4.9 shows two activities, A & B, which have times of 20 and 15 days, respectively, and are connected by an FF 5 relationship. In order to calculate the starting time for B, the early finish for A must first be determined; it is $0 + 20 = 20$. The finish time for B can then be calculated by adding the lag value of 5 to the finish time of A, or $20 + 5 = 25$. Now that the finish time of B has been determined to be 25, the early start of B can be determined by subtracting the duration of Activity B from the finish time of B, or $25 - 15 = 10$.

Constrained Dates

In addition to showing overlapping relationships, the scheduler is often faced with the problem of showing or factoring in events or circumstances that are outside the actual construction process. For example, it is very common in construction to have delivery dates determined by factors completely outside the job site, such as manufacturing schedules. In another typical circumstance, a portion of the site may not be available until a given date, or an owner may impose a required finish date on all or part of the project. In these cases, it is common practice to use what are known as *constrained dates*, or as they are sometimes known, *plugged dates*. These constraints are classified as *no later than (NLT)* or *no earlier than (NET)* dates, and each affects the schedule calculations differently.

The NET date affects only the forward pass. To illustrate the point, Figure 4.10 shows the small sample network with a constraint added. Specifically, the constraint is that the gypsum wallboard cannot be delivered to the job site until Day 25. Logic tells us that the gypsum wallboard installation cannot take place before the material arrives—a fact that must be considered in the calculations. This situation leads to what is known as a *start no earlier than* (SNET) date of Day 25 for gypsum wallboard. The SNET is determined by simply imposing the constraint of Day 25 over the calculated day of 20.

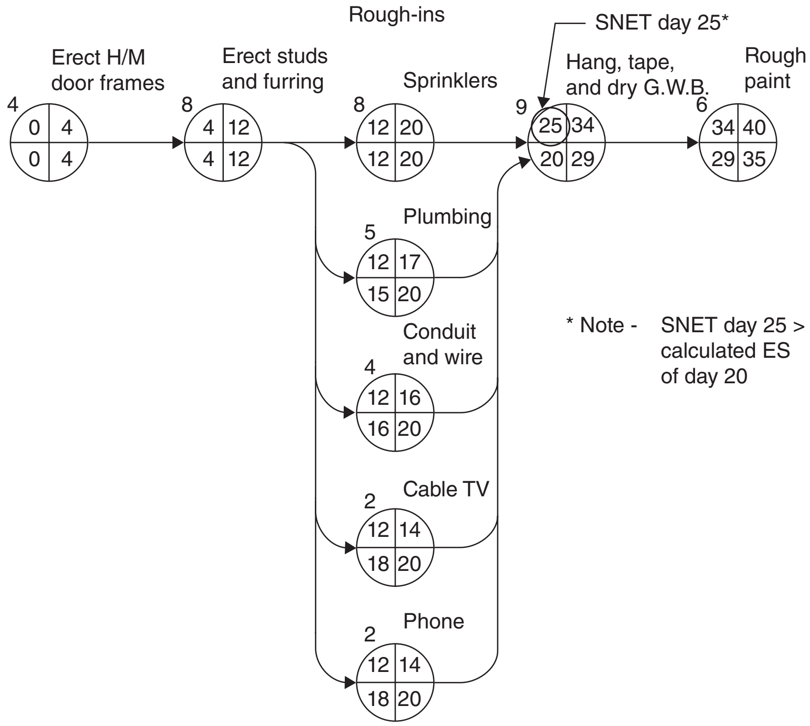


Figure 4.10 Start no earlier than (SNET) constraint

Continuing the calculations for the rest of the forward pass shows an early finish for gypsum wallboard of 34 and ES/EF (early start/early finish) of 34 and 40 for rough paint. This schedule puts the completion of the project at Day 40, which is five days later than originally planned and is equal to the five-day delay in the start of the gypsum wallboard caused by the delay in delivery. It must be noted, however, that if the constraint was SNET Day 18, it would have no effect, since the gypsum wallboard could not start until Day 20 anyway.

By contrast, the NLT (not later than) date affects only the backward pass. As an example, Figure 4.11 points out a case in which, for some external reason, the rough paint must be finished no later than Day 32 (FNLT Day 32). In this case, the constraint is simply imposed over the late finish of rough paint, which becomes Day 32 instead of Day 35. The backward pass calculation is then carried out as before.

Note that at this point, the late start time for hollow metal door frames is now –3. This is not an error; the reason for this value can be shown if the float calculations are carried out. The floats now show a critical path with floats all equal to –3. This float is now what is known as *negative float*. It tells the project manager that this project is three days behind before it even starts, if the constraint of finishing no later than day 32 is to be met. It means that somewhere along the critical path, some durations must be reduced in order to meet the schedule requirement. Finally, as with the SNET constraint, it should be noted that the constraint would not affect any other activities.

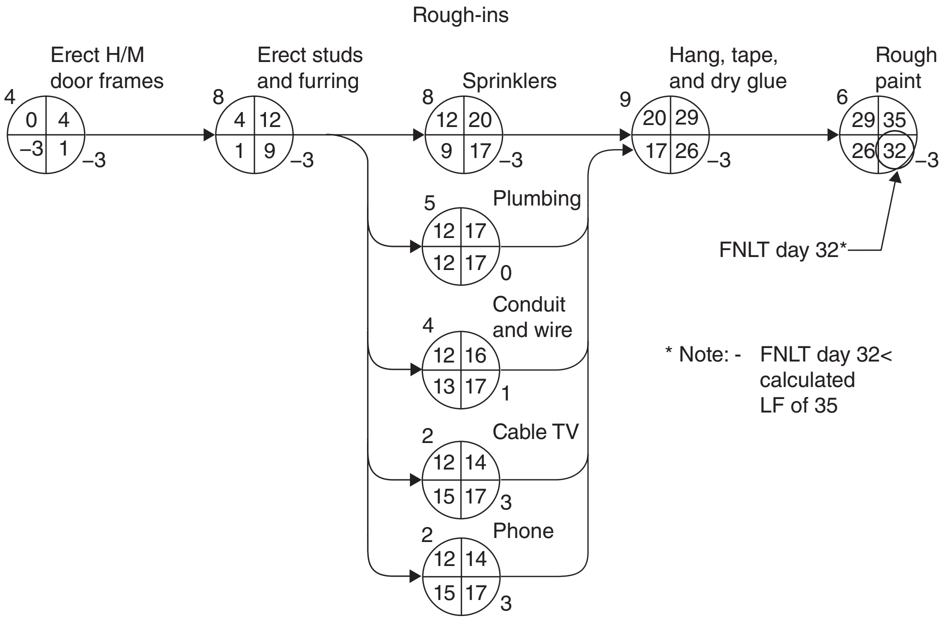


Figure 4.11 Finish no later than (FLNT) constraint

It is possible to have *finish no earlier than* constraints, and *start no later than* constraints, but these situations do not commonly occur. In any case, the effect on calculations is the same.

CALENDARS

Basic Calendars

As noted earlier in this chapter, the calculations are done in work days. There are very good reasons for using work days as a time unit when calculating scheduled times. However, the use of work days raises some problems in the use of schedules by workers and managers in the field. Information must be communicated to the persons who must execute the work. Unfortunately for the person who calculated the schedule in work days, no one in the real world thinks in these terms. To say to a superintendent that form walls must start on Day 13 tells him nothing. The calculated work schedule must be converted to calendar dates to be useful.

It is possible to convert calculated work days to calendar days by hand, but in this day and age, there is absolutely no reason to do so. This task can be easily computerized, which is what is typically done. All available CPM computer systems are designed to allow establishment of at least one basic calendar, which takes into account all holidays, the number of days in a work week, and other factors. These programs take the basic logic of the schedule and the activity durations, use them to calculate starts and finishes, and then display the resulting times as calendar days. Many systems also allow the creation of multiple calendars, some with varying work weeks, and permit the assignment of different activities to different calendars to suit the more complex requirements of some projects. The availability of these features provides yet another strong argument for purchase and application of appropriate computer software for scheduling.

Dealing with the Effect of Weather on Project Calendars

There are several ways to deal with the weather factor when scheduling construction jobs. The first principle is that only those activities that are affected by weather should be adjusted or adapted. For example, weather clearly has an effect on excavation, but has no impact on the installation of bathroom tile. Also, some activities can be performed as quickly in poor weather as in good if the proper precautions are taken. Concreting is an example for which weather becomes a cost concern, but not necessarily a schedule concern. The key is to treat each activity individually according to its particular requirements.

There are two methods for dealing with the effect of weather on activity duration; these are:

- Add time to the activity to compensate
- Schedule fewer working days within the calendar period.

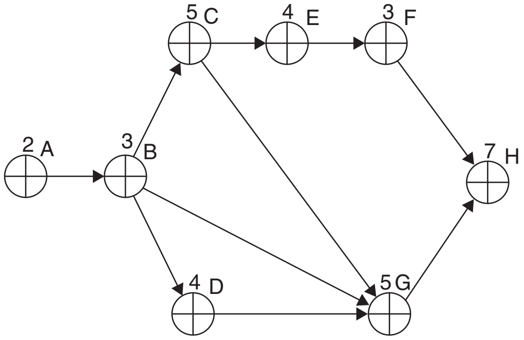
To illustrate the point, consider an excavation activity that is scheduled to take 20 days. If records show that it rains an average of 25 of the days in the season and location specified, then the activity length can be increased to 25 days. The alternative is to schedule the activity on the basis of four-day rather than five-day weeks. In either case, the activity is effectively "stretched" by 25, thus providing extra time to make up for those days when no excavation work can be performed. Lengthening the activity time is the simpler of the two methods, although it will not work in certain circumstances. In such cases, multiple calendars may be needed to reflect the differing effects of weather on various activities. This multiple calendar approach would be needed when it is determined that no work of a certain type could be performed during a certain season or seasons. A specific example might be the erection of structural steel in Wyoming, which may be impossible during the months of December, January, and February. A calendar would have to be established to accommodate the steel erection during the appropriate season(s).

SUMMARY

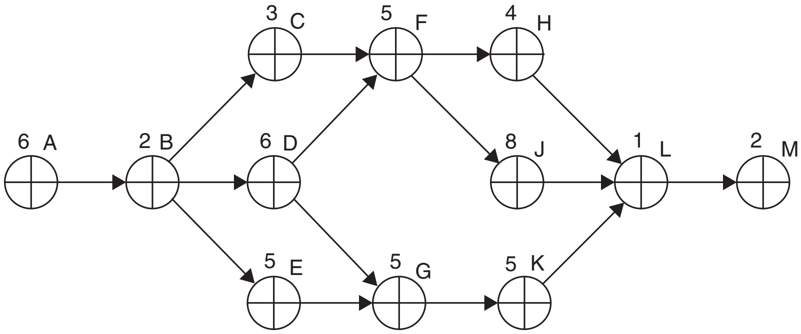
In this chapter, we built on the techniques discussed in Chapter 3 to develop ways a scheduler or project manager can develop activity times and duration for the entire project. When these calculations have been completed, the schedule is then ready for use in the field. It is often true, however, that schedules have many activities and are full of detail which may be difficult to use. The next chapter is, therefore, devoted to the task of organizing and displaying the schedule information for the project in the clearest way possible so that the project managers can attack the key problems on the job and not spend time worrying about tasks which do not need attention.

PRACTICE PROBLEMS

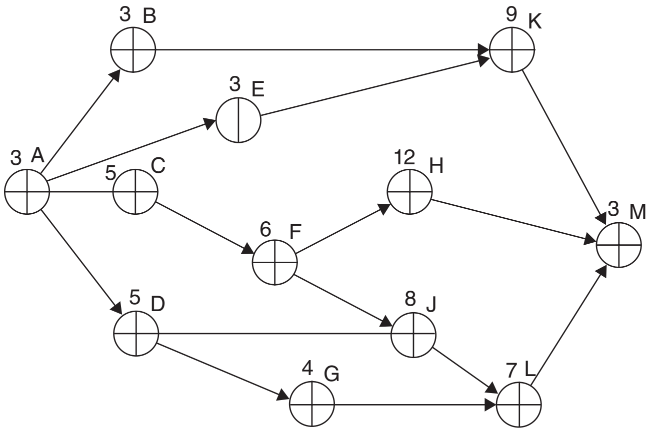
Practice Problem 1



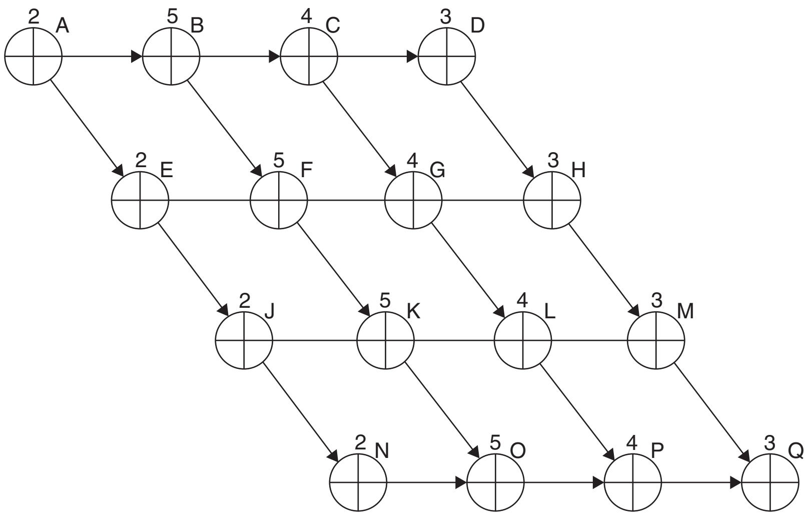
Practice Problem 2



Practice Problem 3



Practice Problem 4



5 PUBLISHING THE SCHEDULE

5 Publishing the Schedule

Scheduling using CPM techniques can involve a considerable amount of detail work. As projects grow larger, the number of activities increases, and a high level of detail becomes almost inevitable. As a result, managers can become overwhelmed by the amount of data, finding it difficult to obtain the information they need for the task at hand. This chapter describes how to use a schedule efficiently even when large amounts of detail are involved. The tasks required to organize and effectively use the schedule may seem too complicated to be worthwhile. In fact, quite the opposite is true. A moderate amount of effort and time invested in organizing the schedule early in the project can yield enormous dividends later by making the right information accessible at the right time, thus helping the managers in their decision making.

CHECKING THE FINAL SCHEDULE

Prior to sending the baseline schedule to the owner and the other players on the project, the project team should perform an extensive review of the schedule as it is planned to ensure that the team's planning process has created a usable schedule that is clear to all. At a minimum, the following items should be checked.

Contract Compliance

In today's industry, more and more owners are now requiring specific schedule features that will give them information that allows them to monitor job progress more closely. These requirements are not unreasonable considering how much of the owner's money is at risk on a typical project, but their requirements are often quite detailed, and if not met, can result in rejection of the schedule. Typical features are:

- Milestones to designate exact start and completion dates, as well interim milestones.
- A schedule duration that meets the allowed contract time exactly. The reason for this is that owners do not want contractors to show a faster schedule than the

contract time allows because it can open the door to a claim of interference with the contractor's work.

- Constraints such as Start no earlier than, or Finish not later than, are often limited to specific causes, for example, limitations placed on the work by the owner. the reason for this is to simplify the schedule calculations.
- Owners often require contractors to include specific work that must be done by the owner's personnel. This certainly makes sense when one considers the fact that a review of an item of submittal has the potential to delay the overall project. Integration of these items into the schedule makes the schedule more realistic.
- Does the schedule include all work required by local code authorities, for example, erosion work?
- Does the schedule reflect professional scheduling practice? Typical items include a prohibition against having more than one beginning node, or more than one ending node, and requiring that schedule calculations be based on retained logic and not progress override. These aspects of schedule are beyond the scope of this text, but if important, they will be stated clearly in the specifications for the project.

Does the Schedule Make Sense Overall?

In addition to the hard specific requirements imposed by the owner, the project team should also look at the schedule from the perspective of: Does the schedule as built truly reflect what it will take to get the job done? At the very least, the team should look at the following general areas.

- Is the entire scope of work of the project covered by activities in the schedule. Very few things are more embarrassing to a project manager than to discover that a plan of action does not include a key piece of the puzzle. The only way to avoid this is to know the plans and specifications well and to very carefully review the subcontractor's scope to ensure that everything is included. Doing this is difficult at the beginning of the project when time is short and the pressure is on, but it is critical nonetheless.
- Is the sequence of work that is reflected in the schedule logic a realistic way to get the project built? This is a judgment call on the part of the project manager and superintendent, and will generally reflect their experience on project of a similar type. Often, a superintendent will carry an implicit vision of how the project should proceed, and the trick for a scheduler is to make sure that the logic of the schedule reflects the superintendent's knowledge of the best way to proceed.
- Are the activity durations realistic? This relates to the discussions in Chapter 3, and the rule of "never give anyone an optimistic time" still holds true. It should be emphasized again that a calculated time is one thing, and a realistic time is quite another.
- Does the schedule include any trade stacking? Trade stacking occurs when too many crews are scheduled to be in the same space at the same time. If this occurs, the effect is reduced efficiency and unnecessary conflicts over progress, and it should be avoided if at all possible.
- Does the schedule take dryin into account? More than one project has gone bad because interior was scheduled before the building was fully enclosed and

protected from weather problems. For example, putting in gypsum wall board before the building envelope is fully sealed and air conditioning is in place can result in serious damage to the walls should a severe storm occur.

Technical Details in the Schedule

In addition to contract requirements and the common sense elements of a schedule that were just discussed, the project team or the scheduler specifically should review the details that underpin the schedule calculations and displays. Typical items that need checking are:

- Are the schedule calendars accurate and correctly applied to specific activities? This can also be a contract requirement, as in the case of some government specifications, but even if it is not, the details should be checked. For example, are the correct holidays included? Or, does the schedule reflect anticipated weather and is the weather-impacted calendar applied only to those activities that are truly weather-related?
- Does the schedule organization support the planned schedule displays? For example, if the project manager wants to show individual subcontractor schedule, are the sub's activities properly coded to allow selection and sorting?
- Is the schedule properly cost loaded? As will be discussed later in Chapter 7, cost-loaded schedules have become more and more common in the industry, and accurate cost loading of individual activities is essential for payment and progress tracking.

KEY QUESTIONS TO ASK

After the schedule has been reviewed and the project team has determined that it meets the needs of the project, the team must ask before publishing the schedule: *Who will use the information?*

To begin with, it must be recognized that not all managers need the same information. For instance, a vice president requires very different information from that needed by the project manager. Likewise, the superintendent requires a different set of data from that which is useful to the VP and the PM. If the schedule is not designed to handle these differing needs, then the VP is forced to wade through information intended for the PM and superintendent, and vice versa. Simply put, different managers need different kinds of information.

The second question is: *What will they need to know?* To avoid confusion, the schedule must be organized in such a way that only the important and relevant elements are presented to each party at the proper time. The manager must not be presented with information concerning portions of the job that are not currently relevant. For example, when the sample office building is in the structural stage, a project manager cannot afford to be concerned with future activities like roofing or the third floor interior work.

The third question is: *How can we design the schedule to provide the proper information at the right time?* To accomplish this task, we must design "intelligence" into the schedule activities so that we can easily and efficiently find the right information elements from among a mass of otherwise irrelevant information, then arrange and display it in such a way that it is easily understood by the parties who need it. Once we have found the correct information, we must then arrange it in such a way that it is clear and easily understood by all users. Fortunately, most modern scheduling software systems provide the tools necessary to do that job.

TASKS THAT MUST BE PERFORMED IN ORDER TO PROVIDE THE RIGHT INFORMATION

So far, we have described the need to organize the schedule information. The question that remains is how to do it. Specifically, the schedule must be organized in such a way that these three key tasks can be accomplished:

1. **Selection:** First, it is necessary to separate certain information from all other information. For example, if the superintendent wants information about the forming of footing line A alone, then our schedule system must allow us to identify each element of footing line A separate from all other work in the job. Or, the superintendent may wish to look only at forming of footings and ignore placement, reinforcement, and so on. Similarly, the schedule should be designed to permit that kind of selection.

2. **Sorting:** In addition to selecting, we must also be able to sort and present the data in an order that has some meaning to the people reviewing it. In the case of footing line A, the superintendent would probably want to list each element in the order in which it is supposed to occur.

3. **Summation:** For example: If the project manager needs to check on the progress of the footings in general, but does not wish to see the detail, then the system must be capable of summarizing all footing activities into a single activity for display.

Finally, it is important to be able to accomplish all of these tasks at one time. For instance, if the vice president wants information about the foundation as a whole, and does not want to see information about the structure above or other elements, then the schedule must permit selection of foundation activities (excluding all others), *and* a summary of that set of activities. If the foundation is presented relative to other work, then sorting is also necessary.

This detailed process of selecting, sorting, and summarizing may at first glance seem like a formidable task. Fortunately, this is not the case. All up-to-date computerized schedule systems are designed with these tasks in mind. The key lies in the coding of activities, using the schemes provided by the systems. In reality, very little work is required to create a well-organized, useful schedule, as you shall see.

TYPES OF CODING SCHEMES

The following coding schemes from the sample office building and other building types are examples of types of coding that allow the project scheduler to provide information in a number of different ways. These schemes are not the only ones that could be used, nor must a coding scheme be as complex as these in order to be useful or effective. They are intended only as representative types of schemes.

Coding by Work Breakdown Structure

A *work breakdown structure*, also known as a *WBS* is an increasingly common way of breaking a project down into workable units and organizing into a viewable form that is easily understood by people working on the project.

At one time, WBSs were most commonly used on large-scale construction projects, but they were not often used on small-scale projects. However, their use has expanded over time, in large part due to the advantages they offer, some of which are:

- A WBS is an effective and well-understood tool, particularly since WBS tools are included in almost all scheduling software systems.
- Information on how to develop and use WBS is widely available. For example, professional organizations such as the Project Management Institute and the Association for the Advancement of Cost Engineering International have both published extensive material on the subject.
- CPM scheduling is often specified by owners on their projects.
- A WBS relates very well to the *level-of-detail* concept introduced in Chapter 3.

The basic concept of a WBS is to organize the elements of work required to complete a project into a hierarchical form that breaks the project down into smaller and smaller units. A WBS can be expressed in two ways: (1) as tree structure, or (2) as an outline. An example of this concept is shown in Figures 5.1 and the feature that follows.

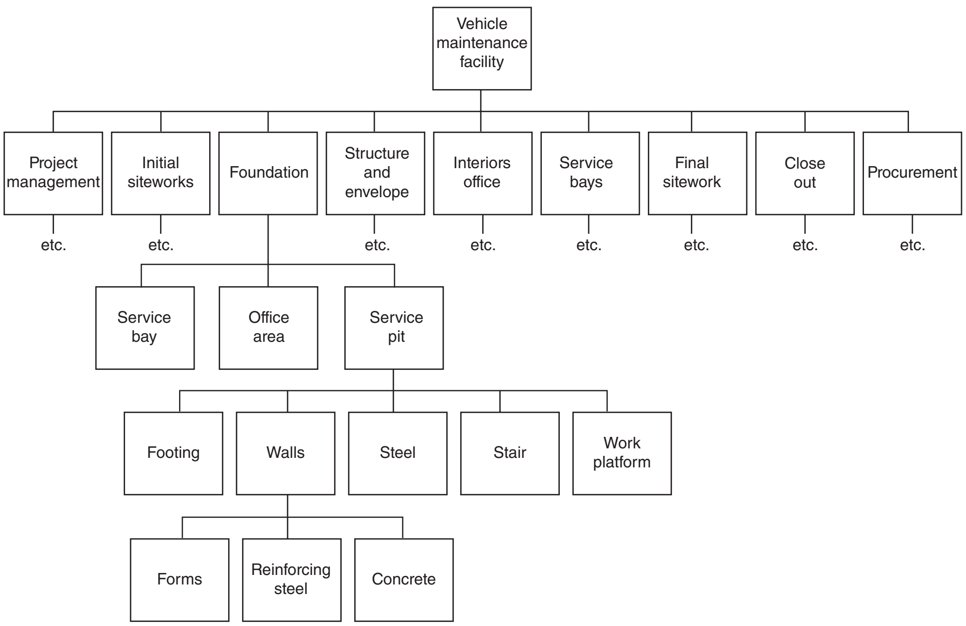


Figure 5.1 WBS scheme – tree format

WBS Scheme – Outline Format

Vehicle Maintenance Facility

- Project management
- Initial sitework
- Foundation
    - Service bays
    - Office area
    - Service pit
        - Footing
        - Walls
    - Forms
        - Reinforcing steel
        - Concrete
    - Steel
    - Stair
    - Work platform
- Structure and envelope
- Interiors – office
- Service bays
- Final sitework
- Closeout
- Procurement

Several points should be noted about WBSs, though.

Even though the WBS concept is widely applicable, actual WBS forms will typically be specific to an industry or to a company.

For example, engineering construction such as petrochemical projects are often broken down into engineering disciplines, as follows:

1. Process design
2. Mechanical
    a. Vessels
    b. Piping
    c. Pumps
3. Civil
    a. Foundations
    b. Support structures
4. Electrical
    a. Power
    b. Controls
5. Etc.

Another typical scheme that is used in the power construction industry is based project systems

1. Structure
2. Boilers
3. Generators

4. Cooling system
5. Power distribution system
6. Etc.

In building construction, WBSs are typically arranged in one of two ways: (1) by CSI division or by (2) construction phases.

The advantage of the first arrangement is that the WBS will line up with the way most building estimators organized their work and their data. The CSI system is a time honored way of working, but unfortunately it does not relate well to the way field people see construction sequences.

As a result, the most common way a WBS is used in the building segment of the construction industry is to organize it by phase and by building element. This scheme is reflected in the organization and process of building and activity list in Chapter 3, and it is used in the schedule of the sample vehicle maintenance facility. The actual WBS used in the schedule shown in Appendix A is given here:

- Project Management
- Initial Sitework
- Foundation
- Structure and Envelope
- Interiors – Office Area
- Service Bays
- Final Sitework
- Project Closeout

It would be entirely possible to break down the work further in the Vehicle Maintenance Schedule, but the question arises, would it be productive to do so? The answer in this case, probably not. A further breakdown would not add anything to the clarity of the schedule and would simply increase the administrative workload.

Coding by Project Phases

Most construction projects are carried out in logical phases, with certain milestones marking the end of each phase. For example, a simple house schedule might use the following phases:

- Foundation
- Framing and roof
- Dry-in
- Rough-ins
- Finishes
- Site work and landscaping

Similarly, a schedule for the sample office building might be broken down into the following phases:

- Site work
- Foundation
- Structure

- Penthouse
- Building envelope
- Basement
- Interiors – 1st floor
- Interiors – 2nd floor
- Interiors – 3rd floor
- Finish site work
- Closeout

Coding by Project Level or Area

High-rise or multilevel projects benefit from schemes that allow the project manager to review work taking place at different levels. A typical scheme for the same office building might be as follows:

- Basement
- 1st Floor
- 2nd Floor
- 3rd Floor
- Roof and penthouse

Similarly, projects spread over large areas typically use codes to denote horizontal location. For example, oil refineries often use a grid reference system to denote location of specific work.

Coding by Trade

It is often helpful to be able to view the sequence of operations of a particular trade or crew without regard to building level. For example, if the general contractor building the sample hotel elects to do all concrete using his company's employees, then it would be a great help to the project manager if he could selectively display the activities involving the contractor's own employees or crews, while ignoring activities involving subcontractors or other trades. This type of code is also helpful in identifying overlaps in scheduling crews, and for allocating labor.

Coding by Contractor or Subcontractor

In addition to reviewing activities involving one particular trade, it may also be helpful for the project manager to see the sequence of an individual subcontractor's work separate from all other work. In fact, subcontractors are usually eager for as much information as is available regarding the dates when they will be required to work, and they are apt to be more cooperative when they are better informed.

Other Coding Possibilities

While the above-mentioned coding schemes are generally useful on commercial building projects, other types are more appropriate for other kinds of work. For example, a contractor who does roadwork may wish to schedule and control bridgework separately from earthwork or paving. A contractor who builds large industrial plants may need to identify work on a horizontal or "geographic" basis. Home builders who construct large subdivisions might want to see or schedule work based on separate streets or by individual houses or groups of houses.

Ways to Arrange the Information

Once we have selected the information from the overall schedule, we must then think of how to arrange the information in ways that are clear to the user. Usually, this means three basic sorting schemes:

1. By identifier
2. By time, for example, early start
3. By degree of importance, for example, total float

The first case, by *activity identifier,* is frequently used by schedulers who must work with large lists of data. For example, if a preliminary schedule has been created and a scheduler must then work with a list of activities to add further information, the information would be sorted and displayed on a worksheet in identifier order so the scheduler can easily find the appropriate activity. Activity identifiers can also be used to select information for schedules for field personnel, especially if intelligence is built into the activity identifier numbers. This approach is less common, but this idea has been built into the schedule for the sample office building. As the reader can see, the site work activity identifiers are in the 1000 series, the foundation is in the 2000 series, and so on.

The second sorting schedule, by time, is much more commonly used. Most people in the construction industry think of time in a "left to right" representation, and many schedules are, therefore, presented in what is known as an "early start" sort. This creates a form of chart, known as a *bar chart* or *Gantt chart*, which is intuitively and readily understood by most people in the construction field. Most of the examples of schedule reports at the end of this chapter are sorted "ES," and the reader can easily see the clarity of the information presented.

The last sorting device, by degree of importance, can be used to emphasize activities that must receive more emphasis than others. For example, a bar chart can be sorted by total float, so that the critical activities, or those with the least float, will be displayed at the top of the list of work to be done. An example of this type of bar chart is also shown at the end of this chapter.

SAMPLE REPORTS: OFFICE BUILDING

Figures 5.2 through 5.9 are samples of typical schedule reports that might be generated for use by managers constructing an office building. All of these samples have been created using Microsoft Project scheduling software.

Overall Bar Chart

An overall bar chart is **a**n example of information about the project as a whole. All the activities in the project are shown in this report as seen in Figure 5.2

through 5.5. All the work is shown grouped into phases, and the report provides an excellent of the total project. The major flaw in this report is that it may provide more detail than upper management needs to know.

Schedule for a Single Phase

Within each phase of the project, there are details of the actual work to be done in one major segment of the project. Figure 5.5 shows the activities required to build out the finishes of the office area.

Schedule for a Single Sub

In addition to details of a phase, it is sometimes necessary to show the work of a single subcontractor or superintendent. In Figure 5.6 all concrete work is shown, which spans two phases, foundation and structure. One valuable bit of information shown in this report is the fact that at several points, more than one concrete crew is scheduled to be working. This would tip off the superintendent that it may be necessary to let some concrete slip within its float range.

Schedule for Two Subs

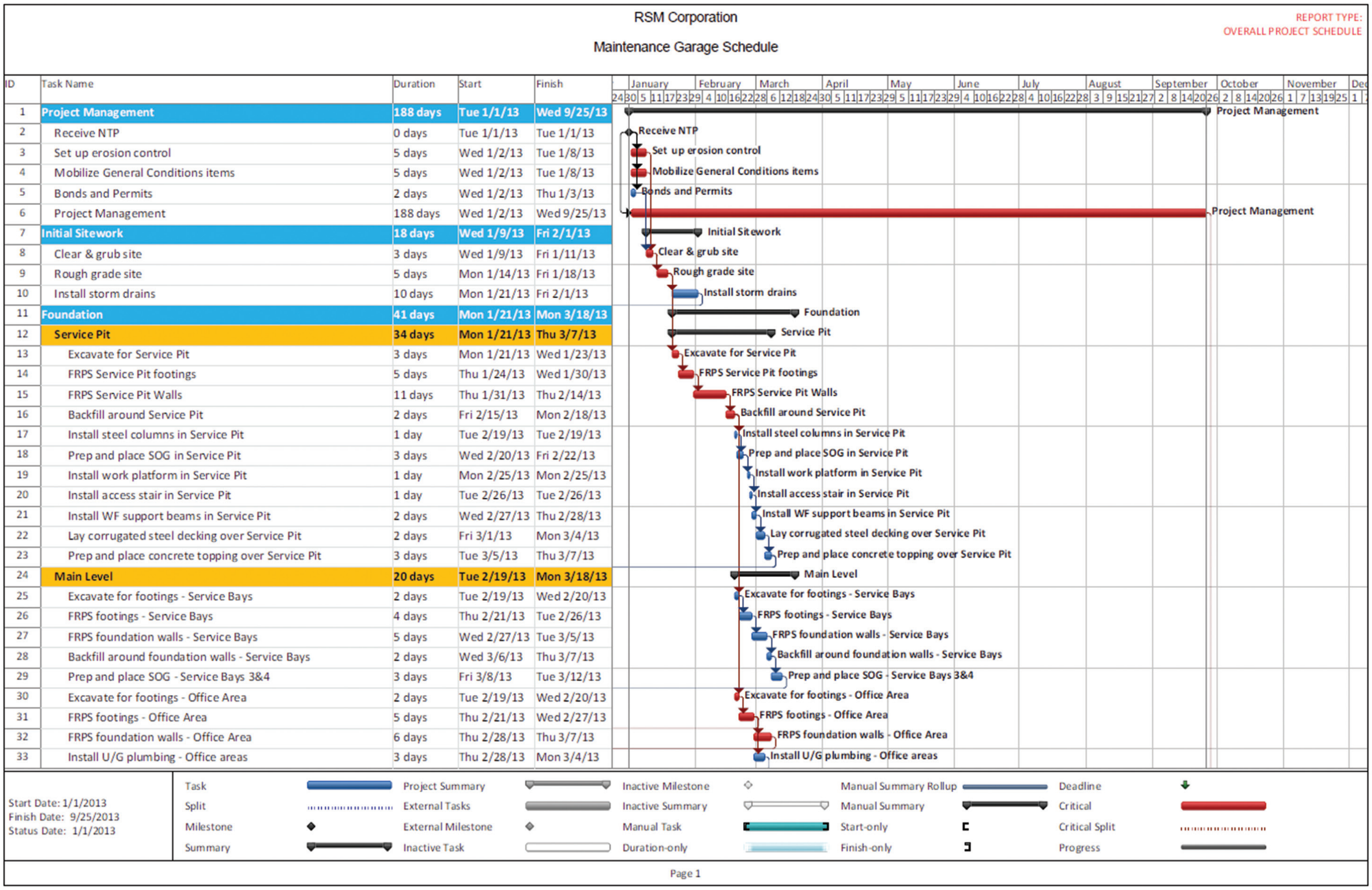
In this case, two subs, HVAC and Electrical are shown on the same bar chart, Figure 5.7. The reason of this is that these two trades are often assigned to work in the same space at the same time. Looking at the amount of work to be done by these two trades in the same space during June, July, and August shows the potential for trade stacking in the office area.

By Time Window

Sometimes it is desirable to show only the work that happens in the very near future. This report, Figure 5.9, shows only the activities that are due to start within the first three months of the project. This kind of time window is frequently used during schedule update meeting so that all parties can look at the work to be done in the short term.

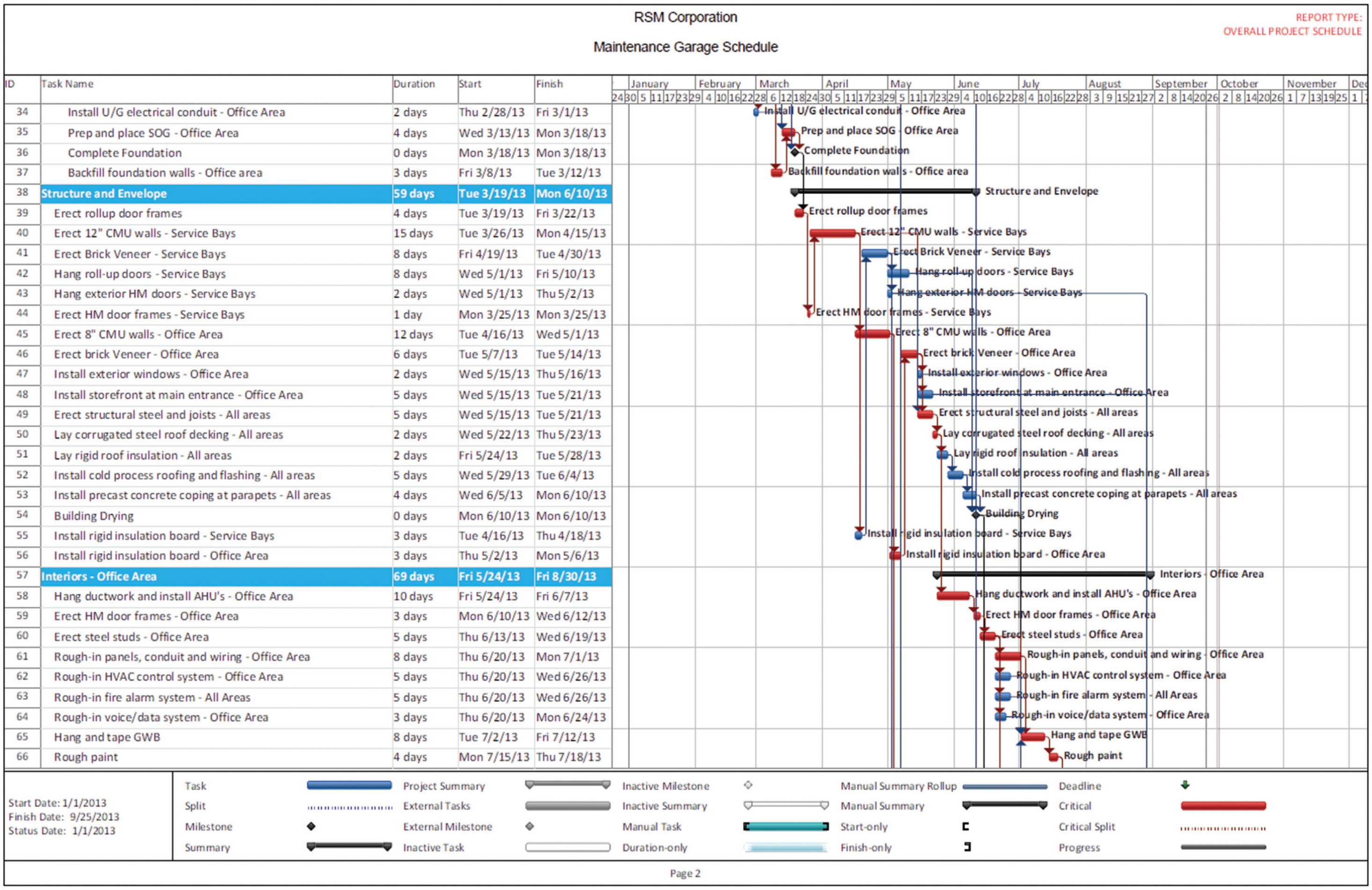
SUMMARY

In this chapter, we covered one of the most important parts of the scheduling process: displaying the information developed during the planning process and beyond. One key point is that the value of the schedule to the project manager can be enhanced considerably if it is displayed in a form which is easily understood by all. Good schedule information helps superintendents and foremen plan their work well and contributes to a smooth and efficient job. Conversely, if it is displayed poorly, its value is lost and much effort can be wasted, not to mention the project may go badly and no one will know. The next chapter deals with the next step after the project is planned and started: monitoring and controlling the work as it proceeds and the inevitable unexpected problems start to surface.



ID	Task Name	Duration	Start	Finish
1	Project Management	188 days	Tue 1/1/13	Wed 9/25/13
2	Receive NTP	0 days	Tue 1/1/13	Tue 1/1/13
3	Set up erosion control	5 days	Wed 1/2/13	Tue 1/8/13
4	Mobilize General Conditions items	5 days	Wed 1/2/13	Tue 1/8/13
5	Bonds and Permits	2 days	Wed 1/2/13	Thu 1/3/13
6	Project Management	188 days	Wed 1/2/13	Wed 9/25/13
7	Initial Sitework	18 days	Wed 1/9/13	Fri 2/1/13
8	Clear & grub site	3 days	Wed 1/9/13	Fri 1/11/13
9	Rough grade site	5 days	Mon 1/14/13	Fri 1/18/13
10	Install storm drains	10 days	Mon 1/21/13	Fri 2/1/13
11	Foundation	41 days	Mon 1/21/13	Mon 3/18/13
12	Service Pit	34 days	Mon 1/21/13	Thu 3/7/13
13	Excavate for Service Pit	3 days	Mon 1/21/13	Wed 1/23/13
14	FRPS Service Pit footings	5 days	Thu 1/24/13	Wed 1/30/13
15	FRPS Service Pit Walls	11 days	Thu 1/31/13	Thu 2/14/13
16	Backfill around Service Pit	2 days	Fri 2/15/13	Mon 2/18/13
17	Install steel columns in Service Pit	1 day	Tue 2/19/13	Tue 2/19/13
18	Prep and place SOG in Service Pit	3 days	Wed 2/20/13	Fri 2/22/13
19	Install work platform in Service Pit	1 day	Mon 2/25/13	Mon 2/25/13
20	Install access stair in Service Pit	1 day	Tue 2/26/13	Tue 2/26/13
21	Install WF support beams in Service Pit	2 days	Wed 2/27/13	Thu 2/28/13
22	Lay corrugated steel decking over Service Pit	2 days	Fri 3/1/13	Mon 3/4/13
23	Prep and place concrete topping over Service Pit	3 days	Tue 3/5/13	Thu 3/7/13
24	Main Level	20 days	Tue 2/19/13	Mon 3/18/13
25	Excavate for footings - Service Bays	2 days	Tue 2/19/13	Wed 2/20/13
26	FRPS footings - Service Bays	4 days	Thu 2/21/13	Tue 2/26/13
27	FRPS foundation walls - Service Bays	5 days	Wed 2/27/13	Tue 3/5/13
28	Backfill around foundation walls - Service Bays	2 days	Wed 3/6/13	Thu 3/7/13
29	Prep and place SOG - Service Bays 3&4	3 days	Fri 3/8/13	Tue 3/12/13
30	Excavate for footings - Office Area	2 days	Tue 2/19/13	Wed 2/20/13
31	FRPS footings - Office Area	5 days	Thu 2/21/13	Wed 2/27/13
32	FRPS foundation walls - Office Area	6 days	Thu 2/28/13	Thu 3/7/13
33	Install U/G plumbing - Office areas	3 days	Thu 2/28/13	Mon 3/4/13

Figure 5.2 Vehicle Maintenance Facility overall bar chart – Page 1. Used with permission from Microsoft.



ID	Task Name	Duration	Start	Finish
34	Install U/G electrical conduit - Office Area	2 days	Thu 2/28/13	Fri 3/1/13
35	Prep and place SOG - Office Area	4 days	Wed 3/13/13	Mon 3/18/13
36	Complete Foundation	0 days	Mon 3/18/13	Mon 3/18/13
37	Backfill foundation walls - Office area	3 days	Fri 3/8/13	Tue 3/12/13
38	**Structure and Envelope**	**59 days**	**Tue 3/19/13**	**Mon 6/10/13**
39	Erect rollup door frames	4 days	Tue 3/19/13	Fri 3/22/13
40	Erect 12" CMU walls - Service Bays	15 days	Tue 3/26/13	Mon 4/15/13
41	Erect Brick Veneer - Service Bays	8 days	Fri 4/19/13	Tue 4/30/13
42	Hang roll-up doors - Service Bays	8 days	Wed 5/1/13	Fri 5/10/13
43	Hang exterior HM doors - Service Bays	2 days	Wed 5/1/13	Thu 5/2/13
44	Erect HM door frames - Service Bays	1 day	Mon 3/25/13	Mon 3/25/13
45	Erect 8" CMU walls - Office Area	12 days	Tue 4/16/13	Wed 5/1/13
46	Erect brick Veneer - Office Area	6 days	Tue 5/7/13	Tue 5/14/13
47	Install exterior windows - Office Area	2 days	Wed 5/15/13	Thu 5/16/13
48	Install storefront at main entrance - Office Area	5 days	Wed 5/15/13	Tue 5/21/13
49	Erect structural steel and joists - All areas	5 days	Wed 5/15/13	Tue 5/21/13
50	Lay corrugated steel roof decking - All areas	2 days	Wed 5/22/13	Thu 5/23/13
51	Lay rigid roof insulation - All areas	2 days	Fri 5/24/13	Tue 5/28/13
52	Install cold process roofing and flashing - All areas	5 days	Wed 5/29/13	Tue 6/4/13
53	Install precast concrete coping at parapets - All areas	4 days	Wed 6/5/13	Mon 6/10/13
54	Building Drying	0 days	Mon 6/10/13	Mon 6/10/13
55	Install rigid insulation board - Service Bays	3 days	Tue 4/16/13	Thu 4/18/13
56	Install rigid insulation board - Office Area	3 days	Thu 5/2/13	Mon 5/6/13
57	**Interiors - Office Area**	**69 days**	**Fri 5/24/13**	**Fri 8/30/13**
58	Hang ductwork and install AHU's - Office Area	10 days	Fri 5/24/13	Fri 6/7/13
59	Erect HM door frames - Office Area	3 days	Mon 6/10/13	Wed 6/12/13
60	Erect steel studs - Office Area	5 days	Thu 6/13/13	Wed 6/19/13
61	Rough-in panels, conduit and wiring - Office Area	8 days	Thu 6/20/13	Mon 7/1/13
62	Rough-in HVAC control system - Office Area	5 days	Thu 6/20/13	Wed 6/26/13
63	Rough-in fire alarm system - All Areas	5 days	Thu 6/20/13	Wed 6/26/13
64	Rough-in voice/data system - Office Area	3 days	Thu 6/20/13	Mon 6/24/13
65	Hang and tape GWB	8 days	Tue 7/2/13	Fri 7/12/13
66	Rough paint	4 days	Mon 7/15/13	Thu 7/18/13

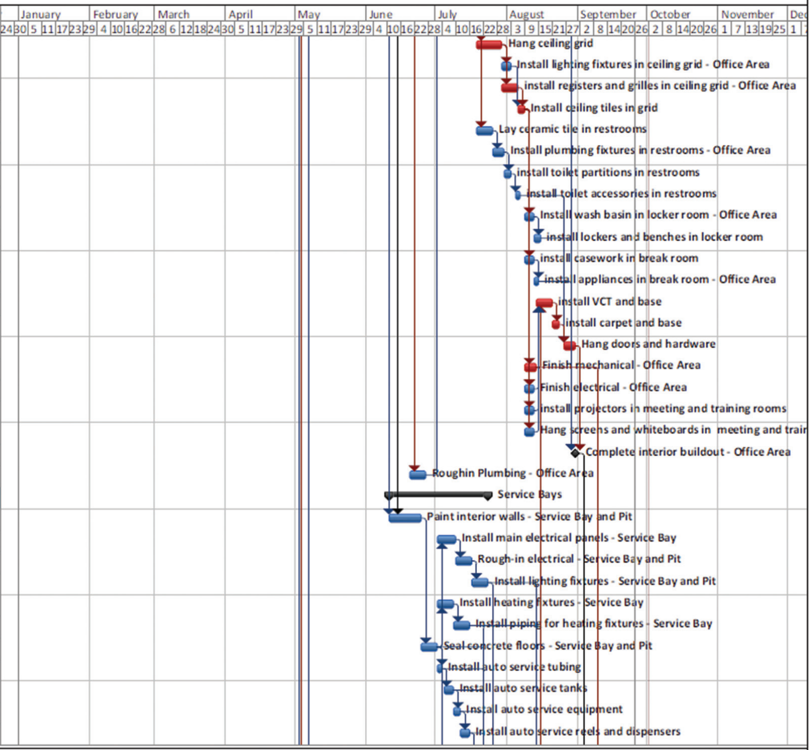
Figure 5.3 Vehicle Maintenance Facility overall bar chart – Page 2. Used with permission from Microsoft.

RSM Corporation

Maintenance Garage Schedule

REPORT TYPE:
OVERALL PROJECT SCHEDULE

ID	Task Name	Duration	Start	Finish
67	Hang ceiling grid	7 days	Fri 7/19/13	Mon 7/29/13
68	Install lighting fixtures in ceiling grid - Office Area	4 days	Tue 7/30/13	Fri 8/2/13
69	install registers and grilles in ceiling grid - Office Area	5 days	Tue 7/30/13	Mon 8/5/13
70	Install ceiling tiles in grid	3 days	Tue 8/6/13	Thu 8/8/13
71	Lay ceramic tile in restrooms	5 days	Fri 7/19/13	Thu 7/25/13
72	Install plumbing fixtures in restrooms - Office Area	3 days	Fri 7/26/13	Tue 7/30/13
73	install toilet partitions in restrooms	3 days	Wed 7/31/13	Fri 8/2/13
74	install toilet accessories in restrooms	2 days	Mon 8/5/13	Tue 8/6/13
75	Install wash basin in locker room - Office Area	2 days	Fri 8/9/13	Mon 8/12/13
76	install lockers and benches in locker room	3 days	Tue 8/13/13	Thu 8/15/13
77	install casework in break room	2 days	Fri 8/9/13	Mon 8/12/13
78	install appliances in break room - Office Area	2 days	Tue 8/13/13	Wed 8/14/13
79	install VCT and base	5 days	Wed 8/14/13	Tue 8/20/13
80	install carpet and base	3 days	Wed 8/21/13	Fri 8/23/13
81	Hang doors and hardware	5 days	Mon 8/26/13	Fri 8/30/13
82	Finish mechanical - Office Area	3 days	Fri 8/9/13	Tue 8/13/13
83	Finish electrical - Office Area	2 days	Fri 8/9/13	Mon 8/12/13
84	install projectors in meeting and training rooms	2 days	Fri 8/9/13	Mon 8/12/13
85	Hang screens and whiteboards in meeting and training rooms	2 days	Fri 8/9/13	Mon 8/12/13
86	Complete interior buildout - Office Area	0 days	Fri 8/30/13	Fri 8/30/13
87	Roughin Plumbing - Office Area	5 days	Thu 6/20/13	Wed 6/26/13
88	Service Bays	30 days	Tue 6/11/13	Tue 7/23/13
89	Paint interior walls - Service Bay and Pit	10 days	Tue 6/11/13	Mon 6/24/13
90	Install main electrical panels - Service Bay	5 days	Tue 7/2/13	Tue 7/9/13
91	Rough-in electrical - Service Bay and Pit	5 days	Wed 7/10/13	Tue 7/16/13
92	Install lighting fixtures - Service Bay and Pit	5 days	Wed 7/17/13	Tue 7/23/13
93	Install heating fixtures - Service Bay	4 days	Tue 7/2/13	Mon 7/8/13
94	Install piping for heating fixtures - Service Bay	5 days	Tue 7/9/13	Mon 7/15/13
95	Seal concrete floors - Service Bay and Pit	5 days	Tue 6/25/13	Mon 7/1/13
96	Install auto service tubing	2 days	Tue 7/2/13	Wed 7/3/13
97	Install auto service tanks	2 days	Fri 7/5/13	Mon 7/8/13
98	Install auto service equipment	3 days	Tue 7/9/13	Thu 7/11/13
99	Install auto service reels and dispensers	2 days	Fri 7/12/13	Mon 7/15/13



Start Date: 1/1/2013
Finish Date: 9/25/2013
Status Date: 1/1/2013

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Critical
Milestone	External Milestone	Manual Task	Start-only	Critical Split
Summary	Inactive Task	Duration-only	Finish-only	Progress

Page 3

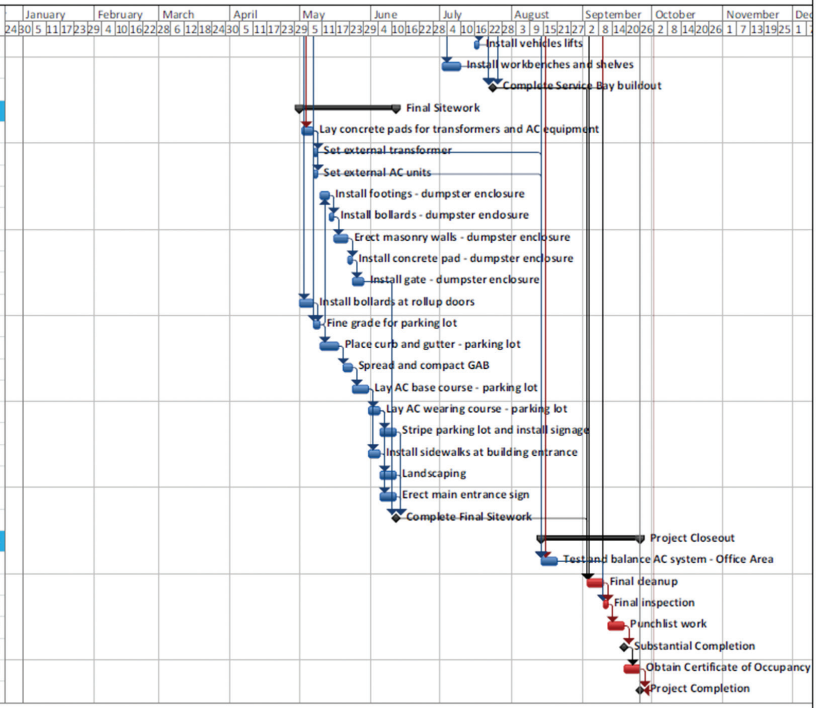
Figure 5.4 Vehicle Maintenance Facility overall bar chart – Page 3. Used with permission from Microsoft.

RSM Corporation

Maintenance Garage Schedule

REPORT TYPE:
OVERALL PROJECT SCHEDULE

ID	Task Name	Duration	Start	Finish
100	Install vehicles lifts	2 days	Tue 7/16/13	Wed 7/17/13
101	Install workbenches and shelves	5 days	Tue 7/2/13	Tue 7/9/13
102	Complete Service Bay buildout	0 days	Tue 7/23/13	Tue 7/23/13
103	**Final Sitework**	**29 days**	**Wed 5/1/13**	**Tue 6/11/13**
104	Lay concrete pads for transformers and AC equipment	3 days	Thu 5/2/13	Mon 5/6/13
105	Set external transformer	2 days	Tue 5/7/13	Wed 5/8/13
106	Set external AC units	2 days	Tue 5/7/13	Wed 5/8/13
107	Install footings - dumpster enclosure	2 days	Fri 5/10/13	Mon 5/13/13
108	Install bollards - dumpster enclosure	2 days	Tue 5/14/13	Wed 5/15/13
109	Erect masonry walls - dumpster enclosure	4 days	Thu 5/16/13	Tue 5/21/13
110	Install concrete pad - dumpster enclosure	2 days	Wed 5/22/13	Thu 5/23/13
111	Install gate - dumpster enclosure	2 days	Fri 5/24/13	Tue 5/28/13
112	Install bollards at rollup doors	4 days	Wed 5/1/13	Mon 5/6/13
113	Fine grade for parking lot	3 days	Tue 5/7/13	Thu 5/9/13
114	Place curb and gutter - parking lot	6 days	Fri 5/10/13	Fri 5/17/13
115	Spread and compact GAB	4 days	Mon 5/20/13	Thu 5/23/13
116	Lay AC base course - parking lot	4 days	Fri 5/24/13	Thu 5/30/13
117	Lay AC wearing course - parking lot	3 days	Fri 5/31/13	Tue 6/4/13
118	Stripe parking lot and install signage	5 days	Wed 6/5/13	Tue 6/11/13
119	Install sidewalks at building entrance	3 days	Fri 5/31/13	Tue 6/4/13
120	Landscaping	5 days	Wed 6/5/13	Tue 6/11/13
121	Erect main entrance sign	5 days	Wed 6/5/13	Tue 6/11/13
122	Complete Final Sitework	0 days	Tue 6/11/13	Tue 6/11/13
123	**Project Closeout**	**30 days**	**Wed 8/14/13**	**Wed 9/25/13**
124	Test and balance AC system - Office Area	5 days	Wed 8/14/13	Tue 8/20/13
125	Final cleanup	5 days	Tue 9/3/13	Mon 9/9/13
126	Final inspection	2 days	Tue 9/10/13	Wed 9/11/13
127	Punchlist work	5 days	Thu 9/12/13	Wed 9/18/13
128	Substantial Completion	0 days	Wed 9/18/13	Wed 9/18/13
129	Obtain Certificate of Occupancy	5 days	Thu 9/19/13	Wed 9/25/13
130	Project Completion	0 days	Wed 9/25/13	Wed 9/25/13



Start Date: 1/1/2013
Finish Date: 9/25/2013
Status Date: 1/1/2013

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline			
Split	External Tasks	Inactive Summary	Manual Summary	Critical			
Milestone	External Milestone	Manual Task	Start-only	Critical Split			
Summary	Inactive Task	Duration-only	Finish-only	Progress			

Page 4

Figure 5.5 Vehicle Maintenance overall bar chart – Page 4. Used with permission from Microsoft.

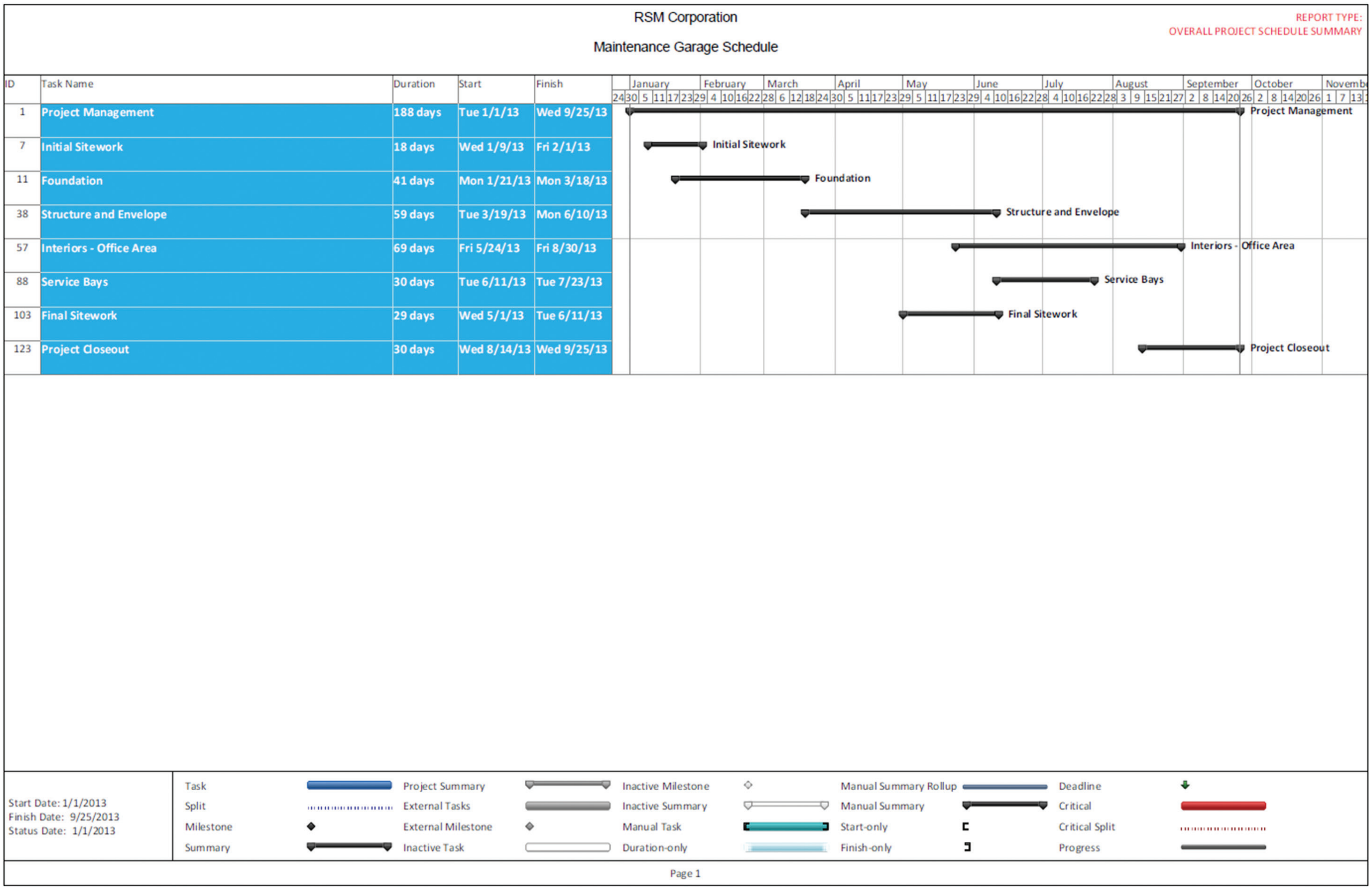
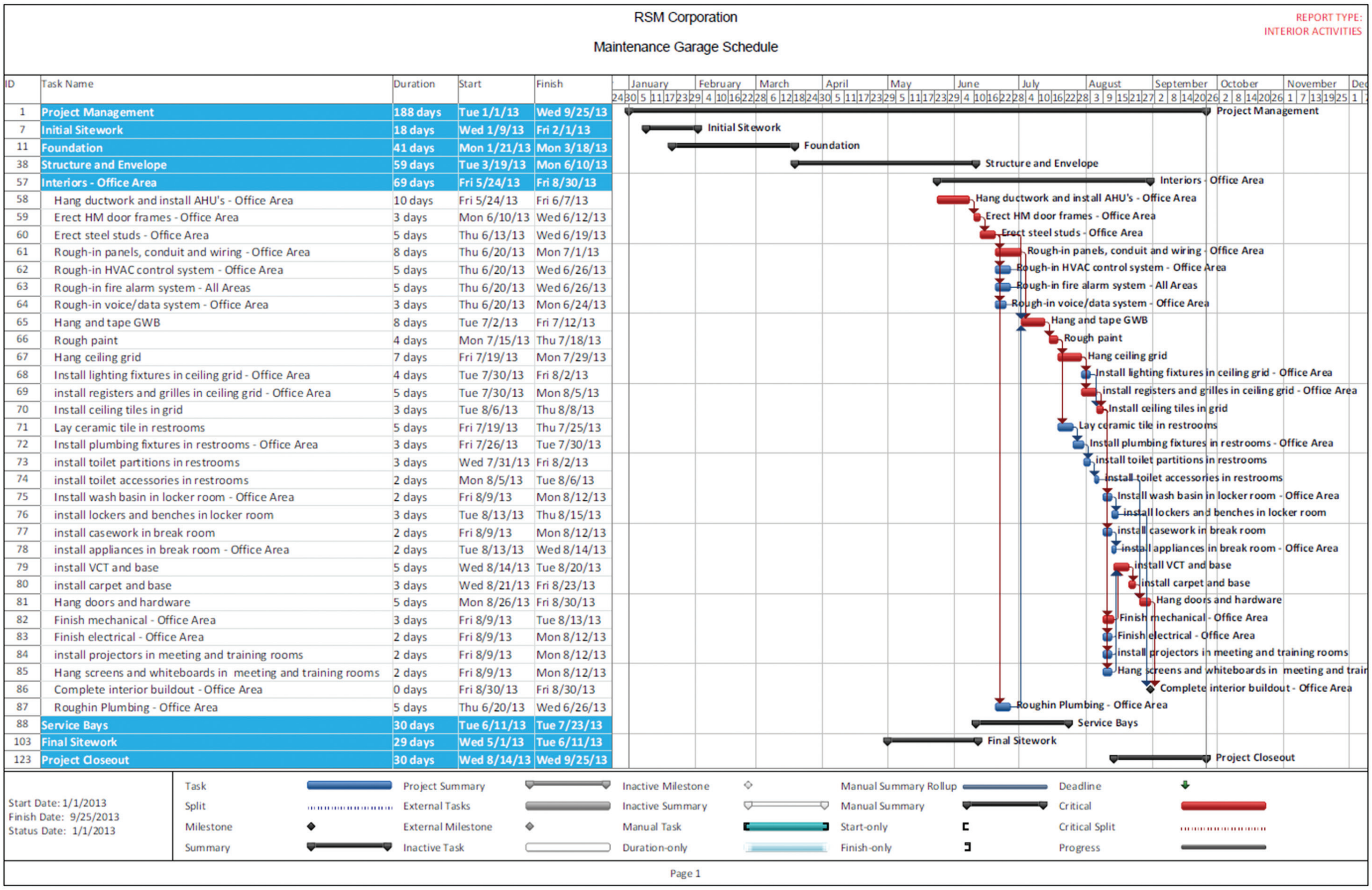


Figure 5.6 Vehicle Maintenance – concrete sub work. Used with permission from Microsoft.



RSM Corporation

Maintenance Garage Schedule

REPORT TYPE: INTERIOR ACTIVITIES

ID	Task Name	Duration	Start	Finish
1	Project Management	188 days	Tue 1/1/13	Wed 9/25/13
7	Initial Sitework	18 days	Wed 1/9/13	Fri 2/1/13
11	Foundation	41 days	Mon 1/21/13	Mon 3/18/13
38	Structure and Envelope	59 days	Tue 3/19/13	Mon 6/10/13
57	Interiors - Office Area	69 days	Fri 5/24/13	Fri 8/30/13
58	Hang ductwork and install AHU's - Office Area	10 days	Fri 5/24/13	Fri 6/7/13
59	Erect HM door frames - Office Area	3 days	Mon 6/10/13	Wed 6/12/13
60	Erect steel studs - Office Area	5 days	Thu 6/13/13	Wed 6/19/13
61	Rough-in panels, conduit and wiring - Office Area	8 days	Thu 6/20/13	Mon 7/1/13
62	Rough-in HVAC control system - Office Area	5 days	Thu 6/20/13	Wed 6/26/13
63	Rough-in fire alarm system - All Areas	5 days	Thu 6/20/13	Wed 6/26/13
64	Rough-in voice/data system - Office Area	3 days	Thu 6/20/13	Mon 6/24/13
65	Hang and tape GWB	8 days	Tue 7/2/13	Fri 7/12/13
66	Rough paint	4 days	Mon 7/15/13	Thu 7/18/13
67	Hang ceiling grid	7 days	Fri 7/19/13	Mon 7/29/13
68	Install lighting fixtures in ceiling grid - Office Area	4 days	Tue 7/30/13	Fri 8/2/13
69	install registers and grilles in ceiling grid - Office Area	5 days	Tue 7/30/13	Mon 8/5/13
70	Install ceiling tiles in grid	3 days	Tue 8/6/13	Thu 8/8/13
71	Lay ceramic tile in restrooms	5 days	Fri 7/19/13	Thu 7/25/13
72	Install plumbing fixtures in restrooms - Office Area	3 days	Fri 7/26/13	Tue 7/30/13
73	install toilet partitions in restrooms	3 days	Wed 7/31/13	Fri 8/2/13
74	install toilet accessories in restrooms	2 days	Mon 8/5/13	Tue 8/6/13
75	Install wash basin in locker room - Office Area	2 days	Fri 8/9/13	Mon 8/12/13
76	install lockers and benches in locker room	3 days	Tue 8/13/13	Thu 8/15/13
77	install casework in break room	2 days	Fri 8/9/13	Mon 8/12/13
78	install appliances in break room - Office Area	2 days	Tue 8/13/13	Wed 8/14/13
79	install VCT and base	5 days	Wed 8/14/13	Tue 8/20/13
80	install carpet and base	3 days	Wed 8/21/13	Fri 8/23/13
81	Hang doors and hardware	5 days	Mon 8/26/13	Fri 8/30/13
82	Finish mechanical - Office Area	3 days	Fri 8/9/13	Tue 8/13/13
83	Finish electrical - Office Area	2 days	Fri 8/9/13	Mon 8/12/13
84	install projectors in meeting and training rooms	2 days	Fri 8/9/13	Mon 8/12/13
85	Hang screens and whiteboards in meeting and training rooms	2 days	Fri 8/9/13	Mon 8/12/13
86	Complete interior buildout - Office Area	0 days	Fri 8/30/13	Fri 8/30/13
87	Roughin Plumbing - Office Area	5 days	Thu 6/20/13	Wed 6/26/13
88	Service Bays	30 days	Tue 6/11/13	Tue 7/23/13
103	Final Sitework	29 days	Wed 5/1/13	Tue 6/11/13
123	Project Closeout	30 days	Wed 8/14/13	Wed 9/25/13

Figure 5.7 Vehicle Maintenance Facility – summary bar chart. Used with permission from Microsoft.

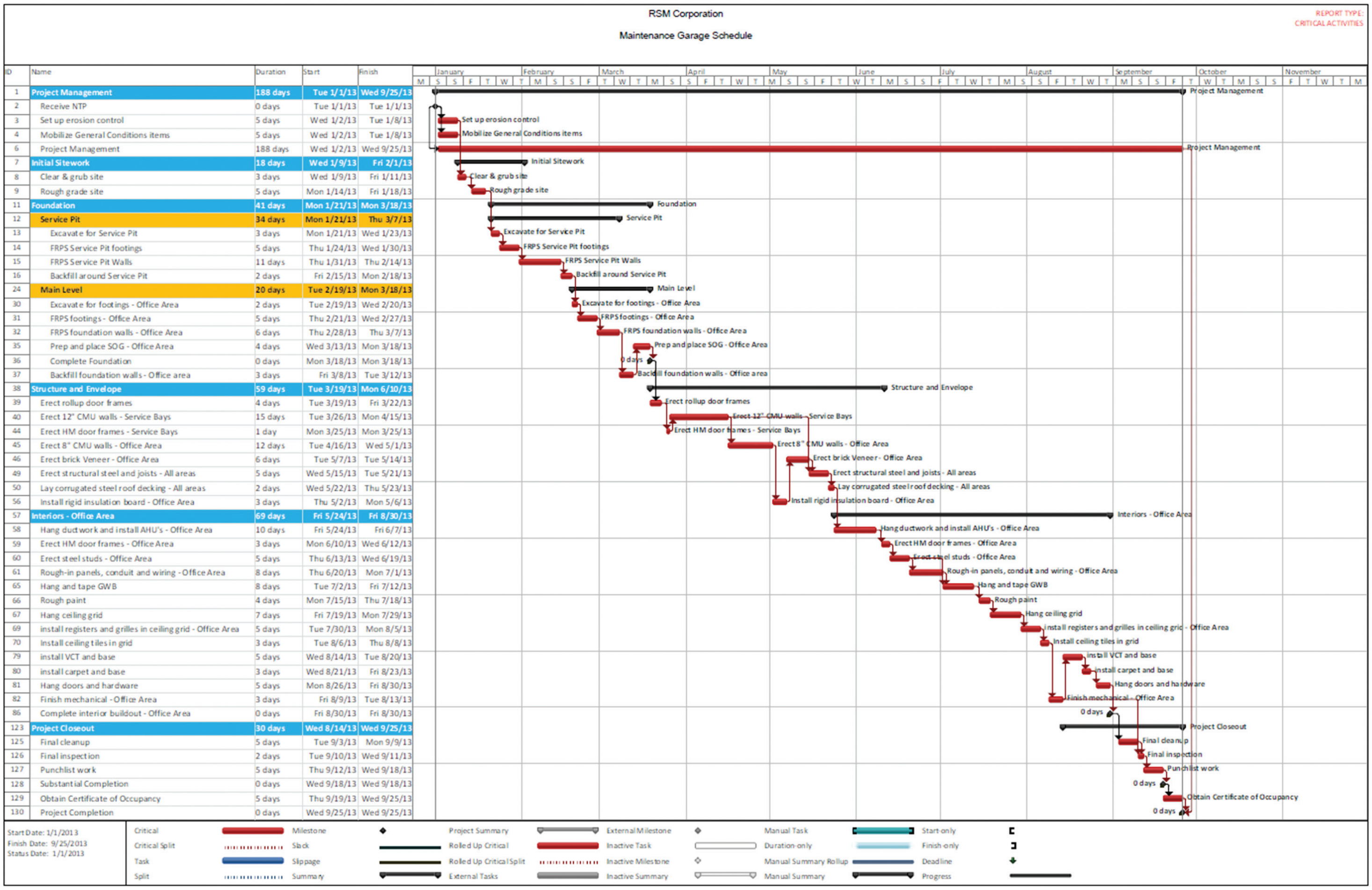
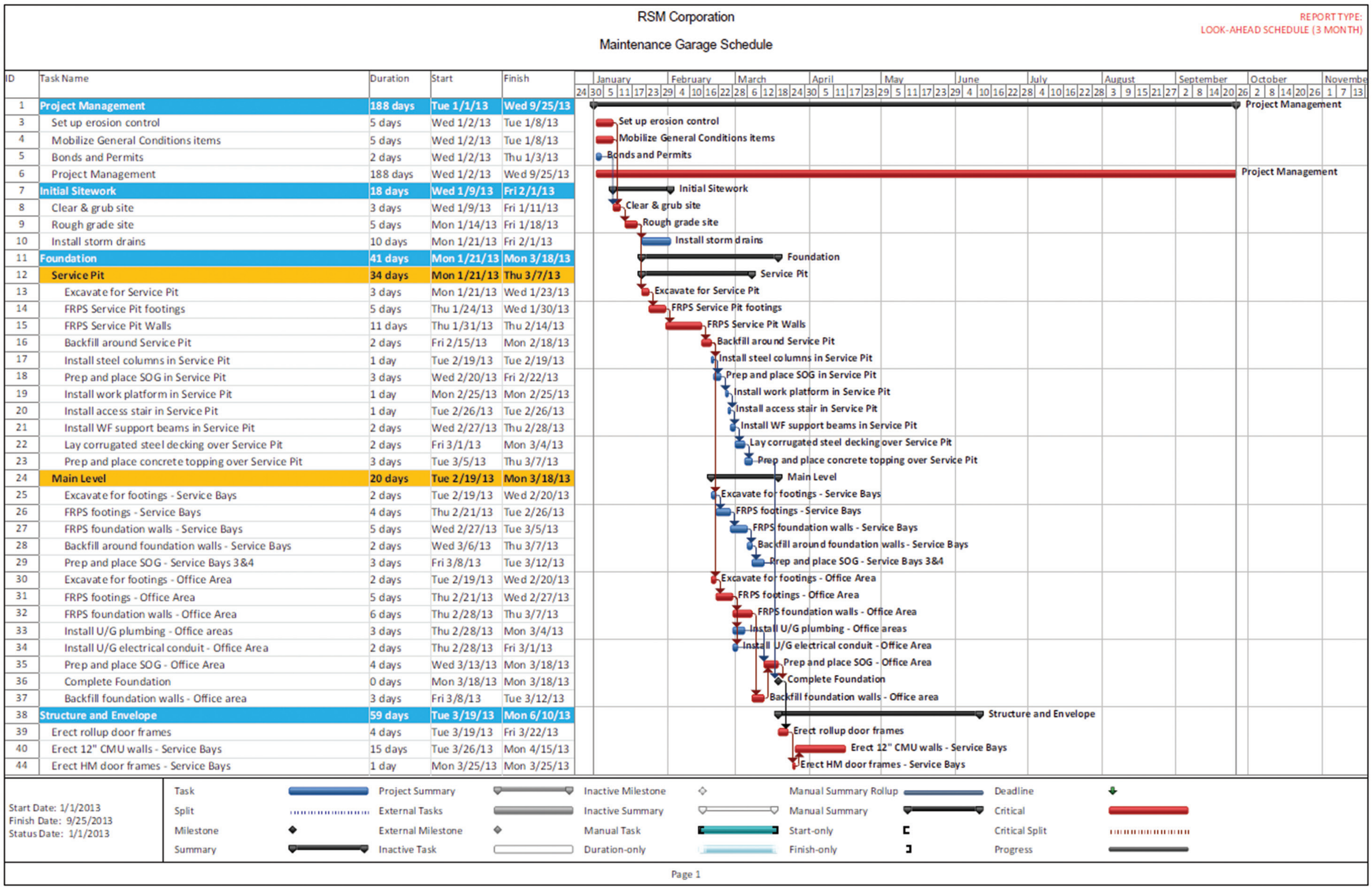


Figure 5.8 Vehicle Maintenance Facility – critical path. Used with permission from Microsoft.



RSM Corporation

Maintenance Garage Schedule

REPORT TYPE:
LOOK-AHEAD SCHEDULE (3 MONTH)

ID	Task Name	Duration	Start	Finish
1	Project Management	188 days	Tue 1/1/13	Wed 9/25/13
3	Set up erosion control	5 days	Wed 1/2/13	Tue 1/8/13
4	Mobilize General Conditions items	5 days	Wed 1/2/13	Tue 1/8/13
5	Bonds and Permits	2 days	Wed 1/2/13	Thu 1/3/13
6	Project Management	188 days	Wed 1/2/13	Wed 9/25/13
7	Initial Sitework	18 days	Wed 1/9/13	Fri 2/1/13
8	Clear & grub site	3 days	Wed 1/9/13	Fri 1/11/13
9	Rough grade site	5 days	Mon 1/14/13	Fri 1/18/13
10	Install storm drains	10 days	Mon 1/21/13	Fri 2/1/13
11	Foundation	41 days	Mon 1/21/13	Mon 3/18/13
12	Service Pit	34 days	Mon 1/21/13	Thu 3/7/13
13	Excavate for Service Pit	3 days	Mon 1/21/13	Wed 1/23/13
14	FRPS Service Pit footings	5 days	Thu 1/24/13	Wed 1/30/13
15	FRPS Service Pit Walls	11 days	Thu 1/31/13	Thu 2/14/13
16	Backfill around Service Pit	2 days	Fri 2/15/13	Mon 2/18/13
17	Install steel columns in Service Pit	1 day	Tue 2/19/13	Tue 2/19/13
18	Prep and place SOG in Service Pit	3 days	Wed 2/20/13	Fri 2/22/13
19	Install work platform in Service Pit	1 day	Mon 2/25/13	Mon 2/25/13
20	Install access stair in Service Pit	1 day	Tue 2/26/13	Tue 2/26/13
21	Install WF support beams in Service Pit	2 days	Wed 2/27/13	Thu 2/28/13
22	Lay corrugated steel decking over Service Pit	2 days	Fri 3/1/13	Mon 3/4/13
23	Prep and place concrete topping over Service Pit	3 days	Tue 3/5/13	Thu 3/7/13
24	Main Level	20 days	Tue 2/19/13	Mon 3/18/13
25	Excavate for footings - Service Bays	2 days	Tue 2/19/13	Wed 2/20/13
26	FRPS footings - Service Bays	4 days	Thu 2/21/13	Tue 2/26/13
27	FRPS foundation walls - Service Bays	5 days	Wed 2/27/13	Tue 3/5/13
28	Backfill around foundation walls - Service Bays	2 days	Wed 3/6/13	Thu 3/7/13
29	Prep and place SOG - Service Bays 3&4	3 days	Fri 3/8/13	Tue 3/12/13
30	Excavate for footings - Office Area	2 days	Tue 2/19/13	Wed 2/20/13
31	FRPS footings - Office Area	5 days	Thu 2/21/13	Wed 2/27/13
32	FRPS foundation walls - Office Area	6 days	Thu 2/28/13	Thu 3/7/13
33	Install U/G plumbing - Office areas	3 days	Thu 2/28/13	Mon 3/4/13
34	Install U/G electrical conduit - Office Area	2 days	Thu 2/28/13	Fri 3/1/13
35	Prep and place SOG - Office Area	4 days	Wed 3/13/13	Mon 3/18/13
36	Complete Foundation	0 days	Mon 3/18/13	Mon 3/18/13
37	Backfill foundation walls - Office area	3 days	Fri 3/8/13	Tue 3/12/13
38	Structure and Envelope	59 days	Tue 3/19/13	Mon 6/10/13
39	Erect rollup door frames	4 days	Tue 3/19/13	Fri 3/22/13
40	Erect 12" CMU walls - Service Bays	15 days	Tue 3/26/13	Mon 4/15/13
44	Erect HM door frames - Service Bays	1 day	Mon 3/25/13	Mon 3/25/13

Start Date: 1/1/2013
Finish Date: 9/25/2013
Status Date: 1/1/2013

Figure 5.9 **Vehicle Maintenance Facility – three-month look ahead. Used with permission from Microsoft.**

REVIEW QUESTIONS

1. The following questions can be answered by (1) examining the software you use in class, (2) by interviewing a scheduling software salesman, or (3) by collecting sales information from the Internet or other written material.
   a. What is the limit on the number of activities that the software can handle?
   b. Can you activity codes to identify phases, areas, and the like?
   c. Can you use summary activities?
   d. Can you create a WBS in the software?
   e. Can you create bar charts that use time windows? (for example, a three-week look-ahead or a 90 day look-ahead)
   f. Can you create a cost-loaded schedule?
   g. Can you import and export data from Excel or another spreadsheet?
2. Visit a job site or contractor's office, and interview someone who is responsible for running a construction schedule. In particular, ask that person the following:
   a. How do they group activities into phases?
   b. What is their naming convention for activities?
   c. What other codes do they use? (e.g., subcontractors, type of work, etc.)
   d. Does the owner require any special scheduling features?
   e. How do they make sure their schedules are readable?
   f. Are they required to make a narrative report with each update?
   g. Ask your interviewee if they can show you a typical set of update reports. Compare what they have to the features listed in this chapter.

6 MONITORING AND CONTROLLING THE PROJECT

6 Monitoring and Controlling the Project

THE MONITORING PROCESS

While a good initial plan is essential, it is not enough to ensure a successful project. During the course of construction, uncontrollable events are bound to alter the original plan. The project manager must have a means of monitoring the effects of these outside factors. Once the deviations have been detected and measured, the project team must be mobilized to bring the project back on schedule. The monitoring process consists of the following steps.

1. **Monitoring progress.** This step is frequently called *progress measurement, or updating the schedule*. It is primarily a process of collecting detailed data on the work, then processing it in a computer or manual system to arrive at an accurate representation of the current job status. Monitoring progress corresponds with Steps 3 and 4 of the Project Control Cycle (see Chapter 1 for a definition and illustration of the Project Control Cycle).
2. **Comparing progress to goals.** The actual progress on the job is compared to the progress planned in the original schedule. This is Step 5 of the Project Control Cycle and consists of displaying the data collected in the updating step. The project team uses this information to make decisions regarding future actions.
3. **Taking corrective action.** In this final stage, the project manager corrects any schedule problems based on all of the available information. Personnel and equipment are mobilized to carry out a new plan for finishing the job.

The Key Element of Communication

First of all, the controlling function depends on good communication at the construction site. A project manager who thoroughly monitors and compares, and then decides on a course of action to correct deficiencies, but does this without the participation of the subcontractors, superintendents, and other members of the project team, may find that his or her measures are doomed to failure. First, it is almost impossible to determine the status of the project without talking to the people who are actually carrying out the work. As good as they are, CPM systems have real limitations, and they will not provide all of the details needed to get an accurate picture of where the job stands. CPM may provide a warning system indicating where a problem is occurring, but it does not diagnose the problem. Second, the project manager depends on the project team (subcontractors, superintendents, and others) to carry out whatever corrective action is needed. Members of the project team may not be highly motivated to solve problems unless they are involved in the decision-making process. In any case, if the team members are not competent to participate in the problem solving process, they probably should not be on the team in the first place.

Controlling is like the planning and scheduling processes that precede it in that the first vital step is to bring all pertinent parties into the process. Effective communication requires the following:

1. **Consulting personnel** during the monitoring process, since they are the best source of data regarding the individual parts of the job. This chapter covers the specific procedures for updating the schedule, but it must be recognized that the basic source of input is the project team.
2. **Displaying the information obtained in the clearest possible way.** This means using simple, straightforward, graphic displays that are understandable to everyone. As a general rule, the best means of communication are time-scaled bar charts developed from the CPM schedule. It is best to provide only the information that is pertinent to the tasks or activities being dealt with at that moment, thereby avoiding information overload. Fortunately, most of today's computer systems have the capacity to selectively organize and display information.
3. **Communicating regularly** with all parties in order to determine what corrective actions need to be taken. A project manager should hold regularly scheduled meetings that include all of the parties working on a job at that time. The following elements should be included in such meetings.

   - Attendance at the meeting should be required (preferably by contract) for all subcontractors and superintendents whose work is either under way or due to begin in the near future.
   - Every attendee should be given a photocopy of the schedule, showing progress during the last reporting period and what is anticipated for the next two reporting periods. For example, if the meetings were held weekly, the schedule would show a three-week time span. Provisions would also be made to project the schedule on an overhead or schedule board of some kind so that all parties can see the changes as they are made.
   - The meeting must be conducted in such a way that all parties can comment on what has happened thus far and what is being planned. By encouraging this kind of participation, an atmosphere is created that fosters public commitment to schedule performance. These kinds of commitments tend to be honored more faithfully than private ones, since reputation among one's peers can be a strong motivator. It is not necessarily critical to reach an absolute consensus on every decision, but it is important not to dictate to subs or superintendents without consultation.

- The decisions that result from the meeting should immediately be published and distributed to all parties.
- Finally, the meetings must be held without fail on a regular basis and the decisions followed up on by the project manager.

MONITORING PROGRESS

The goal of updating is to determine the present status of the job. In the simplest terms, is the job behind, on time, or ahead of schedule? It is also necessary to know which specific aspects of the job are behind. Thus, details of individual activities are also important. In order to perform updates, it is necessary to establish the start and finish times of activities, and if possible, their production rates.

In addition to recognizing currently active parts of the job, it is important to know how the present work status affects future work. This factor is known as the *downstream impact*. For example, it is possible to be approximately on schedule at a given time, but—if the correct details are not observed—to end up behind later on in the job without realizing that the schedule is not going to be met. The capacity to measure such downstream effect is one of the most important aspects of the CPM technique and serves as a very useful tool in planning recovery when behind schedule. It is also necessary to record the progress of the job for legal purposes. Good schedule records serve as the basis for claims and as a defense against them.

Steps in Updating

To determine the present status of the job, a two-step process is necessary and must be taken in order. Bypassing one to get to the other leads to inaccuracy at best and can be dangerous at worst. The two steps are:

1. Measure the progress of each activity individually. The updating need not occur in the order that the activities occur, especially since updating is often done sometime after the actual work is performed. It is important to update all activities before attempting to update the job as a whole.
2. Measure the impact of the activity progress on the job as a whole. This is done by using the information derived from the individual activities to recalculate the forward pass and backward pass and then determining a new overall job duration.

How Often to Update?

How often should the monitoring process be carried out? In the industry, it is not performed frequently enough, as a general practice. The value of a construction management system is in direct proportion to the timeliness of the information it provides. If the controlling process is not carried out often enough, or on a regular basis, the benefits are likely to be lost.

To be more specific, once a month should probably be the maximum period between updates and schedule meetings. Many construction jobs can be run with meetings held at monthly intervals, but in most cases, weekly meetings and updates are advisable. In fact, if the situation warrants, daily schedule updates may be necessary. An example of such a situation is when the potential for lost revenue from a facility being built is extremely high relative to the value of the construction on the facility. In any case, the benefits of updating by carrying out the control cycle must be measured against the costs. The benefits are difficult to measure precisely, but considering the costs of schedule delays, it is usually better to err on the side of too many schedule updates rather than too few.

Updating the Individual Activities

The status of individual activities can fall into several different categories, depending on how much progress has been made at the time the update occurs. Progress is reported on the basis of the concepts illustrated in Figure 6.1.

Each reporting cycle covers a predetermined time period; the status of each activity is reported from the perspective of a "time now" date, usually called a *data date*. As can be seen in Figure 6.1, the data date represents the end of the chosen reporting period. (In this case, a monthly reporting period is used.) The status of individual activities relative to the data date, or "time now" point, falls into one of the following cases or a variation thereof.

Case 1 in Figure 6.1 is an activity that was started and completed prior to the data date. In this circumstance, the activity simply has an actual start (AS) and an actual finish (AF) reported.

Case 2 is more complex. The activity was started prior to the data date but has not yet finished. The start is reported as an actual start (AS). The problem is determining present status and subsequent expected finish (ExF). It is important to be as accurate as possible so that the expected finish has the proper effect on the downstream impact calculations. The three methods for determining present status and expected finish are listed here:

1. **Percent complete (PC):** This method involves determining how much of the total work is complete, calculating a rate of progress per day, and then extending this value to determine an expected finish. To establish a percent complete, a project team member must calculate—in the field—the percentage of work that

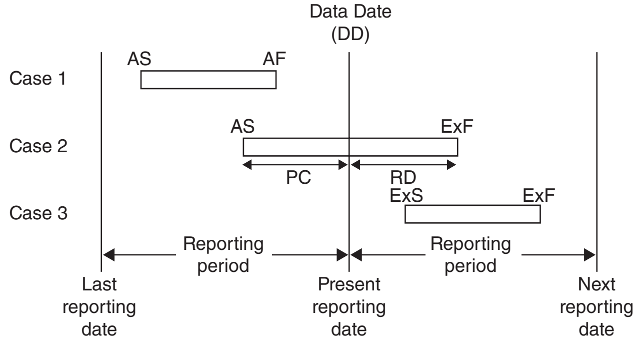


Figure 6.1 Basic reporting concepts

has been accomplished as of the data date. The actual finish date is subtracted from the data date in order to determine the number of days worked. The percent complete is then divided by the number of days in order to arrive at a rate of progress per day. The remainder of the work can be divided by the rate per day to determine how many work days remain for this activity. This number is then added to the data date to determine the expected finish. This procedure is illustrated in the following formulas.

% per Day = % Done/Days Worked, or

% per Day = % Done/DD (Data Date) – AS (Actual Start), then

DD + (% Remaining/% per Day) = ExF (Expected Finish)

Using a computerized scheduling system, the percent complete number is simply input and the calculations carried out automatically.

2. **Remaining duration (RD):** Using this procedure, the number of remaining work days is estimated, and this value is added to the data date in order to determine the expected finish. The following formula is used:

DD + RD = ExF

The estimate of the remaining duration can be anything from an educated guess to a carefully calculated value based on field data.

3. **Expected finish (ExF):** For this procedure, the expected completion date is entered as a value. It is an appropriate method where the project manager has good reason to believe an activity will finish at a specific time and wishes to display that fact in the update reports.

Problems with the Various Updating Methods

All three of these methods have limitations and, therefore, should be used judiciously to ensure an accurate update. The problem with the use of actual starts and finishes is that this information is usually gathered long after the fact. Ideally, all job activity should be recorded on a daily job log. Unfortunately, entries are sometimes sporadic or incomplete. The person who reviews the reports at the end of the month often has to read between the lines to get a picture of the actual work done. Inadequate record keeping is a problem that also affects the percent complete method, since the actual starts may be missing as well.

The percent complete method tends to fall short primarily because detailed, accurate determinations are very seldom made for the actual work done. Usually, the percent complete is simply estimated, typically in 10% increments. As a result, the calculated expected finish may be even more inaccurate. Even when fairly accurate calculations are made, the production rate is often variable or may be affected by stops and starts.

Finally, the expected finish method is often inaccurate because it depends on the prediction of a future event. This is especially difficult where both an expected start and expected finish are involved. Also, the further the expected event is into the future, the more likely it is to be inaccurate.

So, the practical question remains—how to get the best possible information on the individual activities. The good judgment of the scheduler helps, but procedures can also be set up that will contribute to more accurate input and updates.

How and Where to Find Information about Activity Progress

The previous section covered how to calculate progress on individual activities, and how to predict completion dates on activities using such pieces of information as Percent Complete, Remaining Duration, and the like. When entered into a scheduling software program, the values will provide a reasonably accurate calculation of the status of a project. However, scheduling software systems is like any other program; the rule of "garbage in, garbage out" applies. If the percent complete value and other information about individual activity status are not accurate, then the information provided by the updated schedule will not be accurate either. With this in mind, the following section describes some of the methods that can be used to gather accurate information.

Measure Actual Work Done

The best of all possible methods is to physically count or calculate work done, then translate that count to a percent complete or remaining duration value. Calculating actual work accomplished is generally easier said than done, however. Construction is not like manufacturing, where the number of units coming off an assembly line can be easily and accurately determined.

In some cases, the task is relatively simple. Consider for example, the case of calculating the work done in a single concrete activity "Place Footing Concrete." The scheduler can simply observe which footings are complete, calculate the cubic yardage in each footing, add the totals, and then calculate the percentage of the whole task of placing concrete in footings. This kind of calculation is probably fairly accurate. The same kind of thing can be done with other kinds of work where it is relatively easy to see where one unit of the building has been completed, and others have not.

Other kinds of activities are much more difficult. Consider the difficulty in calculating how much work has been done in an activity called "Form Footings." The problem in measuring formwork effort is that often a great deal of work is done before any footings are actually erected or placed. Fabrication of the formwork takes place long before any actual panels are erected, and this effort would go unmeasured if the scheduler relied on simple observation of work in place.

Other examples might include installation of piping, erection of stud walls, and other highly detailed tasks that take place in a variety of places which makes physical observation and measurement difficult. In these cases, a scheduler is often forced to rely on a superintendent's judgment call, which may or may not be accurate, depending on the degree of the superintendent's optimism or pessimism.

Daily Job Logs

Quite often, superintendents are required by company policy to keep a log of their daily activities and of the work done on a job. These records are often dictated by legal considerations, but they can also be useful tools for the scheduler trying to figure out where a specific activity stands in its progress. The quality of these records can be a mixed bag. Some superintendents keep quite detailed records, in which they note precisely where work took place, how many laborers were working, and what delays were experienced. Others provide a lot less. Where one superintendent will note, "placed footing concrete—column line A," another may record no more than, "placed footing concrete," worse yet, "placed concrete." Given this tendency, information obtained from these logs must often be supplemented with that obtained from direct interviews.

Interviewing Field Personnel

Quite often, a scheduler is reduced to simply asking a superintendent or project manager what work was performed or completed in the last reporting period. While this can be reliable, more often than not, it is not. Problems include the usual limits and inaccuracies of human memory, the reluctance of an action-oriented field person to sit still for detailed questioning, and the constant telephone interruptions that invariably occur during such meetings. Still, there are times when interviews are the only way to gather data. In such cases, it is better to update more often so that memories are fresher and presumably more accurate.

Job Records

Many types of job records can be useful for gathering information on job progress. Typical examples include time cards, purchase orders, and other accounting records, or in many cases, test results and other records of work action. Better still, however, are the minutes of job meetings that most architects, superintendents, and project managers use to memorialize the discussions and other aspects of job site meetings. These meetings often occur weekly and begin with a review of progress for the most recent period. If recorded in sufficient detail, the minutes can provide a highly accurate and useful source of data.

Other Areas to Check

In addition to the actual field activities, there are other influences that affect the schedule. These, too, must be checked. The following are examples:

1. **Changes in contractual dates.** Any change in contract dates, such as an extension of time, must be entered. These dates are typically recorded as constraints or "plugged dates."
2. **Changes in work sequences by field personnel.** It is not uncommon for field superintendents to perform work out of sequence without informing the project manager or scheduler of the changes. Work done out of sequence may not affect the schedule, but if the changes are major, they should be reflected in the update in the form of logic changes. This is particularly true if more work of the same type remains to be done.

3. **Changes in material delivery dates.** This is an area that can have a tremendous impact on projects, yet this information can be difficult to track. Ideally, a company should have some sort of a system for recording these changes. Unfortunately, this is often not the case. Gathering all the information about materials usually means consulting a variety of sources, such as telephone logs or submittal data logs, or interviewing purchasing agents or other individuals who are responsible for buying. At the very least, there should be a log of purchase orders and a correspondence file for each vendor on the job site. These files should contain all of the most recent information.

Measuring Progress on the Entire Job

Once the progress of all the individual activities has been determined, the progress of the entire job can be assessed. This task is relatively simple in concept, but can unfortunately be fairly cumbersome in practice.

To determine the progress of the job as a whole, information from the updating of individual activities is used, and a new set of dates and times is calculated. This is done using the same calculation techniques shown in Chapter 4. The process of carrying out the forward and backward passes is no different at this point than it was for the original schedule, except that the actual and expected dates become fixed in both passes.

Because updating the entire job can be a cumbersome task, use of a computer CPM system offers a great advantage. A computer system is not foolproof, however, and care must be taken to avoid input errors. Also, it may be necessary to do several computer runs to ensure that the information is accurate before proceeding to the next step.

Comparing Progress to Goals

After the status of each activity has been established and the impact on the entire project has been determined by performing a new forward and backward pass, the project manager can then determine whether or not corrective action is necessary. To do this, it is necessary for the project manager to compare the progress on the schedule to date to the planned schedule and determine if a significant variation exists, for example, if the project is behind schedule.

Setting the Baseline Schedule

The first step in this process is the establishment of a standard against which progress can be measured. This standard is known as a **baseline schedule**, or in some cases, a **target schedule**. It reflects the original plan of attack for completing the job and serves as the reference point for determining whether or not the plan is being executed adequately.

Establishing the baseline schedule is a relatively simple task. The project manager does, however, have certain options in drawing it up, and making the correct choices is important to the long-term success of the project. The following paragraphs describe some of the approaches that the project manager can use to ensure the overall effectiveness of the scheduling process.

- The initial schedule contains both early and late times. It is generally best to set the baseline schedule based on early rather than late times, since this approach fosters an “earliest possible” perspective, and it does not allow putting off an activity until the latest possible start time. The idea is to promote an attitude that encourages getting on and off the job with each item of work as rapidly as possible.
- Some activities will be critical, while others will have float and can, therefore, be started at various times. It is best not to display or consider the float as part of the baseline schedule, since this approach defeats the sense of urgency created by the use of early start dates in the baseline schedule.
- It is important to note that there are sometimes legitimate reasons for changing the baseline schedule times. For example, the weather or delayed delivery of owner-furnished materials may both be grounds for an extension of time for the project. If an extension is necessary, a new baseline schedule should be worked out and used. This new schedule must be clearly communicated to project personnel and the reasons for the change explained thoroughly.
- The project manager may also decide to delay the start of certain activities in order to use manpower or equipment more efficiently. The baseline schedule should be changed to reflect this kind of modification. Once again, the change and the reasons behind it should be clearly explained to project personnel.

Setting baseline schedules can be accomplished easily with most up-to-date computer CPM systems. The initial schedule or any updated versions can be designated as the baseline schedule. This plan can be stored and remain unaltered until the decision is made to change it. CPM systems are programmed to allow display of the baseline and the current schedule alongside one another, thereby making the comparison process much simpler.

Displaying the Results

Normally, the comparison between baseline and actual progress is done using a bar chart or other display that places the planned activity beside the actual outcome so that any differences are readily apparent. Typical of these kinds of reports are baseline bar charts or variance reports, some examples of which are shown in the sample update at the end of this chapter.

Preventing Information Overload

It is important to direct the project’s decision makers to the major issues of a job at the time that these events are occurring. One of the computer’s assets—the ability to store vast amounts of data—can actually present problems in that having this much information can make it difficult to zero in on the most critical issues. It, therefore, becomes important to abstract or sort out information for display, to highlight that which is pertinent and ignore—for the moment—all other data.

To highlight the most pressing issues, the computer can be directed to display only *exception information*. Exception information pertains to situations that are not going according to plan. As long as there are only a few activities, it is not difficult for the manager to pick out the ones that are behind schedule. However, if there are 100 activities, then it is very important to have a method for singling out the late ones and flagging them for attention. The display created for the regularly scheduled meetings should clearly identify and separate the activities that need attention.

When displaying the schedule, only those parts that are currently being worked on should be shown. It serves no purpose, for example, to display schedule information pertaining to work completed three months ago or work that will be performed four months in the future.

Finally, the experienced judgment of the scheduler or project manager plays a key role in deciding what information to display. It is important to remember that the schedule is only a tool, used to gather and display information that is needed to build the job. Rigid rules about how to run or display the schedule are inappropriate and certainly unnecessary given the flexibility that modern CPM systems offer. It is often helpful to people in the field to see information in a familiar format. The schedule system should be used to accommodate personnel in this way and not to force them into predetermined, unfamiliar procedures.

What to Look for in Project Reports

In reviewing update information, it is important to look beyond the job status as simply ahead or behind schedule. Other areas to be examined are:

1. What caused the job or parts of the job to fall behind schedule?
2. What events that have occurred thus far are likely to continue downstream as the job proceeds?

Answering the first question is important because knowing causes is essential to finding effective corrective actions. The answer to the second question is also key to the prevention of further delays. These questions are among the most typical. However, to get a complete picture of the job situation, the project manager and scheduler should look beyond the overall schedule results to other general points, including the following items:

Status of critical activities: By definition, the critical path is the list of activities that must be started and completed on time in order for the job to be finished on time. This group of activities should immediately be examined to determine their status, since failure to keep them on schedule will delay the project as a whole.

Noncritical activities that are late in starting: The problem with activities that start late is that they are more likely to finish late. This is true for reasons other than the obvious. The problem is that late-starting activities also tend to progress more slowly than they should. It is quite common to see activities that start before the late start date, which is acceptable, but then end up finishing beyond the late finish date. This puts them on the critical path. It is best to prevent this occurrence by detecting the problem at the start.

Activities with low production rates: A related problem is activities that start on time but are proceeding more slowly than planned. Early on, their progress may seem fine, but their duration may be extended, undetected, until an overly late finish.

Delays in resource delivery: This element is one of the most difficult to deal with in construction. As any experienced construction manager knows, material suppliers frequently move delivery dates back. Much effort is spent trying to compensate for the delays. Fortunately, most delivery delays are grounds for extensions of contract time. Nevertheless, the fact of the delay must be recorded and its effects shown in the schedule. Most schedules use constrained dates to reflect material deliveries or use a separate chain of activities for each major item. It is, therefore, good practice to check every constrained date or major material item on the project at the time of each update and control cycle.

Activities with more downstream: Any activity that either starts late or shows a low rate of progress must be carefully watched. This is particularly true if there are more activities of the same type occurring later in the project. It may then be necessary to change the durations of the similar activities downstream, so that the schedule is realistic.

Changes in outside factors: Quite often, a scheduler concentrates on the field work, while ignoring the outside factors that also influence the schedule. For example, if a time extension has been granted, and the finish-no-later-than date for the project is not changed, then the calculated floats will be inaccurate. If the date has been moved back, the floats will be too large, and the field will be working with less flexibility than they actually have.

How to Find Out Why the Job Is Behind

Usually a scheduling system informs the project manager only about the parts of a job that are behind. It does not provide the reasons why. To truly know the condition of the job, the project manager must get out of the office and trailer and deal with the people in the field. While the schedule information points the way to where the problems lie, there is no substitute for face-to-face interviews with those responsible for the actual work.

The project manager must carry out the information-gathering interviews in a non-threatening manner. A superintendent or other supervisor who perceives that a project manager is out to "hang the guilty party" is more likely to provide self-serving information. As a result, the true causes of the job site problems may go unnoticed, and the job continues in trouble. A far better approach is to encourage open communication and to involve the field supervisors in solving the problem. Most construction superintendents and foremen are quite proud of their achievements and want to do everything possible to maintain their reputations. This includes working toward an effective solution when problems arise.

TAKING CORRECTIVE ACTION

The feedback loop is not complete until corrective action has been taken to bring the project back in line with the original plan. There are several points worth considering in this last part of the process.

The Necessity for Follow-Up

Follow-up frequently does not occur. It is all too common for a construction company or project manager to set up a good general plan for completing a job, then fail to properly monitor and control it. Effective follow-up requires a methodical and organized approach. Otherwise, it is all too easy to bypass problems in the rush of daily concerns. Follow-up can be challenging in that it requires regular meetings, and many people in construction tend to regard meetings as an unproductive waste of time.

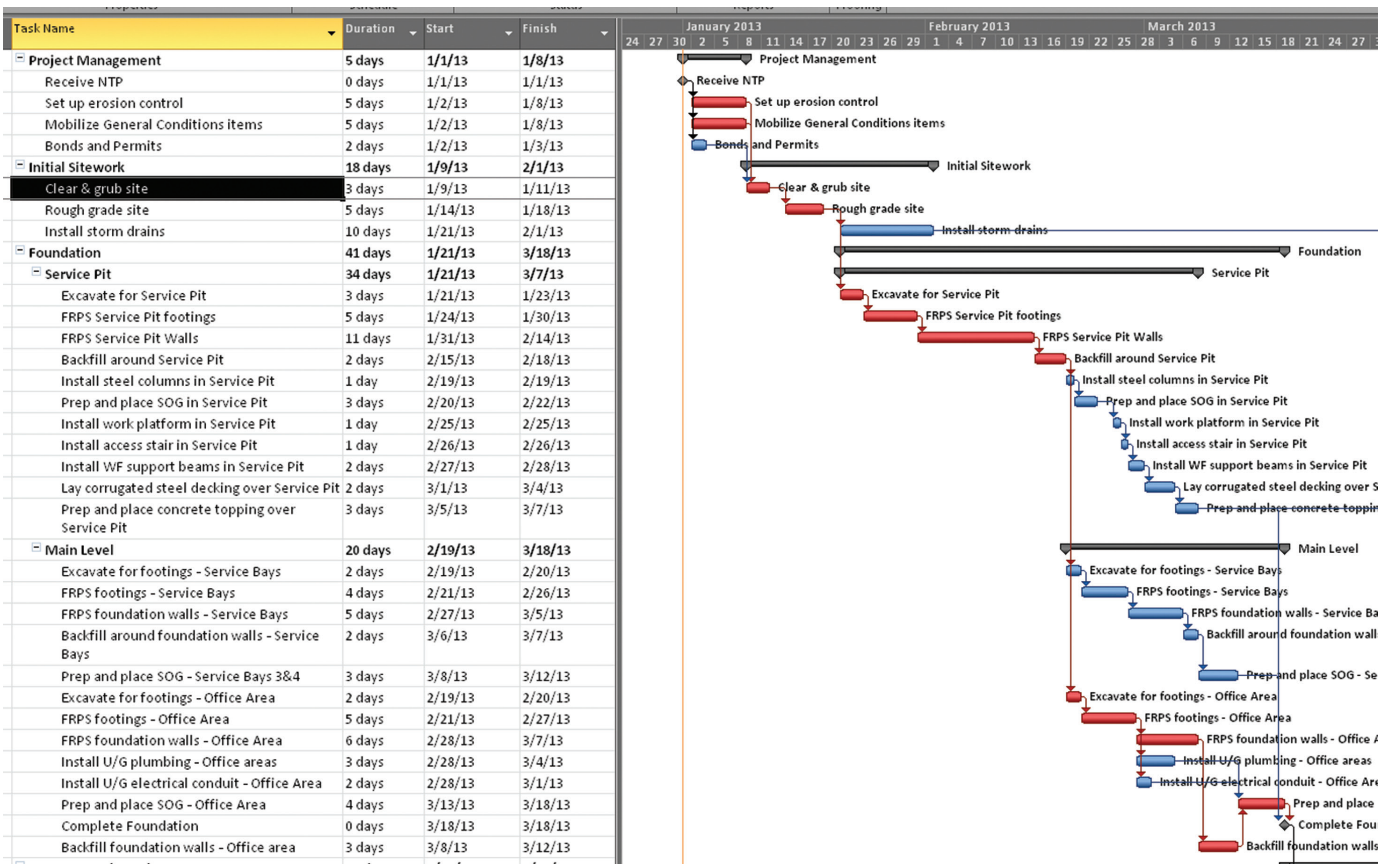
A positive attitude ("we will run this job, it is not going to run us") is also important. Too often, managers say that events inevitably come along which make a schedule useless, when what they should be saying is that a way will be found to meet the schedule, regardless of circumstances. This constructive approach is particularly important since those who choose to simply react to events almost guarantee failure on a construction job.

Types of Corrective Actions

It is impossible to cover all of the possible actions that a project manager can take to bring a schedule back in line. Nevertheless, there are some basic, sound measures that can be grouped into general categories, as follows.

Apply more resources: The classic first response to schedule delay involves getting more people on the job, going to overtime, or mobilizing more equipment. Any of these responses may be appropriate under certain circumstances, but each must be considered carefully. For example, there is almost always an additional cost associated with speeding up work. The problem is that it is difficult to determine whether or not the costs of speeding up are less than the cost of a schedule overrun. It is clear that additional resources should be applied only to those activities that are on the critical path. Speeding up activities with float simply buys more float, which is of no value in completing the job earlier. Applying more resources can be a difficult decision. However, there are techniques available to assist the project manager in making these choices. These techniques are covered in Chapter 7.

Reexamine the job logic: In addition to applying more resources, the project manager also has the option of revising the sequence of activities on the job. For example, if the original job logic was done conservatively and used mainly finish-to-start lags, it is usually possible to go through the logic diagram and overlap activities more than was originally called for. Usually this is a better solution than applying additional resources. It does, however, call for closer control as the job progresses. It is, of course, possible to completely revise the sequence of operations to reflect an entirely new approach. This more drastic method would probably not be justified except in cases of extreme delay and penalties.



Task Name	Duration	Start	Finish
Project Management	5 days	1/1/13	1/8/13
Receive NTP	0 days	1/1/13	1/1/13
Set up erosion control	5 days	1/2/13	1/8/13
Mobilize General Conditions items	5 days	1/2/13	1/8/13
Bonds and Permits	2 days	1/2/13	1/3/13
Initial Sitework	18 days	1/9/13	2/1/13
Clear & grub site	3 days	1/9/13	1/11/13
Rough grade site	5 days	1/14/13	1/18/13
Install storm drains	10 days	1/21/13	2/1/13
Foundation	41 days	1/21/13	3/18/13
Service Pit	34 days	1/21/13	3/7/13
Excavate for Service Pit	3 days	1/21/13	1/23/13
FRPS Service Pit footings	5 days	1/24/13	1/30/13
FRPS Service Pit Walls	11 days	1/31/13	2/14/13
Backfill around Service Pit	2 days	2/15/13	2/18/13
Install steel columns in Service Pit	1 day	2/19/13	2/19/13
Prep and place SOG in Service Pit	3 days	2/20/13	2/22/13
Install work platform in Service Pit	1 day	2/25/13	2/25/13
Install access stair in Service Pit	1 day	2/26/13	2/26/13
Install WF support beams in Service Pit	2 days	2/27/13	2/28/13
Lay corrugated steel decking over Service Pit	2 days	3/1/13	3/4/13
Prep and place concrete topping over Service Pit	3 days	3/5/13	3/7/13
Main Level	20 days	2/19/13	3/18/13
Excavate for footings - Service Bays	2 days	2/19/13	2/20/13
FRPS footings - Service Bays	4 days	2/21/13	2/26/13
FRPS foundation walls - Service Bays	5 days	2/27/13	3/5/13
Backfill around foundation walls - Service Bays	2 days	3/6/13	3/7/13
Prep and place SOG - Service Bays 3&4	3 days	3/8/13	3/12/13
Excavate for footings - Office Area	2 days	2/19/13	2/20/13
FRPS footings - Office Area	5 days	2/21/13	2/27/13
FRPS foundation walls - Office Area	6 days	2/28/13	3/7/13
Install U/G plumbing - Office areas	3 days	2/28/13	3/4/13
Install U/G electrical conduit - Office Area	2 days	2/28/13	3/1/13
Prep and place SOG - Office Area	4 days	3/13/13	3/18/13
Complete Foundation	0 days	3/18/13	3/18/13
Backfill foundation walls - Office area	3 days	3/8/13	3/12/13

Figure 6.2 Bar chart showing status of work before applying progress information. Used with Permission from Microsoft.

UPDATE PROBLEM EXAMPLE

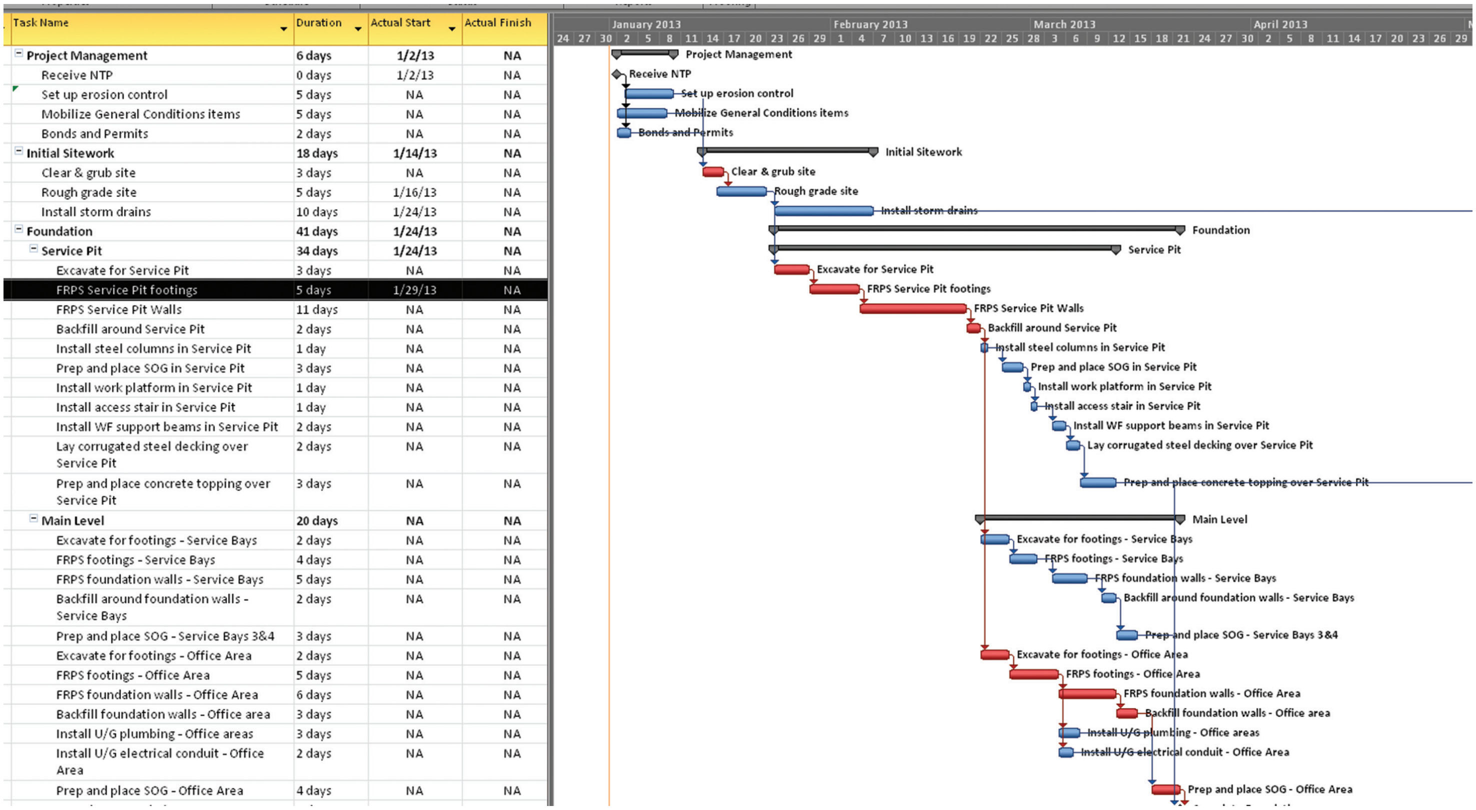
The following example illustrates the principles described in this chapter.

In this case, the project is assumed to have started on time (January 2), and the update is being performed at the end of the first month of work. Figure 6.2 shows the work that would probably occur in the first few months of the job. Note that the work scheduled for the first month includes the following activities: *Receive NTP*, *Bonds and Permits*, *Set Up Erosion Control*, *Mobilize General Conditions Items*, *Clear and Grub Site*, *Rough Grade Site*, *Install Storm Drains*, *FRPS Service Pit Footings*, and *FRPS Service Pit Walls*.

Typical information from the field might have yielded the following information on activity progress:

> **Receive NTP:** Received letter earlier authorizing start of construction on January 2.
>
> **Bonds and Insurance:** Certificates delivered to owner on time.
>
> **Set Up Erosion Control:** Sub was on site January 2, and completed work on the 9th.
>
> **Mobilize General Conditions Items:** Fence, trailer, portable toilets, signs, and so on, installed on time.
>
> **Clear and Grub Site:** Started on January 7, completed January 16. Contractor was early getting dozer to site, but work was held up by rain during last part of the week of the 7th.
>
> **Rough Grade Site:** Work started on January 16, immediately after completion of Clear and Grub. Finished on January 23. Work was slowed somewhat by wet conditions.
>
> **Install Storm Drains:** started late on the 24th, due to delays in Grading Site. Work progress as of Data Date was 50%.
>
> **Excavate for Service Pit:** Started on the 24th, immediately after Rough Grade Site. Finished on January 28.
>
> **FRPS Service Pit Footings:** Started on January 29, work was 50% complete as of data date.

If we establish a data date of February 2 and apply this information to the project, it provides us with a bar chart as shown in Figure 6.3. We can see that all of the "administrative" items are complete (*NTP*, *Bonds and Insurance*, *General Conditions*, and *Erosion Control*) are complete. Also, some work on the project is complete (*Clear and Grub*, *Rough Grade Site*, and *Excavate for Service Pit*) have been completed although slightly behind schedule due to the wet weather than occurred during the week of January 7. Also, some work has been done on *Install Storm Drain System* and on *FRPS Service Pit Footings*. However, FRPS Service Pit Walls should have started on January 31 but are not yet underway.



Task Name	Duration	Actual Start	Actual Finish
Project Management	6 days	1/2/13	NA
Receive NTP	0 days	1/2/13	NA
Set up erosion control	5 days	NA	NA
Mobilize General Conditions items	5 days	NA	NA
Bonds and Permits	2 days	NA	NA
Initial Sitework	18 days	1/14/13	NA
Clear & grub site	3 days	NA	NA
Rough grade site	5 days	1/16/13	NA
Install storm drains	10 days	1/24/13	NA
Foundation	41 days	1/24/13	NA
Service Pit	34 days	1/24/13	NA
Excavate for Service Pit	3 days	NA	NA
FRPS Service Pit footings	5 days	1/29/13	NA
FRPS Service Pit Walls	11 days	NA	NA
Backfill around Service Pit	2 days	NA	NA
Install steel columns in Service Pit	1 day	NA	NA
Prep and place SOG in Service Pit	3 days	NA	NA
Install work platform in Service Pit	1 day	NA	NA
Install access stair in Service Pit	1 day	NA	NA
Install WF support beams in Service Pit	2 days	NA	NA
Lay corrugated steel decking over Service Pit	2 days	NA	NA
Prep and place concrete topping over Service Pit	3 days	NA	NA
Main Level	20 days	NA	NA
Excavate for footings - Service Bays	2 days	NA	NA
FRPS footings - Service Bays	4 days	NA	NA
FRPS foundation walls - Service Bays	5 days	NA	NA
Backfill around foundation walls - Service Bays	2 days	NA	NA
Prep and place SOG - Service Bays 3&4	3 days	NA	NA
Excavate for footings - Office Area	2 days	NA	NA
FRPS footings - Office Area	5 days	NA	NA
FRPS foundation walls - Office Area	6 days	NA	NA
Backfill foundation walls - Office area	3 days	NA	NA
Install U/G plumbing - Office areas	3 days	NA	NA
Install U/G electrical conduit - Office Area	2 days	NA	NA
Prep and place SOG - Office Area	4 days	NA	NA

Figure 6.3 Bar chart showing status of work after applying progress information. Used with permission from Microsoft.

While this information, in general terms, that we are slightly behind schedule is probably useful to some degree, it does not indicate the degree to which project is late.

To answer this question, we must look at a bar chart or other display that compares actual to planned. This concept is shown in a baseline bar chart (Figure 6.4).

This bar chart clearly shows some key pieces of information. Reviewing actual progress on each activity in turn against its planned time, we can see the following:

Receive NTP: On time. The bar indicating actual performance corresponds exactly to the baseline bar.

Bonds and Insurance: On time.

Set Up Erosion Control: Started on time, finished on time.

Mobilize General Conditions Items: Started on time, finished on time.

Clear and Grub Site: Started on January 7, which is two days early, but was not completed until January 16, which is five days after planned completion. Looking at Figure 6.4, you can see relationship between the baseline schedule and the actual work.

Rough Grade Site: Started on January 16, immediately after completion of Clear and Grub. Finished on January 23, which is also five days late. It is apparent at this point that the project is now running five days behind schedule.

Install Storm Drains: Started on the 24th, due to prior delays in Grading Site. Work progress as of Data Date was 50%.

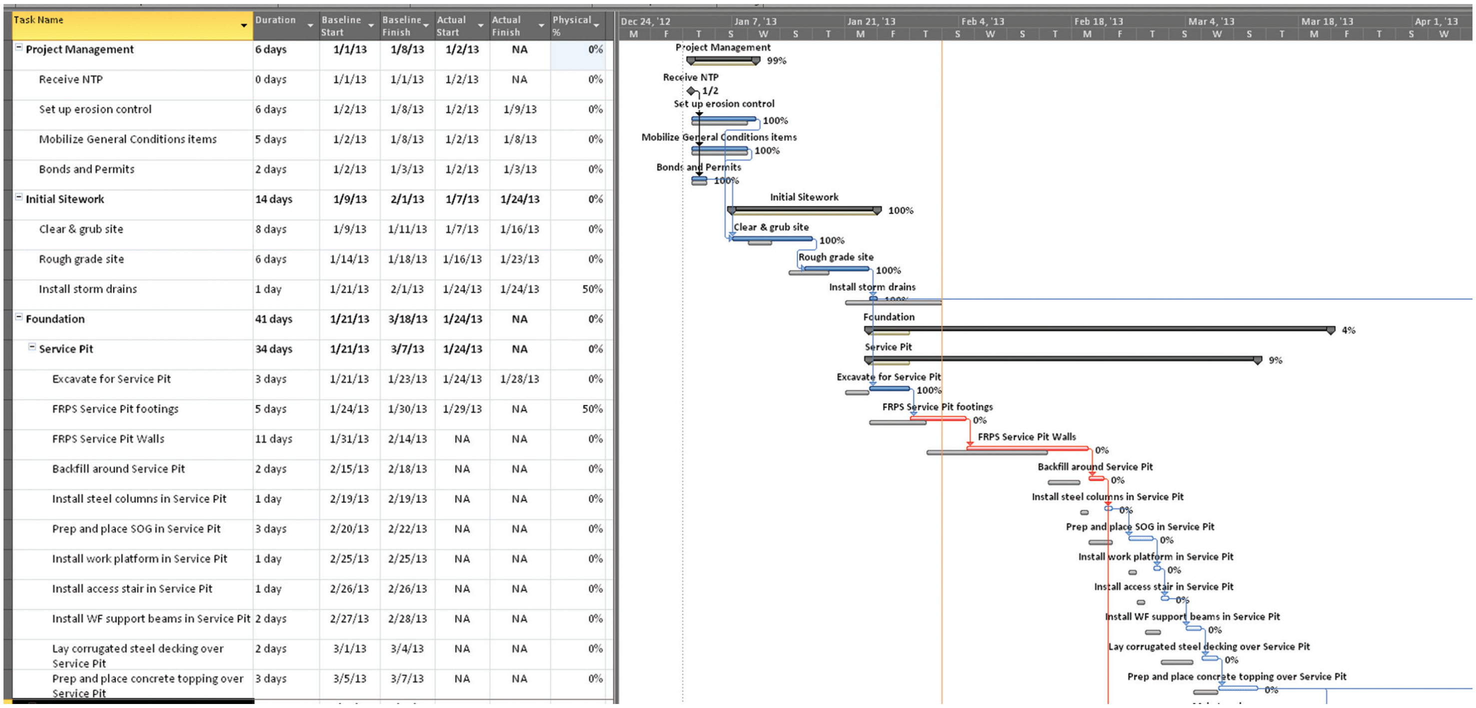
Excavate for Service Pit: Started on the 24th, immediately after Rough Grade Site. Finished on January 28, which is again five days late.

FRPS Service Pit Footings: Started on January 29, work was 50% complete as of Data Date.

Given these comparisons, it is apparent that some delay has occurred. Doing the comparison between the baseline schedule and the actual schedule shows us that the project is about one week, or five days behind the baseline schedule, which was our original goal. In the beginning of a project that has a duration of over one year, this is not a significant period of time, and there are no doubt many activities downstream that could be speeded up to recover the time. However, without the information shown in these basic reports, a project manager would have no way to even know that a problem existed.

SUMMARY

In this chapter, we have just discussed the important process and techniques of monitoring and controlling a project. In Chapters 1 and 2, we also discussed how critical these steps can be to the final success of a project. However, in the hectic real world of project management, these monitoring steps are all too often forgotten or given short shrift. This is understandable in a way, since managing construction



Task Name	Duration	Baseline Start	Baseline Finish	Actual Start	Actual Finish	Physical %
Project Management	**6 days**	**1/1/13**	**1/8/13**	**1/2/13**	**NA**	0%
Receive NTP	0 days	1/1/13	1/1/13	1/2/13	NA	0%
Set up erosion control	6 days	1/2/13	1/8/13	1/2/13	1/9/13	0%
Mobilize General Conditions items	5 days	1/2/13	1/8/13	1/2/13	1/8/13	0%
Bonds and Permits	2 days	1/2/13	1/3/13	1/2/13	1/3/13	0%
Initial Sitework	**14 days**	**1/9/13**	**2/1/13**	**1/7/13**	**1/24/13**	0%
Clear & grub site	8 days	1/9/13	1/11/13	1/7/13	1/16/13	0%
Rough grade site	6 days	1/14/13	1/18/13	1/16/13	1/23/13	0%
Install storm drains	1 day	1/21/13	2/1/13	1/24/13	1/24/13	50%
Foundation	**41 days**	**1/21/13**	**3/18/13**	**1/24/13**	**NA**	0%
Service Pit	**34 days**	**1/21/13**	**3/7/13**	**1/24/13**	**NA**	0%
Excavate for Service Pit	3 days	1/21/13	1/23/13	1/24/13	1/28/13	0%
FRPS Service Pit footings	5 days	1/24/13	1/30/13	1/29/13	NA	50%
FRPS Service Pit Walls	11 days	1/31/13	2/14/13	NA	NA	0%
Backfill around Service Pit	2 days	2/15/13	2/18/13	NA	NA	0%
Install steel columns in Service Pit	1 day	2/19/13	2/19/13	NA	NA	0%
Prep and place SOG in Service Pit	3 days	2/20/13	2/22/13	NA	NA	0%
Install work platform in Service Pit	1 day	2/25/13	2/25/13	NA	NA	0%
Install access stair in Service Pit	1 day	2/26/13	2/26/13	NA	NA	0%
Install WF support beams in Service Pit	2 days	2/27/13	2/28/13	NA	NA	0%
Lay corrugated steel decking over Service Pit	2 days	3/1/13	3/4/13	NA	NA	0%
Prep and place concrete topping over Service Pit	3 days	3/5/13	3/7/13	NA	NA	0%

Figure 6.4 Bar chart showing progress compared to baseline schedule. Used with permission from Microsoft

can seem like one long series of crises, and it is difficult to pay enough attention to the routine tasks like updating and holding regular scheduling conferences. However, we know that attention to these tasks pays dividends in the long run. Experience has shown us that if a project manager can establish and maintain an effective and regular monitoring process, the number of problems that are caught and solved early goes up, and the number of nasty surprises tends to go down.

REVIEW QUESTIONS

1. Interview a project manager to determine what methods he or she uses to maintain effective schedule communication with subcontractors as the project progresses.
2. If possible, sit in on a monthly schedule meeting and note how the project manager conducts the meeting.
3. Interview a working scheduler and ask how he or she gathers progress information from the field. Also, ask what works best and what doesn't work well.
4. Do some research online or in the library to determine the difference between duration percent complete and physical percent complete
5. If a subcontractor told you that the delivery of materials for his work would be 30 days later, how would you enter than in a schedule update?
6. What is the difference between a baseline schedule and a target schedule?
7. Define management by exception. How would use this principle if you were responsible for updating a schedule and preparing reports for the project manager?
8. Is it possible to be on schedule as far as the critical path is concerned, but still be behind on the job as a whole?
9. What is meant by "trade stacking"? Why is it to be avoided when trying to make up time on a project?
10. Look at the schedule in this chapter and determine how far behind the work is for the Vehicle Maintenance Facility. Then, look at the overall schedule contained in the appendices and figure out where you could recover the time lost by changing logic or speeding up some work.

7 RESOURCE MANAGEMENT

7 Resource Management

One of the project manager's most important jobs is ensuring that all the resources necessary to build the project are available at the right time and place. While submittal data and procurement of material are important aspects of project management, they are not the only issues. Adequate labor of the right type or trade must also be available, as well as proper equipment for the trades to perform their work. Furthermore, the right amount of money has to be available at the right times to pay for resources of all types. This chapter deals with the techniques of ensuring the correct amount and timing of these three resources—material, equipment, and labor.

HOW TO MANAGE RESOURCES

The process of managing resources has two key aspects: first, ensuring that enough of the right resource is available at the right time and second, ensuring that the resource is used efficiently.

To address the first aspect, adequate and timely resources must be supplied in order to keep the work flowing so the project will be completed on time. Any shortage of resources will inevitably lead to delays, first in the activity in question and then in the project as a whole. Consider the case of a project manager trying to decide how much labor to hire for a particular phase of the project. The project manager can, of course, use the estimate to find out how much total labor of a given type will be needed for the total activity. As you have seen, that information must be used in the calculation of how long an activity will take. However, the estimate seldom, if ever, addresses the issue of *when* the labor will be needed. Nor does it indicate how much labor will be needed on a daily or weekly basis. The estimate also cannot provide any information about conflicting demands for resources, for example, when two activities of like types are scheduled to occur at the same time and, therefore, need the same labor. This kind of information can only be derived by consulting the schedule.

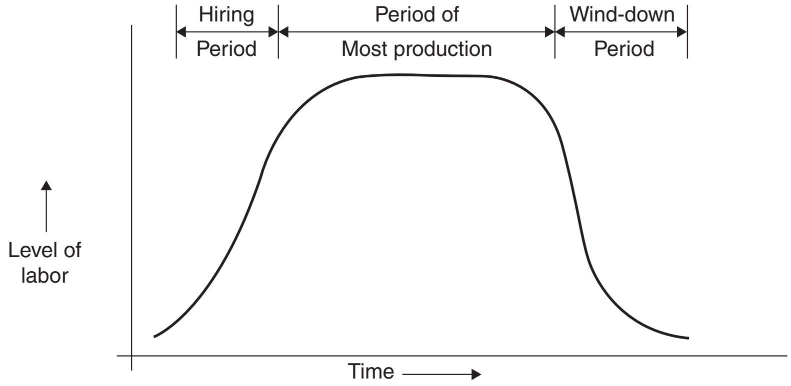


Figure 7.1 Ideal resource use pattern

The second case key aspect, efficient use of resources, can be promoted on a project by observing several principles. First, the rate and flow of work should be as orderly and even as possible. The PM should try to schedule crews so that hiring is smooth and even from the beginning of the job, and that the overall size of the work force remains as constant as possible. Extreme peaks of demand should also be avoided. Crews should be kept together, working on similar work for longer periods of time. It is very disrupting for skilled labor to have to jump around between different tasks, and to be alternatively laid off and rehired. Productivity invariably suffers when these conditions occur. The ideal pattern for a given trade should look something like Figure 7.1, which shows an even build-up of labor, then a constant period for the middle of the project when most of the work gets done, followed by a smooth reduction of labor at the end of the job.

While it can be difficult to create a perfectly smooth labor utilization pattern, or to predict exactly when and how much of a resource will be needed, a project manager can apply the techniques in this chapter to obtain better information than would be available by consulting the estimate alone.

THE RESOURCE MANAGEMENT PROCESS

Resource management is the decision-making process in which activities are prioritized and scheduled so that the expenditure of labor and/or equipment occurs in a desirable way. The best time to begin this process is early in the project. If resources are handled properly from the start, the project's chances of falling behind are minimized and there is no need to play "catch-up."

The logical starting point for resource management is the critical path schedule as calculated for the project. In the beginning, this schedule is based on physical logic. It typically has an uneven pattern of resource expenditure but serves as the starting point for the resource management analysis and refinement.

To perform the analysis, the project manager must be able to project the pattern of expenditure for a particular resource. There are two basic views of this pattern:

1. The *resource profile* (sometimes called a resource histogram), which is a compilation of the demand by time period for a given resource.

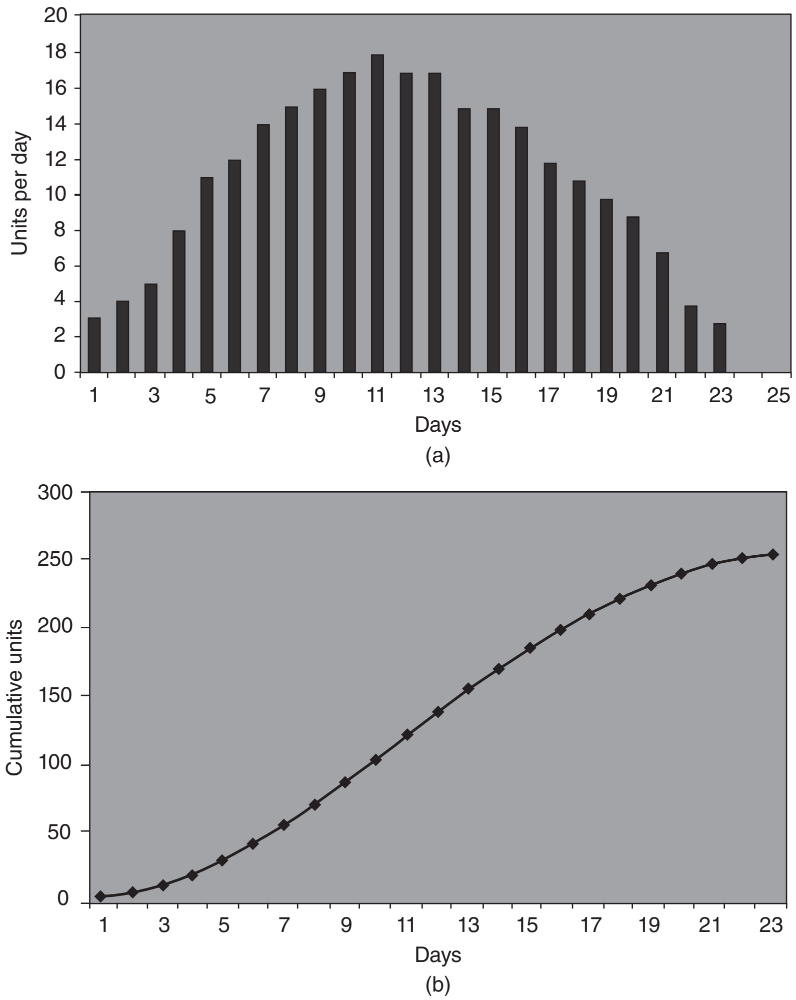


Figure 7.2 (a) Typical resource profile (b) typical resource summary

2. The *resource summary curve* (sometimes called an "S" curve): the sum of the resource expenditures over time. (See Figure 7.2. for a typical resource profile and resource summary)

DEVELOPMENT OF THE RESOURCE PROFILE

The development of the resource profile is a four-step process, illustrated in Figures 7.3 and 7.4. The sample used for this illustration is the building of the foundation up through the foundation walls. The resource being plotted for analysis is *formwork carpenters*, used for the forming and stripping work.

Step 1: Calculation of Required Resources

This initial step is a listing of each activity in the hypothetical network with quantities of work, labor-hours per unit required, total labor-hours, crew size, and number

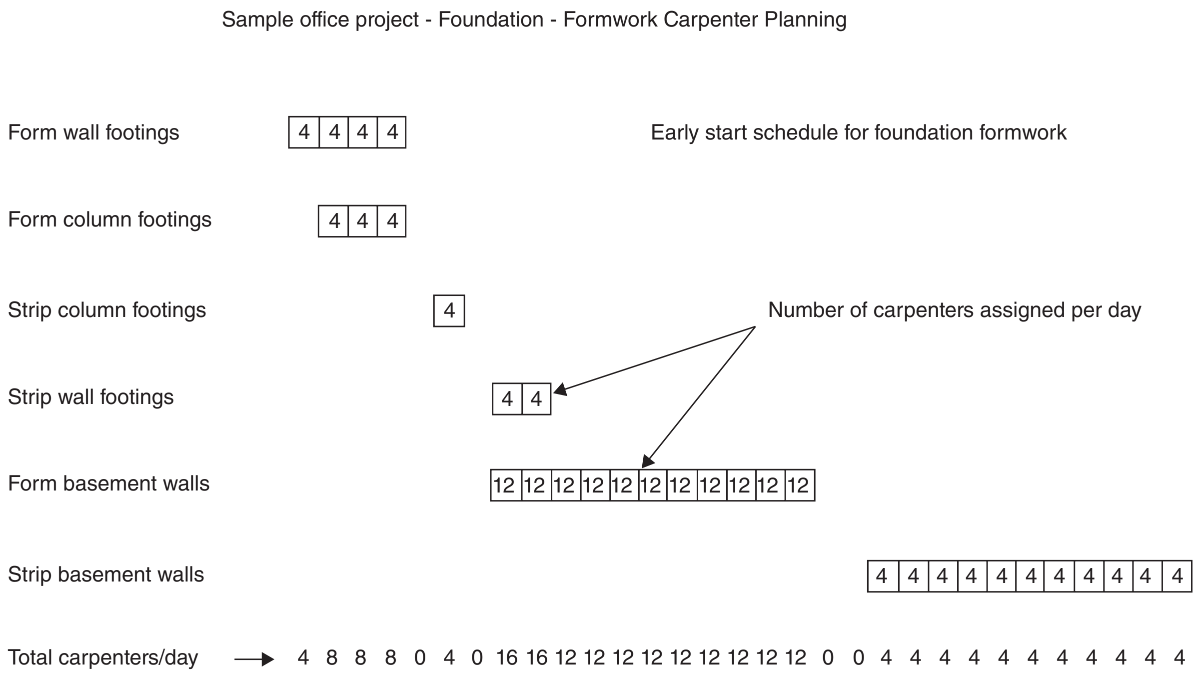


Figure 7.3 Distribution of resource across activities

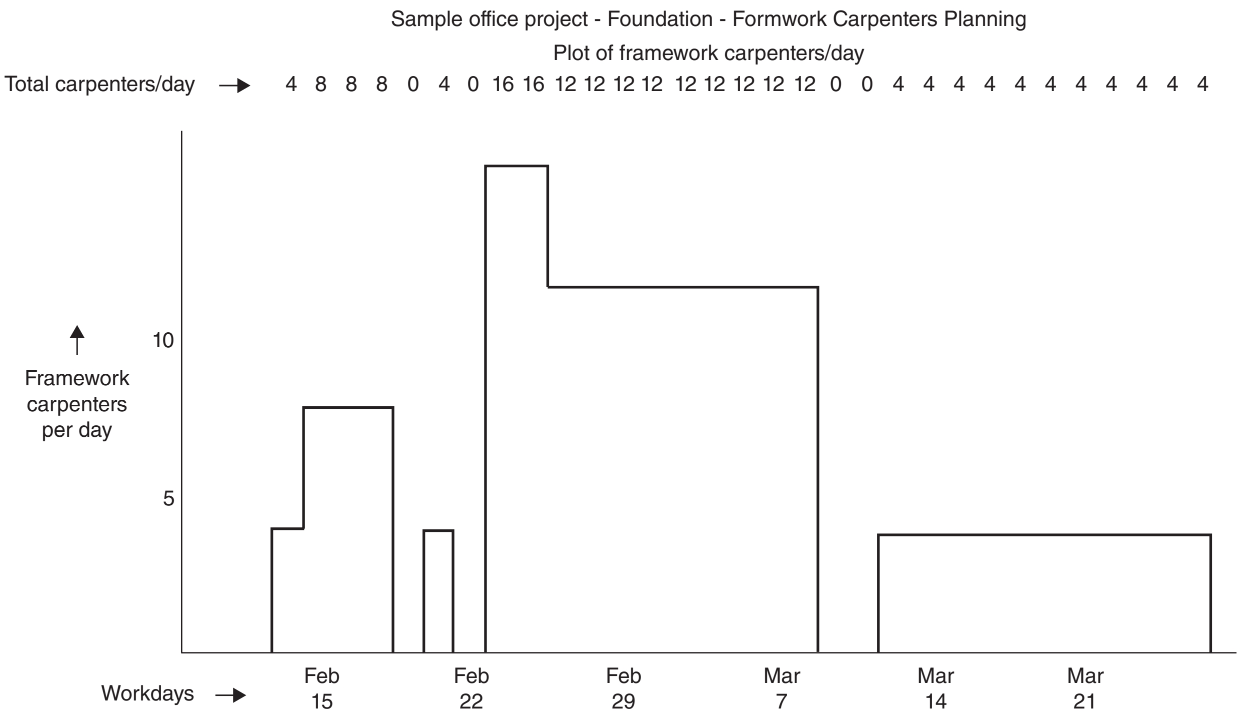


Figure 7.4 Resource profile

of days required. All of this information can be obtained from the estimate and/or a published source such as *Means Building Construction Cost Data*. The key numbers here are the total labor-hours and crew size.

Step 2: Distribution of Resources across Activities

The next task is to assign the required resources to the appropriate activities. There are two methods for assigning resources. They may be based on:

1. A rate of expenditure per day, or
2. A total amount of resources for the entire activity

The two methods are basically interchangeable. For example, if the number of carpenter labor-hours assigned per day is 4 Men × 8 Hours per Day, the total number of carpenter labor-hours for a six-day activity is:

6 Days × 32 = 192 Labor-Hours for the Activity.

Alternately, the activity might have an assigned 192 labor-hours, which can be translated back to four workers per day.

192 Labor-Hours/6 Days = 32 Labor-Hours per Day, and

32 Labor-Hours per Day/8 Hours per Worker = 4 Workers per Day

Both methods have advantages. If the time of the activity is likely to be varied, and the number of workers adjusted up or down to vary the rate of progress, then it is probably better to assign total labor-hours. If the number of workers is to be fixed and the time of the activity is less definite, then assignment of number of workers per day is preferable. In the case of the sample problem, the formwork carpenters are assigned by number of workers per day, since it is much simpler to calculate by hand. It can be seen in Figure 7.4 that the number of carpenters assigned per day to *form wall footings* is four, for *form column footings*, four, and so on.

It should be noted that any unit of measure can be used for the resource. In this case, labor-hours is used, but work days are equally valid. In analyzing another resource, such as bulldozers, the unit of measure might be *equipment hours* or *equipment days*. It is best if the unit of measure remains consistent for all resources where possible in order to prevent confusion.

The schedule across which the resources are spread can be *early start*, *late start*, or a combination of both. The most commonly used schedule is *early start*, since it represents the desired schedule of most project managers.

Step 3: Summarize Resource Expenditure by Time Period

This task is performed by totaling the figures (downward) at the end of each day of the job. In the sample problem (See Figure 7.4), it can be seen that the number of carpenters required per day for the first day is four, but for the second day the number required rises to eight, and it stays at that level until the fifth day, at which point it drops to zero. This process is carried out across the project schedule until the end of the last carpenter activity, *strip basement walls*.

Step 4: Plot the Resulting Profile

The tabular data arrived at in the previous step, while accurate, is not very useful to a project manager, who is better served by converting this information to a graphic representation. The resource profile shows more clearly the periods of demand for formwork carpenters on the foundation.

ADJUSTING THE SCHEDULE TO IMPROVE THE RESOURCE CURVE

The pattern of resource expenditure is important in that it has a very real effect on efficiency and productivity. Laying off crews because no work is available for several days is not very good for morale and is not a desirable alternative. For one thing, the tradesmen may decide to find other work, and thus not be available when needed, causing more disruption to the project schedule. Clearly, a project manager should do all he can to keep crews employed doing productive work and keep the crew manning as level as possible throughout the job.

Fortunately, once a diagram is created showing the pattern of expenditure for the resource, there is a way to determine how best to alter the schedule. The project manager has several options. The goal is to alter the schedule so that the pattern of use is as close as possible to the curve shown in Figure 7.1. To achieve this goal, the project manager should try first to adjust noncritical activities within their float range to move peak periods of need into gaps in the diagram. This can be accomplished by delaying the start, extending the time, or working at varying rates to smooth out the flow. If the manipulation of noncritical activities does not work, then the project manager must begin altering the critical activities. A critical activity will probably have to be lengthened, and therefore the job as a whole is extended. This situation presents the project manager with one of his biggest challenges; trade-off decisions must be made between the value of smooth work flow and delay to the job.

The following example shows how schedule adjustments might be made. Figure 7.5 is a bar chart showing a schedule for the carpentry work involved in forming, placing and stripping a large waffle slab structure. (Note: reinforcing has been omitted for clarity)

In this case, it is assumed that the superintendent has broken the work down into three separate placements. Each placement consists of *Forming*, then *Placing*, followed by *Stripping* after an interval of five days to allow for curing prior to stripping. It should also be noted that for *Forming* the three segments are sequential, and the crew moves immediately from one segment to the next. It can also be seen that there are gaps in the schedule for *Stripping*.

Comparing the bar chart to the resource profile for this set of activities, Figure 7.6, it can be seen that there is a peak demand for formwork carpenters during the

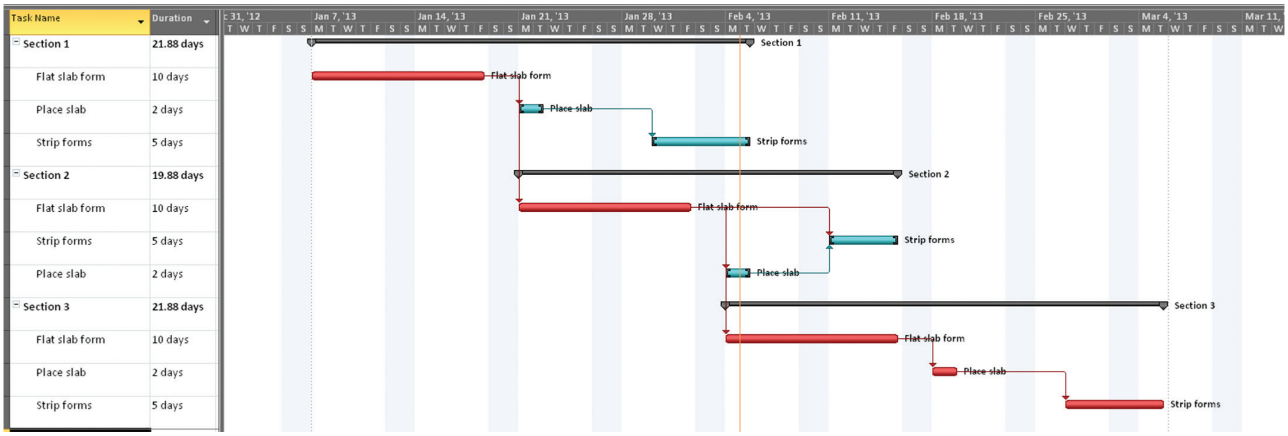


Figure 7.5 Waffle slab forming schedule. Used with permission from Microsoft.

weeks of January 28 and Feb 4. Looking at the bar chart at the top of the page, you can see that stripping section overlaps forming sections 2 and 3.

Also, the demand peaks again during the week of February 11 because stripping section 2 coincides with the last part of forming section 3.

Unfortunately, the demand falls to zero on February 18, and there is no carpentry work available until February 25. Clearly, this pattern of work involves peaks and valleys in manpower demand that need to be eliminated or reduced.

Using the principle that it is better to move noncritical activities than critical ones, the superintendent might consider adjusting the stripping activities as follows. The superintendent could delay stripping section 1 until forming section 3 has been completed. At this point, half the forming crew could begin stripping all three segments in turn. At this point, the other half could be moved to other work on the project, or in a worst case, they could be laid off. Being laid off is not the best of all worlds, but from the standpoint of job efficiency, it is better to have consistent crew loading than on again, off again. Also, workmen in the industry understand that sometimes layoffs are unavoidable, and had the superintendent laid out this scenarios ahead of time, the second half of the crew would have known about their impending layoff, and they could have taken steps to line up other work.

The effect of these changes can be seen in Figure 7.7. Now the superintendent has an even crew size for the forming process, then moves a few carpenters to other work, and keeps an even crew size on for the stripping process. The overall time of erecting the waffle slab has slipped only three days, yet the work flow and crew sizes have been smoothed out considerably.

Also, it should be noted that while it may have been possible to perform this simple resource-leveling task by hand, consider the difficulty in doing it if multiple structures and forming had been involved. Clearly, computerization is a useful tool in these situations.

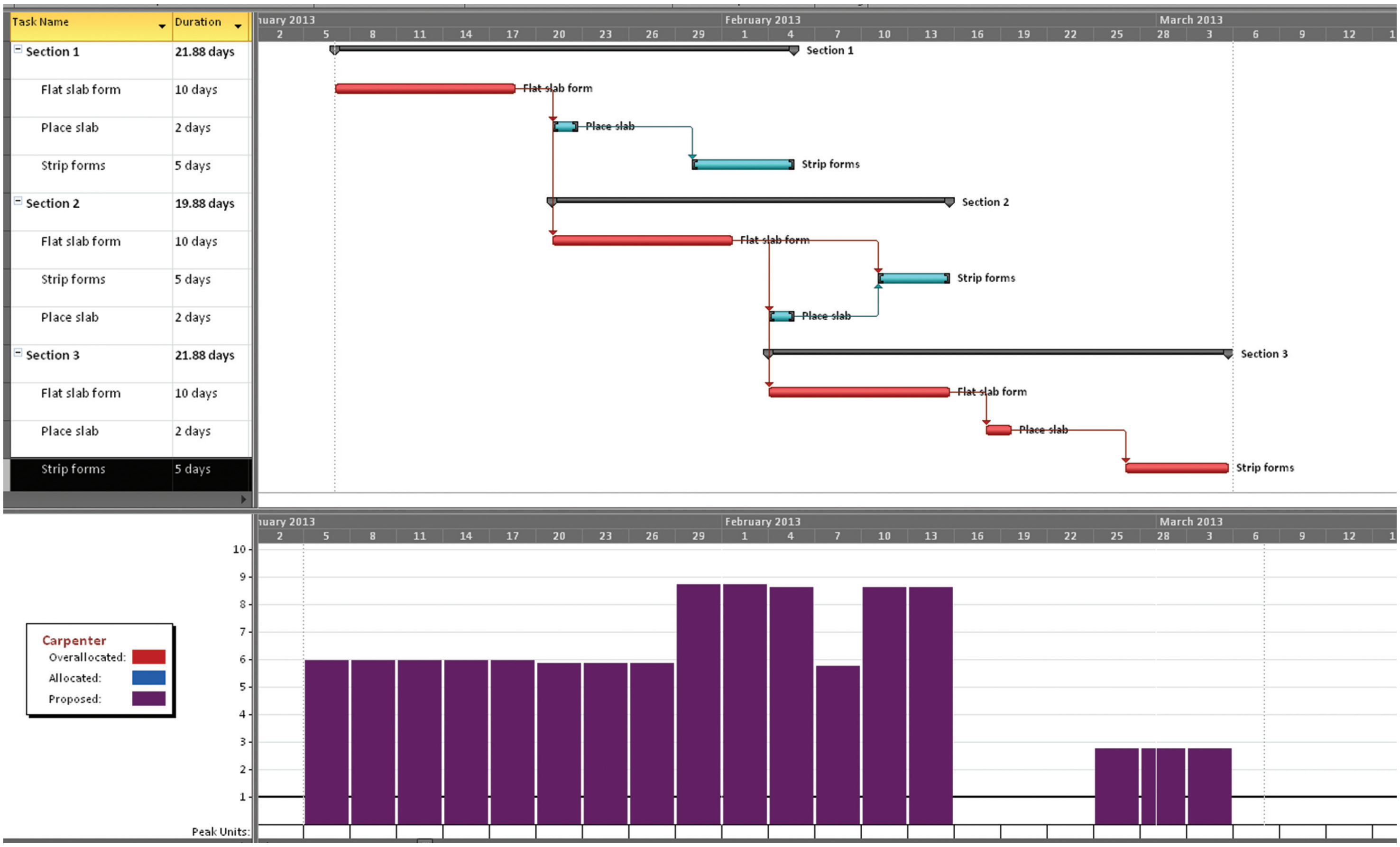


Figure 7.6 Waffle slab resource profile before leveling. Used with permission from Microsoft.

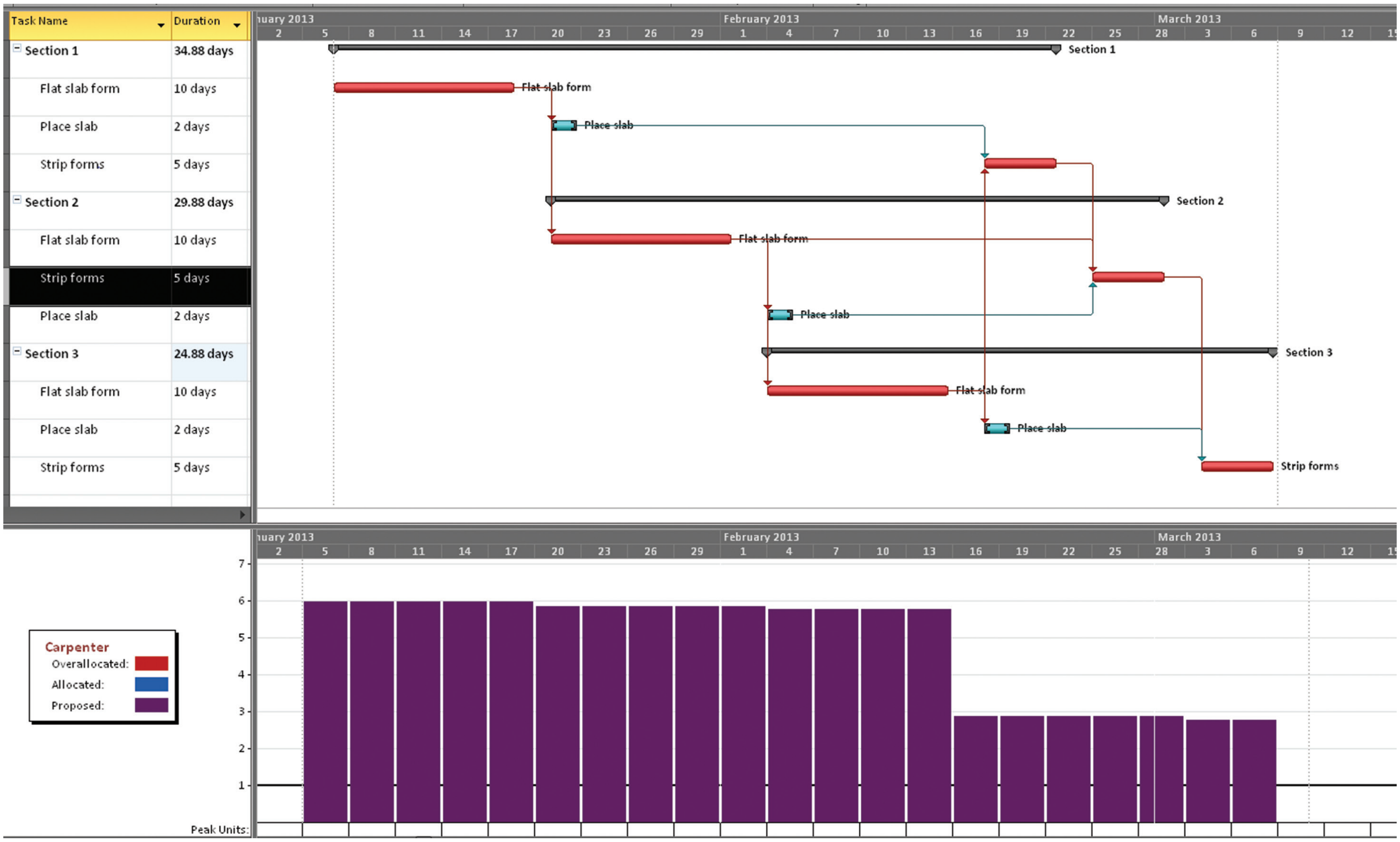


Figure 7.7 Waffle Slab Resource Profile after leveling. Used with permission from Microsoft.

PRACTICAL ASPECTS OF RESOURCE MANAGEMENT

Some people in the construction industry claim that resource management techniques are relatively precise. This may be true on huge projects where the project managers have a large work force that can be moved around. However, on the vast majority of construction projects, precision is extremely difficult to attain. The techniques of resource management are at best an approximation. Nevertheless, it is still a very valuable tool. These techniques can smooth the rough edges and improve the overall project plan. When using resource management, it is helpful to observe the following guidelines:

1. As noted, these techniques offer approximate solutions, so perfection should not even be attempted, much less expected. They are also very much trial and error; be prepared to take several passes at leveling and smoothing out a resource such as *formwork carpenters*.
2. Give priority to the critical and near critical activities, ensuring that they receive enough labor and equipment to stay on schedule. The noncritical activities can be adjusted as necessary, with the activities that have the most float having the greatest flexibility. Be careful, however, not to let the noncritical activities slip by unnoticed.
3. Constant monitoring of labor and equipment use is necessary to ensure compliance with the plan or to notice if the plan is not working. Toward this end, be prepared to revise and replan frequently and whenever necessary.
4. It is probably not realistic to look ahead more than a few weeks at a time in an attempt to work things out in detail. The advantage of revising along the way is that it is possible to apply what is learned in the early stages of a job to the later stages.
5. Computers are great for plotting the data, but they are terrible for making decisions. Some computer programs have leveling algorithms, which can calculate the most efficient redistribution of labor or other resources. As a practical matter, these programs work only on the largest of jobs. These leveling programs are also extremely complex. Thus, one can use them in good faith without completely understanding what they are calculating.
6. The best use of computers is plotting resource profiles. The project manager can take the computer printout sheet, mark it up with ideas for change, input the changes back into the computer, and find out the result. The computer allows this "what-if" game, where a number of options can be tried out very easily, leading to a better overall solution by the project manager.

OTHER APPLICATIONS: EARNED VALUE

So far, our discussion of resource management has focused on traditional uses of the concept: leveling labor and other resources to ensure smooth and efficient workflow.

There are, however, ways to use the technique to track progress and to make the administrative process of payment much easier for project manager by using a system called *earned value*.

Earned value is a more sophisticated technique, which uses the dollar value of activities to implement the basic concepts of planning and measuring job performance as laid out in the Project Control Cycle (Figure 1.2).

The techniques of earned value were initially developed by the Department of Defense in the 1960s to plan and control large-scale defense acquisition programs. It was originally called Cost/Schedule Control Systems Criteria and has evolved over the years, and it is now known by several names, including earned value management system (EVMS), among others.

In its full-blown form, EVMS is a highly complex process, and as such, it is difficult and expensive to implement. As a result, its adoption by the construction industry has been slow and has been largely limited to government projects, where it is required as a matter of contract.

In spite of this, there are tools within the earned value system that can be applied in simplified form to smaller projects, and which can be quite useful to owners and contractors for tracking progress and performance.

The two main areas where earned value has proved useful are in tracking simple schedule performance and in making contract payments more accurate and easier to administer. The following section will discuss these specific areas.

Key Terms and Concepts

As we noted above, earned value measurement systems can be highly complex. However, a simplified system suitable for use on a project like the Vehicle Maintenance Facility can be created using five basic definitions, which follow.

Basic Cost Definitions

Budgeted Cost of Work Scheduled (BCWS)

This gives us a value for the work that the schedule shows is expected to be done at in point in the project's life. A better term for this value might be value of work scheduled, rather than cost of work scheduled, but either way, the point is to recognize that the value shown at any point on the BCWS curve is a planned or target amount. If we accomplish more than planned at any point on the curve, progress is good; if not, progress is poor.

Budgeted Cost of Work Performed (BCWP)

This figure represents the value of the work we have accomplished at any point in the project's life. A better term for this figure would be *earned* value of work performed, rather than *cost* of work performed.

Another way to view this term is that it represents the sum of the value of work completed at any given point, or to use any older term, it is the value of work in place.

Finally, with regard to BCWP, it is also the amount of money that we had planned to spend the accomplish the work in place at a given point. This part of the definition is important for the next concept.

Actual Cost of Work Performed (ACWP)

This value represents the actual dollars that we have to spend in order to create the work in place.

It should be noted that it is not uncommon to use the first two concepts to measure schedule performance but not use this last value to measure cost performance. There are two reasons for this. One is that on most small projects, work is completely subcontracted so that the risk of cost overruns is completely transferred to the subs, and a general contractor no longer has to track cost performance. The second is that cost information is generally not tracked by schedule activities, but rather by trade or other classification, and it is difficult to tie this cost information to the schedule itself. We will however demonstrate later how cost performance can be measured if that is necessary.

Basic Performance Definitions

Schedule Performance Index (SPI)

Once we have collected data on progress through the updating process, that is, percent complete, remaining duration, and so forth, we can calculate metrics that give us a measure of performance. The first of these pertains to schedule performance, and is calculated using the following formula:

$$SPI = BCWP/BCWS.$$

For this index, any number greater than one represents positive or ahead of schedule performance. For example, if at the end of a reporting period, we have an SPI of 1.50, it means that we have accomplished 150% of the work that we had planned to have accomplished at that point.

Cost Performance Index (CPI)

Also, we can measure cost by using the formula:

$$CPI = BCWP/ACWP$$

For this index, any number greater than one means that we are performing well in terms of cost. For example, if at the end of a reporting period, we have a CPI of 1.25, it means that we are 25% more efficient than we expected to be.

We can also express cost performance in terms of having spent only 80% of what we anticipated spending. We can arrive at this figure by calculating the reciprocal of the CPI: $1/1.25 = .80$.

Setting Up an Earned Value System

The first step in using earned value is to assign a dollar value to every activity in the CPM schedule. This process is fairly easily done even though most projects are estimated and bid using a traditional CSI breakdown. It is made easier by the fact that most work in today's industry is done by subcontractors. Usually, the project manager defines the schedule activities, then requests the subs to assign a dollar value to their activities, which are then "loaded" into the CPM schedule as a nonlabor resource. This process is called *cost loading*. The cost loading for the sample Vehicle Maintenance Facility is given as an example in Appendix B.

Once the schedule has been cost loaded, the scheduler or whoever is responsible for maintaining the schedule can recalculate, and display a resource profile and cumulative resource curve using their scheduling program. Figure 7.8 shows what the cost profile would look like for the Vehicle Maintenance Facility.

The top portion shows the schedule for the project in summary form, except of the initial site work phase, which shows the individual activity values within that phase. It also shows the total value of the work in the project and in each phase. The bottom portion shows the dollar value of work that is anticipated in each month. This particular profile is not the ideal that was shown in Figure 7.1, but it is typical of the kind of profile we could expect to see in smaller projects.

Figure 7.9 shows the cumulative cost curve, which results from summing the monthly values. The curve peaks on the right at a value equal to the overall value of the work and shows the total amount of work that the project can anticipate at any point during the project. The curve itself is not a "perfect" S-curve as might be desired, but it is a reasonable approximation, and it shows a steady rise over the life of the work.

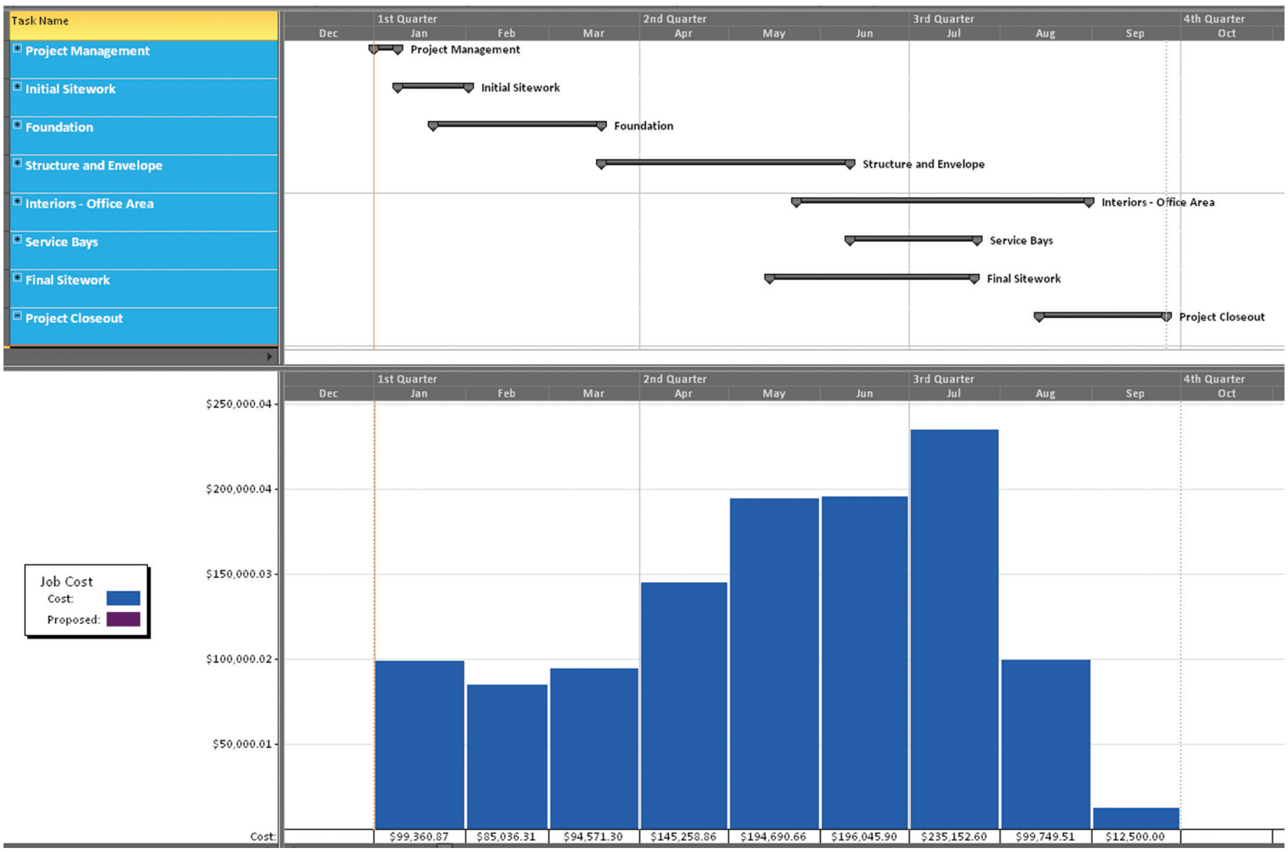


Figure 7.8 Vehicle maintenance facility resource profiling. Used with permission from Microsoft.

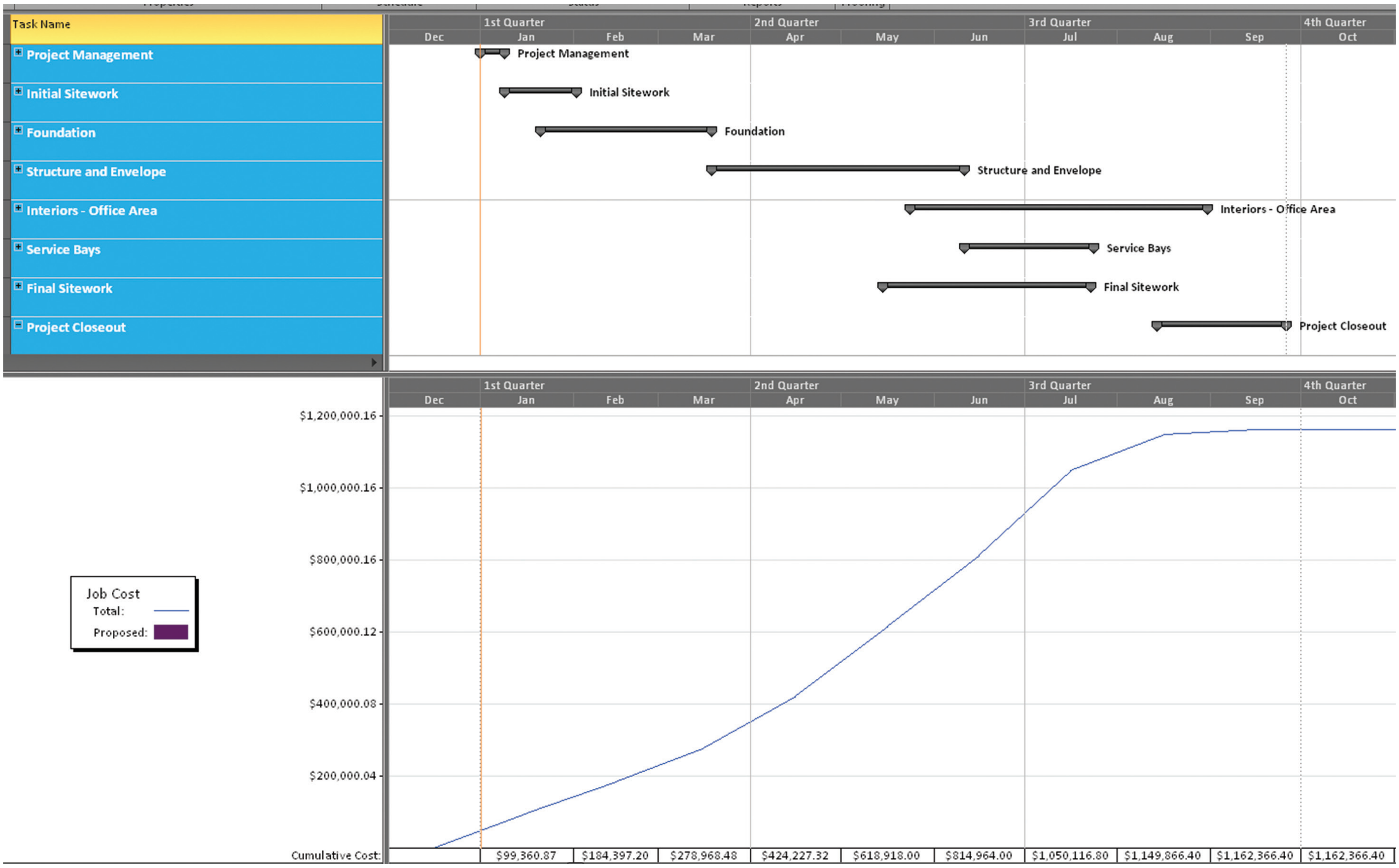


Figure 7.9 **Vehicle maintenance facility resource profile. Used with permission from Microsoft.**

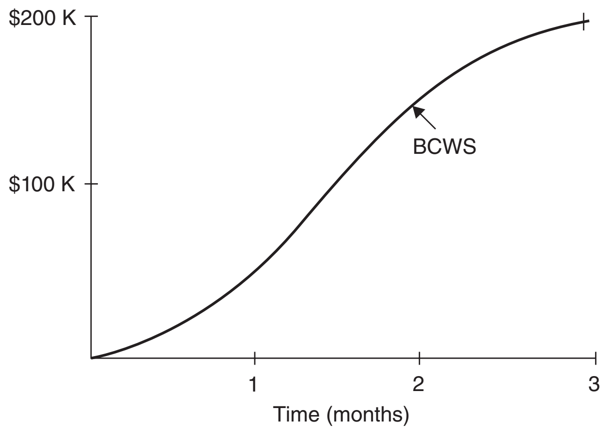


Figure 7.10 Simple EV schedule.

Earned Value Example

To illustrate how these concepts work, consider the following example of a simple project to erect a building costing $200,000 over a period of three months. For purposes of illustration, let us assume that the building is a barn pole structure, consisting of simple wooden components, erected using basic carpentry labor. Also, we shall assume that the contractor uses a simple CPM based on previous experience and that this CPM predicts that the value of the work will take the form of a clean S-curve, shown in Figure 7.10. This curve represents BCWS in our earned value "system."

To demonstrate how earned value works, let us consider several possible outcomes.

Case 1

In this situation, the contractor measures his progress by updating his CPM at the end of the first month. (Figure 7.11) He discovers that the earned value of the work performed (BCWP) at this point is equal to $75,000. If he plots BCWP and compares it to BCWS at the end of the first month, he can see that the BCWP curve is above and to the right of the BCWS curve.

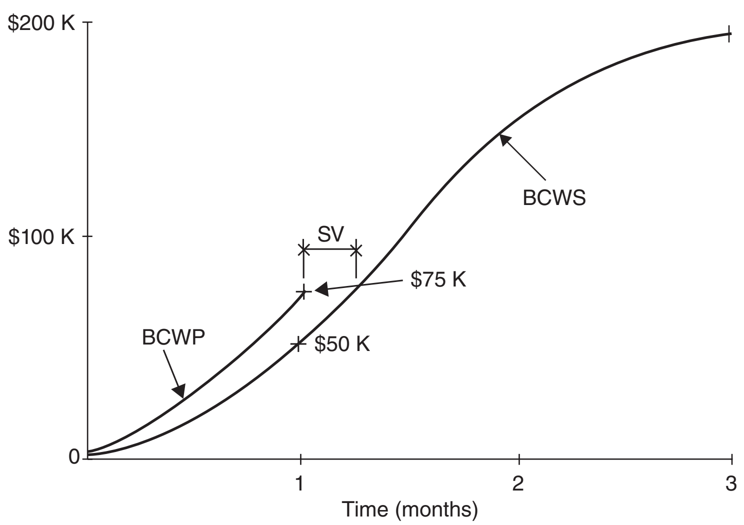


Figure 7.11 EV scenario – case 1.

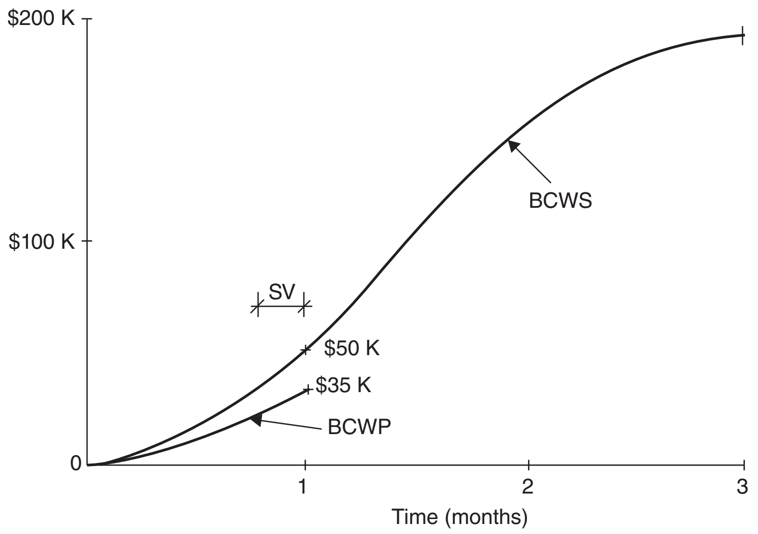


Figure 7.12 EV scenario – case 2.

This plot clearly shows that the project is ahead of schedule, which can be confirmed by calculating the SPI, as follows:

$$SPI = BCWP/BCWS = 75{,}000/50{,}000 = 1.50$$

Case 2

In this case, the contractor updates the schedule and discovers that the value of the work in place is only $35,000. Using the same plotting technique, he can see that the BCWP curve is below and to the left of the BCWS curve. A curve in this location shows that the project is behind schedule, as shown in Figure 7.12

Also. the SPI is provides another measure of poor performance, as follows:

$$SPI = BWCP/BCWS = 35{,}000/50{,}000 = .70$$

Clearly, this is a less desirable situation. Having found out that he is behind schedule when he is only a third of the way through the project, he may be able to find ways to improve progress, or if the reasons for being behind schedule are beyond his control, he may be able to claim an extension of time. Either way, knowing is better than not knowing, and having a tracking and performance measurement system is key to taking corrective action.

Case 3

In this case, let us add the cost factor to the earned value system, as shown in Figure 7.13

If at the end of the first month, the contractor has put in place a work value of $75,000, and has spent only $60,000 to do this, he can plot both against the original S-curve that represent our BCWS.

In this scheme, BCWP is equal to $75,000, and we are adding an ACWP of $60.000 to the plotted diagram. Now the BCWP curve is again above and to right of the BCWS curve, so schedule performance is better than planned.

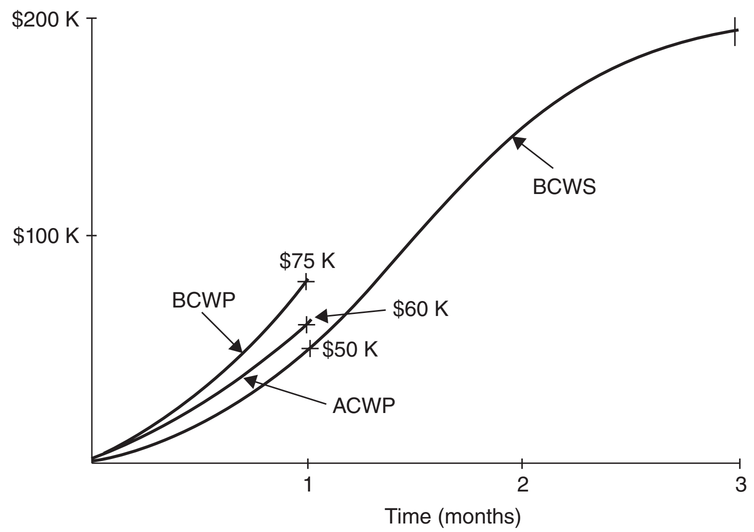


Figure 7.13 EV scenario – case 3.

Judging the cost performance is slightly different, however. In order to assess cost, we compare the ACWP curve to the BCWP, *not* to the BCWS curve. The point is to determine how much we spent versus what we should have spent to accomplish the work we actually completed, not the value of what we should have completed.

We can see this in that the ACWP curve is below and to the right of the BWCP curve, so that cost performance is also better than planned. It does not matter where the ACWP is relative to the BCWS curve.

Also, if we calculate the CPI, we find that we also have a numerical as well as a graphic indication of cost performance.

$$\text{CPI} = \text{BWCP/ACWP} = 75{,}000/60{,}000 = 1.25$$

Overall, the barn project is in good shape by both measures.

Case 4

Finally, let us look at case that represents the other side of the cost and schedule coin.

Looking at Figure 7.14, we can see that the BCWP or earned value of the project at the end of the first month is only $40,000, which when plotted against BCWS, shows that the project is behind schedule. This is confirmed when we calculate the SPI:

$$\text{SPI} = \text{BCWP/BCWS} = 40{,}000/50{,}000 = .80$$

Looking further at the cost situation, we see that the contractor has spent far more than planned for the amount of work done. The actual cost or ACWP is $70,000, which puts the cost curve far above and to the left of the curve for the budgeted cost of the work accomplished (BWCP), which indicates a severe cost overrun. Again, the CPI confirms the graphic indication of poor performance:

$$\text{CPI} = \text{BCWP/ACWP} = 40{,}000/70{,}000 = .57$$

With these numbers the project is clearly in severe trouble.

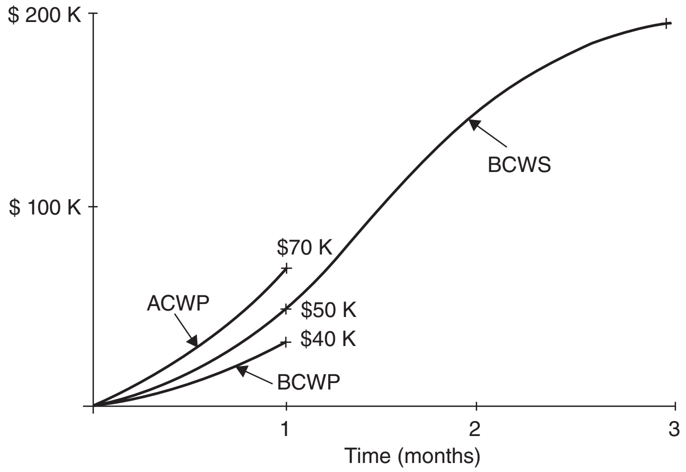


Figure 7.14 EV scenario – case 4.

OTHER APPLICATIONS: COST-LOADED SCHEDULES

In addition to using resource management techniques to measure project performance and improve the use of resources such as labor and equipment, we can use them to make our administrative tasks easier.

Traditionally, payment to the contractor has done using what is call a *schedule of values*, which is a breakdown of contract cost based on the taxonomy of the Construction Specifications Institute (CSI). In this classification scheme, the work is divided into segments based on the type of materials used to build the project. For example, the costs would be broken down into site work, concrete, masonry, metals, thermal and moisture protection, finishes, and the like.

At the beginning of the project, a schedule of values would be prepared by the contractor, approved by the owner and architect, and each month, the parties would negotiate how much of each type of material was in place. This system developed primarily because architects wrote specifications based on the CSI system. Also, contractors estimated based on it as well. These factors made it relatively easy for the contractor to prepare a schedule of values and for the architect to read it and approve it.

This system had many disadvantages, not the least of which was the fact that estimates of the amount of each material in place was often little more than a guess. Also, a specific material such as concrete could occur all over the project, and there was often no recognition of that fact in the schedule of values. Overall is was an imprecise system at best.

However, as CPM scheduling became more and more common, this old CSI based system had the disadvantage of duplicating work done in the scheduling process. Contractors and owners very quickly figured out that if they assigned a value to each schedule activity, they could determine a value of work put in place almost automatically every time the schedule was updated. Each activity had a percent complete figure that could be applied to the dollar value of the activity to determine the amount that the contractor was due for that piece of work. Using the resource management summation feature in scheduling software, a total amount due to the contractor could easily be calculated.

In addition to easing the administrative workload, this schedule based payment also has the advantage of being more “accurate” in determining the value of work in place. For example, on the Vehicle Maintenance Facility, it would be easy to see how much concrete work was complete since it is divided into discrete units of work that can be observed as being either complete or not complete.

It should be noted however, that schedule based payment is still not without its flaws. It is still possible for a contractor to front load the costs in a schedule, and disputes over how much work is done are still possible, but overall, cost loaded schedule payment is a better way to handle the payment process.

SUMMARY

In this chapter, we looked at the task of planning and monitoring the use of resources, as opposed to controlling time alone. One key point covered was the idea that resource planning need not be complex or difficult, as is sometimes believed. Even the simplest job can sometimes benefit from monitoring key resources, especially with the ease with which modern software products can be used.

Also, we looked at two “advanced” uses of resource management, specifically Earned Values and cost loaded schedules. The latter tool is becoming more and more common in the industry because of its simplicity and ease of use, and we can expect greater use over time of earned value techniques, although implementation will probably be slower because of the complexity and expense involved.

In any case, the reader is encouraged to experiment with these techniques on a small scale and “work up” to larger and more comprehensive problems.

REVIEW QUESTIONS

1. Why is it important to maintain a “smooth” resource profile, as shown in Figure 7.1?
2. Assume that you are a project manager who is behind schedule and are faced with this question: Which is more important, a smooth labor resource profile or finishing the project early? If you cannot figure out a precise answer to this question, what are the factors that you should look at before you decide?
3. What does the term “resource leveling” mean? Can this task be carried out using a computer program?
4. Look at the overall cost-loading profile for the Vehicle Maintenance Facility in the appendices, Determine in which month the greatest amount of work takes place.
5. Looking again at the overall cost-loading profile and the bar chart schedule, see if you can determine why there is a significant spike in spending during the early months of the project.
6. Interview a scheduling professional to get his or her take on cost-loaded schedules and earned value systems. In particular, ask whether or not he or she believes these tools are cost-effective.

8 PROCUREMENT SCHEDULING

8 Procurement Scheduling

Our emphasis so far has been on planning and scheduling the physical building tasks necessary to complete a project. However, the construction process involves more than the actual placement of concrete, steel, and other materials. The technical complexity of many of today's construction projects requires the purchase of materials meeting rigorous specifications, often from remote vendors. Contractors often must go through a long review and approval process for these materials, which involves collecting and submitting technical data to the owner and/or architect/engineer for determination of a product's suitability for the project. Only after this review and approval can the actual purchase and installation take place.

Submittal data and procurement are proving to be major problems for many contractors. It is an unavoidable process, but one that can be a significant cause of delay in the overall building process. This chapter provides guidelines for the project manager who is interested in setting up a simple yet effective system using the project's CPM schedule to manage the procurement process. Using the methods outlined here, progress on submittal data and procurements may be tracked and reported accurately and, when used properly, these methods can provide reliable schedule information that will help the project's managers recognize potential problems. Once recognized, these problems can be addressed early, thereby minimizing delays.

THE SOURCE OF THE PROBLEM

Clearly, construction work cannot be performed unless the necessary materials are delivered to the job site on time. For readily available materials, this is usually not much of a problem. In the case of more unusual materials and equipment, the review, approval, and procurement process may create a long lead time. Unfortunately, the longer a lead time, the greater the potential for causing delay. The reasons for procurement delays are many and varied, but some of the most prominent are listed here.

First, the procurement process is inherently cumbersome and involves a considerable amount of detailed record keeping and paperwork. Consequently, there is ample opportunity for error and oversight.

Second, most construction professionals are oriented not to the administration of paperwork, but rather to physical action. Many of their careers have been built around the management of actual construction tasks, not "office work." It is only natural for such individuals to concentrate on the problems in the field, paying less attention to off-site planning.

Third, most of the tasks necessary for good procurement management take place off the site. As a result, the project management team may up in an "out of sight, out of mind" situation. Unless a distinct effort is made to do the necessary administrative tasks, the progress of the procurement process may not be visible and it may, therefore, be ignored.

Fourth, many parts of the process are controlled by others who may not share the project manager's sense of time, schedule, and priorities. For example, the architect/engineer is not contractually obligated to the contractor in any way. He is acting as the agent of the owner, and as such has a limited legal obligation to act expeditiously in carrying out the review tasks required of him. The subcontractors, while legally obligated to the contractor, often do not have the same priorities as the general contractor, and may have equally pressing obligations to other projects. The subcontracting firms may be manned by personnel even less office-oriented than the general contractor, further compounding the "out of sight, out of mind" point of view. Finally, suppliers of materials and equipment have their own schedules for production—schedules that may have only the remotest connection with the general contractor's project. Their production schedules are typically determined by the order in which the materials required for their products are purchased, leaving the contractor with little, if any, control over the fabrication schedule that affects his specific project.

Procurement is an essential process. As we noted earlier, it has the potential to cause significant delays, yet the project manager has only limited control over many parts of the process. It is, therefore, critical that the project manager pay extra attention and take every action to overcome the problems, thereby ensuring a smooth, steady flow of materials to the job.

The key for the project's manager is to ensure that any item of material arrives at the site before it is needed for installation. Fortunately, if CPM techniques are used properly, they can provide a means of coordinating material delivery with the construction schedule to accomplish that end.

BASIC PROCUREMENT PROCEDURES

The basic procurement procedure is typically defined by the architect/engineer and detailed in the project specifications. These procedures typically resemble those outlined schematically in Figure 8.1.

Generally, the project manager begins by issuing a purchase order or subcontract to the appropriate supplier or subcontractor. The supplier or subcontractor then

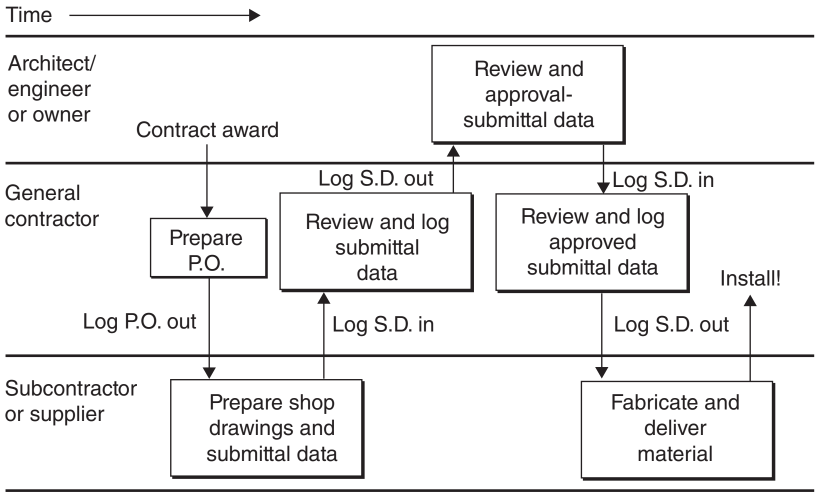


Figure 8.1 Schematic of submittal data/procurement

prepares what is known as *submittal data*, which is transmitted to the general contractor. This submittal data can take many forms. One common type of submittal is shop drawings, which are detailed drawings that further amplify the working drawings for the project. Also, suppliers typically provide *catalog cuts*, which are simply pages from their catalogs that provide technical information describing the materials to be installed and the standards to which the material has been manufactured. Certificates of compliance or inspection reports may also be required.

In any case, the exact requirements should be stated in the project specifications. After a general review by the project manager or other member of the project team, the requirements are transmitted to the owner and architect/engineer for review and approval. Once approved, the submittal documents are transmitted back down the chain to the appropriate parties, who then carry out the tasks of fabrication and delivery. Only after all this has taken place can the material be installed on the project.

KEY ELEMENTS IN SUCCESSFUL PROCUREMENT

Procurement is a straightforward process in most cases. If the quantities of data transmitted are small, there should be few, if any, problems in carrying the procurement out effectively. However, the total amount of data on a typical job is usually very large. To manage procurement activities effectively, the project manager must keep certain key principles in mind and adapt the process to the specific job at hand.

First, it is vital to identify not only the firm (subcontractor or supplier) used at each stage of construction, but also a personal contact at each firm. For example, the architect and/or engineer's offices generally assign specific staff to monitor the designer's reviews. Each subcontractor assigns a project manager; each supplier assigns a salesperson. The project manager (or whomever he assigns to the task of tracking submittal data) should establish a personal working relationship with these representatives and maintain regular contact with them, keeping them informed of concerns and problems at the job site. This contact may be daily early in the project when most of the submittal data is processed. In any case, constant communication is an essential task.

Second, a good tracking system must be maintained. This system has two purposes. The main purpose of the tracking system is to provide a record of two key pieces of information about each item of submittal data.

One item is a notation of when actions were taken during the processing of submittal data up and down the chain, the other is to record who has possession of the submittal data at any given time.

The knowledge of when actions were taken is critical because it provides schedule data about how well the submittal is moving through scheduled review process, which can then be entered into the project's CPM schedule. Once this information about action dates has been factored into the schedule, the project's managers can determine whether or not delays in fabrication or delivery of material have the potential to cause delay.

The second item of information about who has the responsibility for the material at any given stage, which tells the project's managers who needs to be queried about taking further action in order to speed up the approval or fabrication process in order to prevent delays.

Third, communication and follow-up are crucial. For example, it does no good for the project manager to know that the architect is holding up several key shop drawings if no one calls the architect's project manager to promote action on the reviews. Submittal data/procurement probably involves more parties than any other aspect of the overall construction process, and communication problems always increase as the number of communicants grows. In addition to personal contacts with the various parties, it is also an excellent idea to include detailed reviews of submittal data status in the weekly or monthly job schedule meetings. At these meetings, responsibility can be assigned to project team members for tracking down delayed submittals and deliveries which are identified in the meetings.

RECORD KEEPING AND TRACKING

The first task in the management of the procurement process is setting up an efficient record-keeping system. A good system can be maintained easily by the project team members and provides data about the mass of submittals to be developed and submitted during the course of construction. Setting up and maintaining this system is basically a three-step procedure:

1. Making a list of the items that require submittal data
2. Keeping records of their progress in a log
3. Coordinating the submittal data processing with the construction schedule

Making a List of Submittal Items

The first task is determining all of the documents that must be submitted to the owner and architect for approval prior to purchasing the material. Unfortunately, this list will probably be voluminous on all but the smallest jobs. It takes some time to put such a list together; the day after the contract award is not too soon to begin. The starting point for this task is the *project specifications*. If the architect and engineers have done their job properly, each required submittal will be listed in the beginning of each specification section or subsection. Ideally, the specifications should list exactly what documentation is required. If this is not the case, some judgment, based on experience, is required of the person developing the actual list. Ideally, development of this list is assigned to one person in order to prevent gaps. However, on some jobs, preparing a list of submittals may be too large a task for one person to finish in a reasonable period of time.

Once a comprehensive list of submittal items is drawn up, it must be determined exactly who is responsible for the preparation of each item. Most of the submittal items come to the general contractor from subcontractors. If the subcontractor has an organized and professional management system, the general contractor can probably expect submittal items to be delivered on time. The person writing the submittal list must be aware of which subcontractor has the contract for the various elements of each section.

Once the list is developed by the general contractor, the various sublists should be transmitted to the persons responsible for submitting the data. It is a good idea to present these lists to each subcontractor during an initial meeting. At this time, the subcontractor may be asked for commitments on submittal times and delivery. With this information, the project manager can get a better feel for whether or not any of the subcontractor's material deliveries can be expected to cause delay problems. The contractor should also make clear to all subcontractors and suppliers the *procedures* for submitting data. For example, should the material be sent to the home office or to the job site?

Finally, it is impossible to be too thorough in drawing up a list of submittal data items. Very few things are more frustrating to a project manager than to have a job going along smoothly only to discover that everything must come to a halt because a key piece of equipment has not arrived because the need for submittal data was not identified and tracked.

Keeping a Log of Submittal Data Approvals

Once the list of items has been developed and all parties are aware of their responsibilities for submittal and procurement, the submittal items begin to come to the job site for review. The project manager must ensure that detailed and thorough records are established when the first purchase orders are issued then when the submittal items are tracked as the items move up and down the approval process. The easiest and simplest method involves maintaining a log similar to the one shown in Figure 8.2, either on paper or in spreadsheet. This example is not the only acceptable format; any format which can be used to record the key steps in the procurement process is acceptable. Other examples are shown in Figures 8.3 and 8.4. There are also several excellent personal computer programs available that are designed specifically for this purpose.

		P.O. or Sub-contractor		Preparation for Submission		A/E Review and Approval		Fabricate and Deliver			
Spec. Section	Description	No.	Date Sent	Received from Sub.		Date to A/E	Date from A/E	Transmit to Sub.	Deliver to Site	Install	Comments
				SCH							
				ACT							
				SCH							
				ACT							
				SCH							
				ACT							
				SCH							
				ACT							

Figure 8.2 Shop drawing/submittal control log

The procedure for record keeping is quite straightforward: each time a document passes through the project manager's office, it is logged in the appropriate column as it comes into the contractor's office or when it is sent out. The process of logging data consists simply of recording the actions taken by the project team members on the job. For example, when the documents reach the job office, the package or submittal number is assigned and the receipt date is logged under *Purchase Order Issued*, or a similar initial entry. When the documents are sent to and then returned by the architect and/or owner, these dates are logged under *Review/Approval*, and so on.

100 Smith Lane
Kingston, MA 02364
Telephone: 555-1212

Greene and Associates
Construction Management Consultants

Sheet____of___
Date _________

Project ____________________________________ Contractor ______________________________________
Our Job No. ________________________________ Trade _______________________________________

			Shop Drawing Submittals			Arch.Review/Approval			Fabrication and Delivery			
Spec. Sect.	Item	Contract and Date	Sched. Submit Date	Crit. Submit Date	Actual Submit Date	Sched. Appr. Date	Crit. Appr. Date	Actual Appr. Date	Sched. Del. Date	Crit. Del. Date	Actual Del. Date	Work Item Tie-In Point

Figure 8.3 Subcontractors shop drawings/material control

Greene and Associates
Construction Management Consultants

Shop Drawing Checklist — Project: ____________________

Date: ____________________ — Project No.: ____________________

Specification Section	Submittal Item	Submitted to Architect?			Approved?			Returned to Subcontractor		
		Yes	No	Date	Yes	No	Date	Yes	No	Date

Figure 8.4 Shop drawing checklist

The problems with record keeping arise primarily because the volume of documents becomes so great on many jobs. In such cases, hard and fast rules should be preestablished regarding the *processing* of documents. It is important, for example, to establish the maximum amount of time that the documents are permitted to stay under review in the contractor's offices. This time limit varies from contractor to contractor, but should be consistent within the company to ensure that the contractor is not the cause of any delays. Equally important is the establishment of procedures for *transmitting* documents. The project manager should ensure that documents are not allowed to accumulate for several days after approval; there should be a requirement that all processed documents be sent out no later than the following day. Whatever the specific rules, they should ensure *regular, daily* handling of all submittal data.

Coordinating Submittals with the Construction Schedule

One of the keys to effective project management is knowing that *the procurement process should serve the construction schedule, not the other way around*. If work on the job site is to proceed efficiently and smoothly, then the material must reach the craftsmen before it is to be installed. Otherwise, the work sequence is interrupted and must be altered to accommodate disjointed delivery schedules. This situation cannot help but have an adverse effect on overall project time and profit.

To ensure timely delivery of materials, the project manager needs a way to determine the latest acceptable delivery date from the construction schedule and then measure whether or not that delivery date will be met. He must then take all possible action to ensure delivery by that date. The best way to accomplish this goal is to treat the submittal data and procurement tasks as *activities*, just like the construction activities. Figure 8.5 shows that it is possible to convert the sequence of *prepare purchase order, prepare submittal data, review and approve submittal data,* and so on—as shown on the log—to a sequence of critical path activities which are (like construction activities) dependent on one another. The submittal and procurement *activities* can then be assigned scheduled durations in the same way, and the entire string of events that make up the procurement process can be tied to the appropriate construction activity.

This can be illustrated using the maintenance project. For example, the activities necessary to purchase structural steel and joists are shown in Figure 8.5, near the bottom on the bar chart under procurement activities. These tasks are sequential and the final procurement activity, *Fabricate and Deliver—Steel and Joists,* connected to the construction activity *Erect Structural Steel and Joists—All Areas.* The times for these activities are based on various factors. *Prepare purchase order* is an activity within the control of the project manager and can, therefore, be assigned a time by the contractor. Other activity times can be determined by talking to the parties responsible for them. For example, the architect or owner may state in the project specifications that *Review and Approval* will take one month; the subcontractor may require three weeks to *Prepare Shop Drawings* and five weeks to *Fabricate and Deliver* the material. In our sample case, the times for each activity are:

Prepare purchase order – structural steel	2 days
Prepare shop drawings – structural steel	14 days
Review and approve shop drawings – structural steel	30 days
Fabricate and deliver structural steel	35 days
Total time for submittal data, review, fabrication, and delivery	86 days

Scheduling procurement activities is relatively easy from an technical standpoint. The basic sequence of events is typically standard for a given project, and a project manager can set up a chain of activities for each procurement item, and it would be repeated for each type of material being tracked in the schedule. These chains of activities can then be connected to the relevant construction activity. The forward pass, backward pass, and float calculations work in exactly the same manner as before, and a schedule of start and finish times for procurement activities can be generated just as it is for construction activities.

Figure 8.5 is a bar chart that shows our sample case from the maintenance garage. For clarity, it shows just the procurement and erection activities for the structural steel and joists. Note that the procurement process begins right after *Notice to Proceed*, which should be the case for all initial procurement tasks.

The schedule shows that the steel should be delivered on time; however, there are only 12 days of float on the procurement activities, and there is no float on the

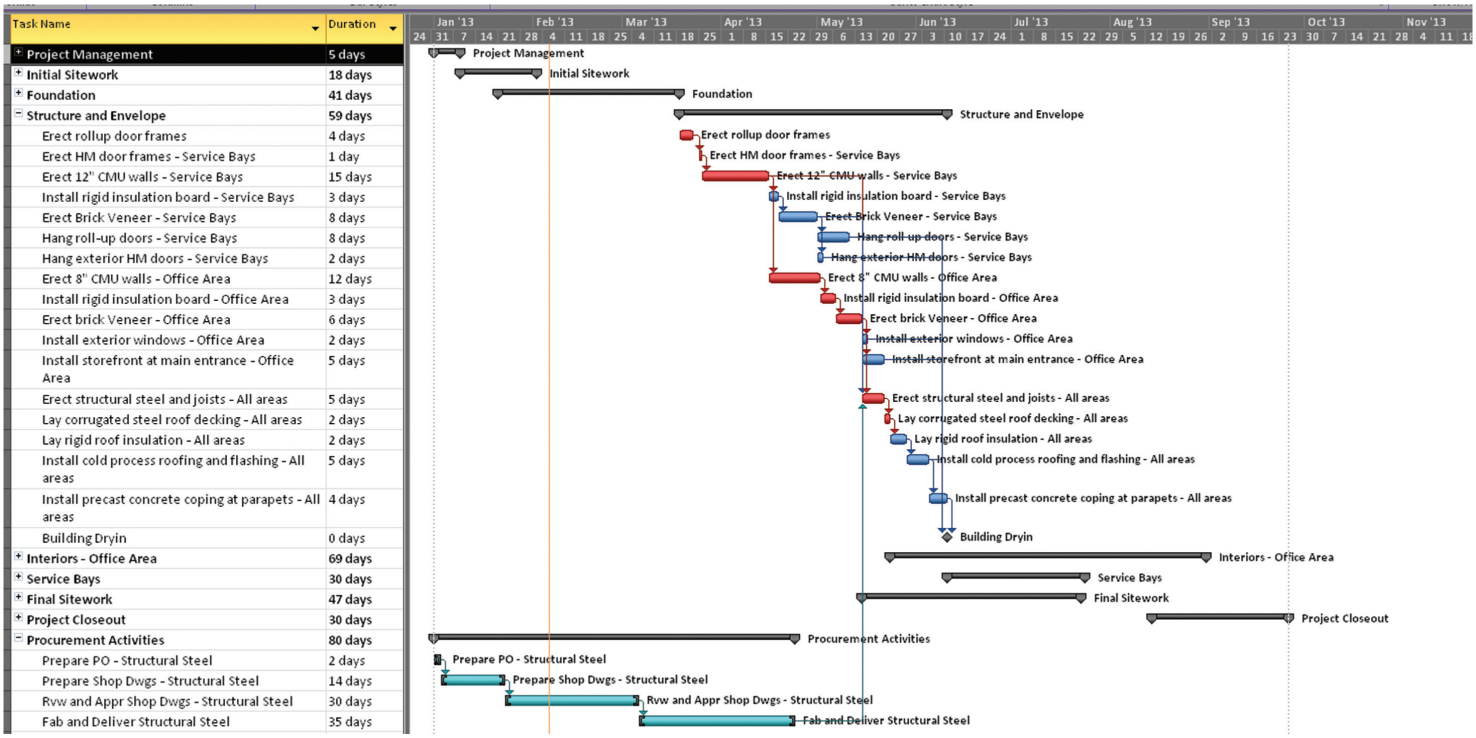


Figure 8.5 Bar chart showing procurement activities. Used with permission from Microsoft.

activity Erect Structural Steel and Joists. Any slippage during the procurement for the steel beyond the 12 days float figure could cause the project as a whole to be delayed. If all goes according to plan, the steel will be delivered with 12 days to spare, and the project will continue as planned.

If any procurement activities do slip, however, the situation becomes is quite different. In this case, the project manager might have to make the architect aware of the need for a particularly quick review in this one case. Or, he could contact the supplier of steel, and ask that special attention be given to the first steel items. In any case, scheduling and then enforcing the time limits on submittal data tasks is just as necessary to the timely completion of the job as is the monitoring of construction activities. The first step in preventing procurement delays is key is maintaining a good tracking system and coordinating procurement and construction in the overall project schedule.

ISSUES WITH SCHEDULING PROCUREMENT ACTIVITIES

One of the problems with using the CPM schedule to track procurement activities is the sheer volume of activities that procurement can generate. It is not uncommon for a CPM schedule to have as many procurement activities as there are construction activities, plus tracking progress on procurement tends to be more difficult than for construction. Sometimes a construction schedule can seriously flawed by virtue of inaccurate information being recorded on procurement activities, with the result that the construction all-important construction critical path becomes obscured. In a large project schedule where many procurement chains are connected to the construction schedule, it can become very difficult to determine where the procurement is affecting the overall project, which violates the basic “rule” that construction should drive the procurement process and not vice versa.

One solution to this problem is run a separate procurement schedule and not connect procurement to the construction activity as part of the overall schedule. The procurement dates can then be compared by hand or in a spreadsheet to the construction dates, and the project manager can be sure that the integrity of the construction sequence he has set up is maintained.

REPORTING

Once the tracking procedures are underway and operating normally, the project manager must use the information developed to see that the submittals and purchases are carried out. The first step is to determine where the hold-ups exist in the process. The data must be viewed from two perspectives.

First, which pieces of submittal data are not meeting the scheduled dates? This determination should be done no less than weekly. It requires a detailed examination of the control log, and flagging of those submittals that have not met their dates. The list of flagged items should be broken down by the party responsible: subcontractors, architect, owner, and so forth. Separate lists should be made for each responsible party, showing how many submittals are in their hands, and the status of each submittal relative to the scheduled date. These lists can then be used in weekly job review meetings or in one-on-one sessions to review status and devise solutions for problem areas.

Developing status lists for submittal data can be done manually, by simply going through each log one at a time or through the CPM schedule and picking out the behind-schedule submittals. This task is much easier if there is a separate log maintained for each subcontractor and supplier. The submittal control log can be kept on an ordinary microcomputer spreadsheet program, which will make the analysis somewhat less tedious.

FOLLOW UP ON THE INFORMATION

Finally, follow-up is essential to the successful management of submittal data and procurement. The daily pressures of a construction project are such that it is very easy to fall into a pattern of performing the update and review on only an occasional basis. Unfortunately, this is an almost certain path to disaster. The procurement process requires regular, consistent, thorough record keeping and follow-up if the materials are to arrive on time, and if the process is to support the construction effort and not vice versa. In the case of our hollow metal door frames, 17 weeks is a long time for a purchase order to be out. This situation needs follow-up at no less than monthly and probably at two-week intervals. With this kind of regular monitoring, the manufacturer of the hollow metal door frames cannot let the fabrication schedule slip without the project manager knowing about it.

SUMMARY

We discussed in this chapter the task of tracking procurement and submittal data. As the reader has seen, this process is always necessary, but hopefully the principles and techniques presented will reduce the task from being onerous and cumbersome to one which is merely tedious.

REVIEW QUESTIONS

1. Why is procurement scheduling so important?
2. Interview a project engineer on a project, and ask him or her the following questions:
   a. How did he create the master list of required submittals?
   b. How does he keep a log of submittal transactions? In a project management program, such as Prolog or Contract Manager, in spreadsheet, in an hand entered log, or in the overall CPM Schedule?
   c. Is there a company policy about the maximum number of days allowed before a submittal must be processed and sent on to the next party?
   d. In his opinion, what is the most difficult aspect of dealing with submittals?
3. What does this phase mean, "the submittal schedule must serve the construction schedule"?

9 LINE OF BALANCE SCHEDULING

9 Line of Balance Scheduling

Our emphasis so far has been on developing and using the critical path method (CPM) for scheduling construction projects. There are, however, some types of work for which traditional CPM is not well suited, such as projects that are not easily divisible into work segments. In this chapter, we will address an alternative to CPM scheduling—line of balance scheduling—and provide an illustrative example.

WHEN TO USE LINE OF BALANCE SCHEDULING

As we have seen, CPM is based on the fact that most construction work can be broken down into separate activities, which can then be analyzed and sequenced to find the best overall schedule for completing the work. This means that when an activity consisting of one type of work ends, after a relatively short period, we must then proceed with a different crew and set of equipment in order to do the next activity's work. For example, in order to build a typical home, we must grade the site, excavate the foundation and place it, frame the structure, and then install siding and roofing so the house is dried in. Once that is done, we can then rough in the interior and install the finishes. None of these activities typically lasts for more than a small part of the overall construction duration, and each crew is generally responsible for only a portion of the work. Also, the crews normally do not work continuously over the entire scope of the work or for long periods of time.

There are, however, some projects that do not fit this mold. For example, in many types of work, the same crews work continuously from beginning to end. Examples of this type of project include high-rise construction, pipeline installation, and mass housing. Also, many types of heavy/civil work, such as canals, tunnels, highway construction, and many large dams, are set up this way.

The key element to note about these types of projects is that they lack the distinctive, individual segments, such as foundations, columns, floors, or curtain walls, that make CPM work so well. Instead, in these projects, there is only one "segment" as such, which is usually fairly large and essentially the same from one point to another. Also, every part of the project is similar to all other parts.

For example, consider an airport runway. Even though the runway might be very large, perhaps two miles long, it is essentially the same at all points. The base at both ends will be the same thickness, as will the asphalt or concrete paving. There are no definable segments or parts, so the CPM technique of breaking the job down into parts defined by physical location, type of material, or crew composition does not work well.

Fortunately, however, an alternative can be found in the *linear scheduling method*, also referred to as *line of balance*, *velocity diagrams*, *or production curves*. Civil engineering contractors and others have adapted this scheduling tool used by other industries, primarily manufacturing. Although the names vary from industry to industry, the basic technique is essentially the same. For our purposes, we will use the term *line of balance scheduling* in this book.

The line of balance method uses a straightforward visual representation that mimics the way linear work is normally done. As an illustration, consider the runway project in more detail. When a contractor starts a runway or similar job, he or she typically starts a clearing crew at one end of the project, and that crew will then work along the path until the end of the runway. After the clearing crew starts, a grading crew will follow, then a crew to lay and compact base material, and so on. As noted earlier, the work of each crew is the same from beginning to end, and each crew performs work over the entire length of the runway.

Also, a superintendent would not wait until the clearing crew had reached the far end of the runway before starting the next crew. He or she would be far more likely to observe the clearing crew as it went down the runway, and when there was enough space between the two, start the grading crew. The superintendent would then keep tabs on both crews to see that they did not interfere with one another. He or she would readily accept the fact that several more crews would end up working on the same runway at the same time, but that the situation is controllable because all crews can be clearly seen and conflicts avoided. A crew that was holding up following crews would have to be speeded up, and a crew that was in danger of overrunning the one ahead would have to be restrained in its progress. The superintendent would also know that the key to making this work is keeping the rates of progress of the crews along the runway roughly similar, and providing sufficient space between the crews so that there is no interference.

It turns out that it is relatively easy to display these factors—rate of progress and crew separation—in a simple graphical form that has been used by many contractors to control linear work quite well. The technique for developing a linear schedule involves a simple four step process, and it is this technique that we will focus on in the rest of this chapter.

GENERAL TECHNIQUE

As with CPM, developing a line of balance schedule (LOB) can be broken down into a series of basic steps that build upon one another. Also, even though line of balance uses different concepts than CPM, it turns out that some of the techniques we used in CPM are also useful here. In any case, the basic steps for creating a good LOB schedule are as follows.

Step 1: Break the Work Down into Activities or Tasks

The first step is to divide the work into activities and crews that can move as units along the sequence of work. This breakdown is usually defined by physical relationships, as well as by crew groupings. For example, if the project is to build a road, laying down a base course is a different task from paving. In this step, the most important consideration is to define those activities or tasks that have crews that move as a unit along the path of work, and that move more or less continuously and independently as a unit from one end to the other.

For example, consider concrete paving. A paving crew typically starts out in the morning and moves down the area to be paved as the day proceeds. All aspects of the paving work must work as a unit in order to lay the concrete properly. It is true that paving progress is dependent on the fine grading that precedes it, but only in the sense that the fine grading must be completed before the paving crew arrives at a given station along the road. Paving does not depend on any crew or equipment from the grading crew, nor does the grading crew rely on any part of the concrete crew.

Consequently, each crew can move at its own pace, with its own resources and production capabilities. This is the most important thing when creating activities for this type of schedule.

Along this line, it should be noted that a crew for a given activity can often consist of a collection of crews and equipment, all of which are carefully sized to complement one another and create the maximum rate of progress along the work with a minimum of cost. In the case of concrete paving, this collection would most likely include a reinforcing crew, a placement crew, a finishing crew, a curing crew, and whatever machinery each needs to do its work.

Step 2: Calculate Overall Duration for Each Activity

The second step of the process is identical to calculating activity duration for a CPM schedule. In this step, the scheduler determines how much work is required to finish each activity, decides on crews and production rates, then calculates how long the work will take for the entire activity. For example, consider a crew laying down the concrete paving mentioned in the previous step. First, a scheduler would find the total square yards of paving to be laid, then he or she would determine the crew and set of equipment that would be used to do the work. If the total area to be paved was 10,000 square yards, and a typical crew of one foreman, plus 10 cement finishers and laborers could lay 2,750 square yards per day, the time required to pave the entire job would be 10,000/2,750 or 3.64 days. In order to be on the safe side, we would normally round up to four days, as we did with CPM durations.

Step 3: Plot All Activities on a Single Chart

This step differs from a CPM schedule in that, instead of creating a logic diagram and then doing a forward and backward pass, the scheduler will represent a sequence of work and time for each activity and the project as a whole in a single diagram.

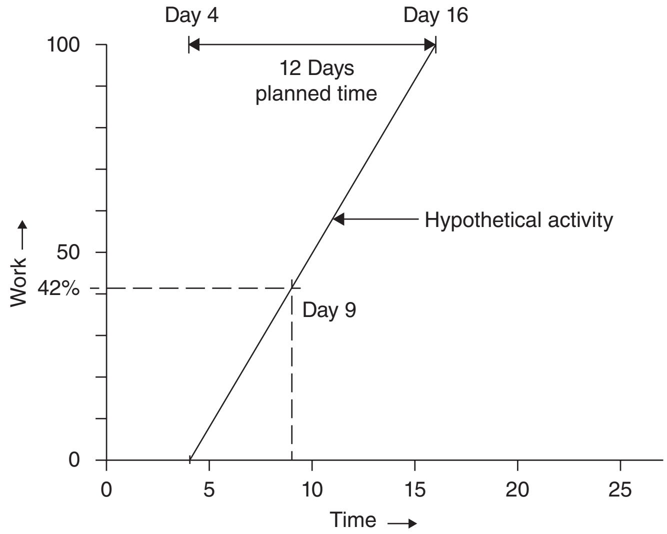


Figure 9.1 Typical LOB schedule format

A typical format for a line of balance schedule is shown in Figure 9.1. Standard practice is to plot work on the Y-axis, and time on the X-axis. It should be noted that work can be measured in any appropriate unit. For highway work, it would probably be station number, or for mass housing it would number of houses. In the case of this example, work is shown as a percentage, which is a simple unit used for many types of work that deal with several disparate units. Also, time can be measured in any unit—days, weeks, or months.

An example of how an activity would be plotted is shown as Hypothetical Activity A. This activity begins at Day 4, continues for 12 days, and ends on Day 16. The diagram also shows that interim data can be derived from the plot, as in the example of the indication that the activity should reach 42% as of Day 9.

We should also note that progress can be shown in other units of measure, such as feet of pipe laid or percent work complete. It is particularly important to note, as you will see later in the example problem, that all activities use a common unit of measure.

Step 4: Examine the Resulting Plot, and Adjust Rates of Progress

After the first schedule has been plotted, it is then necessary to examine the results to see if they can be further refined to plan the project for the best possible mix of crews and overall project time. This is done by observing the slopes of the activity lines and adjusting crew sizes, equipment, and so forth to either speed up an activity or slow it down. Our convention is that steep slopes represent activities that move quickly; shallower slopes represent slower activities. We will cover this process in detail as we work through the scheduling of the example problem, which follows this section.

EXAMPLE PROBLEM

The best way to learn the skill of creating a line of balance schedule is to carry out all the steps for a sample project, as we did earlier in the book with the sample office building. In this case, a hypothetical civil engineering problem will be used—the removal and replacement of a existing runway. In our case, we are assuming a small city will be replacing an old 50 foot by 7,000 foot asphalt runway with a new concrete runway that will be 75 feet by 7,000 feet. The specifics of the project are as follows:

1. The old runway is standard asphalt, built up to a thickness of 6 inches by repeated repair overlays done throughout the years. This asphalt is to be removed for recycling and used elsewhere.
2. The old base has deteriorated over time and is to be replaced by a new compacted gravel base.
3. The subsoil is to be removed and replaced with engineered fill.
4. The new concrete paving will be 8 inches thick with a scored surface.
5. All crews are to stay at least 1,500 feet apart to prevent conflicts.
6. The contractor has readily available sources of materials and enough trucks so that removal and delivery of materials do not affect the schedule.

In order to simplify the problem for illustration purposes, some typical elements of a runway have been omitted, including shoulders, runway lighting, runway marking, and so forth. Cross sections of the hypothetical runways are shown in Figure 9.2

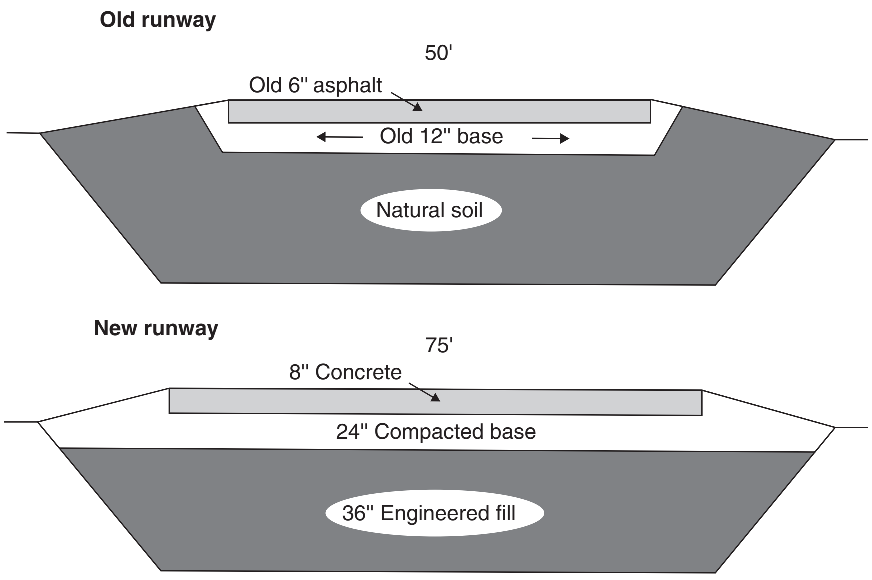


Figure 9.2 (a) Old runway (b) new runway

Step 1: Break the Work Down Into Activities

In this case, the work would involve removing the old asphalt, then excavating the base and subsoil down to a depth of 5 feet. After this, a new 4-foot layer of subsoil brought in from offsite would be laid and compacted to bring the grade up to a depth of minus 1 foot. After that, a new 1-foot gravel base would be laid and compacted to bring the grade up to ground level. The concrete runway itself would be placed, and, after it set, grooving would take place. All crews would start at one end, referred to as Station 0 + 00, and work along the runway to Station 70 + 00. (In this example, standard station number notation is used to indicate location on the project. Station 0 + 00 refers to the beginning of the runway, and Station 70 + 00 means the other end of the runway, 7,000 feet away.)

A logical set of tasks for building the runway would be as follows. Each task would have its own crew(s) and, as noted earlier, can proceed independently from one end to the other. The tasks are: remove old asphalt, remove base and subsoil, lay and compact new subsoil, lay and compact new gravel base, place new concrete, and groove concrete.

Step 2: Calculate Overall Duration for Each Activity

First, a rate of production for each activity must be found, and using that, an overall duration for the activity can be calculated. The first step should be to find appropriate sources of production information, such as in RSMeans cost data publications. Other sources that can be used include the company's own historical data. In the case of equipment, most manufacturers provide excellent manuals for production planning. Any source is acceptable, provided that the data is accurate and fits the planned work. Once the production rate has been found, an overall time for the activity is calculated, which must be based on scope of work. Production rates are normally expressed in units of production per hour or per day, depending on the source.

Several points about calculating total duration times should be noted. First, in many types of work, particularly civil engineering, production is often determined by equipment rather than labor. Second, even though production data is often measured in a variety of units, overall times should be recalculated and expressed in common units. This usually means that production rates measured in cubic yards, square yards, or lineal feet should be converted to some measure common to the job as a whole. This is particularly important so that the rates of progress on each activity can be compared in like terms. An example of how this is done is illustrated later in this sample problem.

As was the case for calculating activity times for CPM schedules, for line of balance schedules, the scheduler should assume normal working conditions, evaluate each activity independently, and use consistent time units, typically work days. The schedule will be adjusted for variable at a later stage in the planning process.

For example, to calculate overall duration for the first activities (removing old asphalt, base, and subsoil), the techniques described in Chapter 6 will be used,

Table 9.1 Runway Replacement Work Quantities

Task	Quantity	Unit
Remove old asphalt	38,889	SY
Remove old base and soil	162,037	CY
Lay down and compact new subsoil	97,222	CY
Lay down and compact new gravel base	64,815	CY
Place and finish new concrete	58,333	SY
Groove concrete	58,333	SY

particularly the daily production rate method. The quantities provided in Table 9.1 will also be needed. In real life, these quantities can be calculated from plans, but, with any luck, they will be provided by the company's own estimating department.

Item 1: Remove Old Asphalt

From the table in Table 9.1, the quantity of work for removing old asphalt is 38,889 SY. Figure 9.3 shows that the daily production rate of crew B-38 is 420 SY per day. This value can be found in RSMeans *Heavy Construction Cost Data,* or any other appropriate source. Crew B-38 consists of one hydraulic hammer, one backhoe loader, and one front end loader, plus the labor necessary to operate this machinery. (See Figure 9.4.) Using this data, the total time for pavement removal can be calculated as follows:

$$38{,}889 \text{ SY} / 420 \text{ SY per Day} = 92.59 \text{ Days}$$

In order to be realistic, this figure should be rounded up to the next whole day, for example, 93 days.

Item 2: Remove Base and Subsoil

Continuing with the calculations, the scope of work for removing the old base and subsoil is 162,037 CY. RSMeans *Heavy Construction Cost Data* 2004, in Figure 9.5, shows that the daily production rate of crew B-10P is 1,040 CY per day. Crew B-10P consists of a track-mounted front end loader with a 2.5 CY bucket, plus the labor

Table 9.2 LOB Schedule: Runway Replacement Initial Plot

Task	Quantity	Units	Production Rate/Day	Total Days	Days/ 1000 feet	Feet/Day
Remove old asphalt	38,889	SY	420	93	12.9	76
Remove old base and soil	162,037	CY	1,040	156	21.6	45
Lay down and compact new subsoil	97,222	CY	600	162	22.5	43
Lay down and compact new gravel base	64,815	CY	1,300	50	6.9	140
Place and finish new concrete	58,333	SY	3,800	15	2.1	456
Groove concrete	58,333	SY	2,750	21	2.9	330

necessary to operate this machinery. (See Figure 9.6.) Using this data, the total time for base and soil excavation can be calculated as follows:

$$162{,}037 \text{ CY} / 1{,}040 \text{ CY per Day} = 155.8 \text{ Days}$$

Again, to be realistic, we round this figure up to the next whole day, e.g., 156 days.

Remaining Activities

Continuing this process, the overall times for all six activities defined for the project are as shown in Table 9.2.

Notes about This Process

First, it should be noted that other choices of crews and equipment can be used to do this work. For example, for excavating the old base and subsoil, a wheel-mounted or track-mounted excavator could have been selected, as well as different sized buckets. In any case, a superintendent experienced in this type of work would undoubtedly have a better feel for the realities of using equipment and for probable production rates, and could make a better choice. Planning could also be based on the equipment already owned by the contractor. However, the methodology of this process would be the same, regardless of who is doing the planning or what the source of data.

Second, note that different activities have their scope of work and production rates measured in different units, either square yards or cubic yards. An important fact is that these different kinds of units are converted to a common unit of measure, such as total days. This value can be later converted to a common rate of progress, specifically total feet of progress along the runway. This is a very important aspect of line of balance scheduling, as it allows one to compare like units when trying to mesh crews of different trades.

Step 3: Plot All Activities on a Single Chart

Using the standard format that we used in Figure 9.1, and the activity times we have in Table 9.2, we can now plot the activities for the runway. The result is the diagram shown in Figure 9.7. This plotted schedule shows all six activities for the project, starting one after another, and all proceeding along the length of the runway. We can see, however, that the activities have unequal slopes (e.g., unequal rates of progress), and the relationship between start and finish times is not readily apparent. The problem is one of ensuring that there are no conflicts between crews, and trying to time the crew progress in such a way as to provide the most efficient progress during the job. The process of resolving these problems is considered in the next sections.

Generally, crews may be in conflict for several reasons. One is that the space a crew actually will need to do their work is not fully taken into consideration. For example, an excavation crew would probably take up relatively little space along the runway, but a crew laying down soil and compacting it, would take up more space because it needs to lay out the soil in long strips using a sheep's-foot roller. The best person to consult about this potential overlap is the superintendent or foremen on the job.

02200 | Site Preparation

	02220 | Site Demolition		CREW	DAILY OUTPUT	LABOR-HOURS	UNIT	2004 BARE COSTS MAT.	LABOR	EQUIP.	TOTAL	TOTAL INCL O&P	
250	0010	**DEMOLISH, REMOVE PAVEMENT AND CURB**										250
	5010	Pavement removal, bituminous roads, 3'' thick	B-38	690	.058	S.Y.		1.69	1.17	2.86	3.88	
	5050	4'' to 6'' thick		420	.095			2.78	1.92	4.70	6.40	
	5100	Bituminous driveways		640	.063			1.82	1.26	3.08	4.19	
	5200	Concrete to 6'' thick, hydraulic hammer, mesh reinforced		255	.157			4.57	3.17	7.74	10.50	
	5300	Rod reinforced		200	.200			5.85	4.04	9.89	13.40	
	5400	Concrete 7'' to 24'' thick, plain		33	1.212	C.Y.		35.50	24.50	60	81	
	5500	Reinforced		24	1.667	,,		48.50	33.50	82	112	
	5600	With hand held air equipment, bituminous, to 6'' thick	B-39	1,900	.025	S.F.		.69	.08	.77	1.16	
	5700	Concrete to 6'' thick, no reinforcing		1,600	.030			.82	.10	.92	1.38	
	5800	Mesh reinforced		1,400	.034			.94	.11	1.05	1.58	
	5900	Rod reinforced		765	.063			1.72	.21	1.93	2.89	
	6000	Curbs, concrete, plain	B-6	360	.067	L.F.		1.87	.58	2.45	3.51	
	6100	Reinforced		275	.087			2.45	.76	3.21	4.59	
	6200	Granite		360	.067			1.87	.58	2.45	3.51	
	6300	Bituminous		528	.045			1.27	.39	1.66	2.39	
310	0010	**SELECTIVE DEMOLITION CUTOUT**										310
	0020	Concrete, elev. slab, light reinforcement, under 6 CF	B-9C	65	.615	C.F.		16.25	2.46	18.71	28	
	0050	Light reinforcing, over 6 C.F.	,,	75	.533	,,		14.10	2.13	16.23	24.50	
	0200	Slab on grade to 6'' thick, not reinforced, under 8 S.F.	B-9	85	.471	S.F.		12.40	1.88	14.28	21.50	
	0250	Not reinforced, over 8 S.F.		175	.229	,,		6.05	.91	6.96	10.40	
	0600	Walls, not reinforced, under 6 C.F.		60	.667	C.F.		17.60	2.67	20.27	30.50	
	0650	Not reinforced, over 6 C.F.		65	.615			16.25	2.46	18.71	28	
	1000	Concrete, elevated slab, bar reinforced, under 6 C.F.	B-9C	45	.889			23.50	3.56	27.06	40.50	
	1050	Bar reinforced, over 6 C.F.	,,	50	.800			21	3.20	24.20	36.50	
	1200	Slab on grade to 6'' thick, bar reinforced, under 8 S.F.	B-9	75	.533	S.F.		14.10	2.13	16.23	24.50	
	1250	Bar reinforced, over 8 C.F.	,,	105	.381	,,		10.05	1.52	11.57	17.35	
	1400	Walls, bar reinforced, under 6 C.F.	B-9C	50	.800	C.F.		21	3.20	24.20	36.50	
	1450	Bar reinforced, over 6 C.F.	,,	55	.727	,,		19.20	2.91	22.11	33	
	2000	Brick, to 4 S.F. opening, not including toothing										
	2040	4'' thick	B-9C	30	1.333	Ea.		35	5.35	40.35	61	
	2060	8'' thick		18	2.222			58.50	8.90	67.40	101	
	2080	12'' thick		10	4			106	16	122	182	
	2400	Concrete block, to 4 S.F. opening, 2" thick		35	1.143			30	4.57	34.57	52	
	2420	4'' thick		30	1.333			35	5.35	40.35	61	
	2440	8'' thick		27	1.481			39	5.95	44.95	67.50	
	2460	12'' thick		24	1.667			44	6.65	50.65	76	
	2600	Gypsum block, to 4 S.F. opening, 2" thick	B-9	80	.500			13.20	2	15.20	22.50	
	2620	4'' thick		70	.571			15.10	2.29	17.39	26	
	2640	8'' thick		55	.727			19.20	2.91	22.11	33	
	2800	Terra cotta, to 4 S.F. opening, 4" thick		70	.571			15.10	2.29	17.39	26	
	2840	8'' thick		65	.615			16.25	2.46	18.71	28	
	2880	12'' thick		50	.800			21	3.20	24.20	36.50	
	3000	Toothing masonry cutouts, brick, soft old mortar	1 Brhe	40	.200	V.L.F.		5.10		5.10	7.80	
	3100	Hard mortar		30	.267			6.85		6.85	10.40	
	3200	Block, soft old mortar		70	.114			2.93		2.93	4.46	
	3400	Hard mortar		50	.160			4.10		4.10	6.25	
	6000	Walls, interior, not including re-framing										
	6010	Openings to 5 S.F.										
	6100	Drywall to 5/8'' thick	1 Clab	24	.333	Ea.		8.65		8.65	13.50	
	6200	Paneling to 3/4'' thick		20	.400			10.40		10.40	16.20	
	6300	Plaster, on gypsum lath		20	.400			10.40		10.40	16.20	
	6340	On wire lath		14	.571			14.85		14.85	23	
	7000	Wood frame, not including re-framing, openings to 5 S.F.										
	7200	Floors, sheathing and flooring to 2'' thick	1 Clab	5	1.600	Ea.		41.50		41.50	65	
	7310	Roofs, sheathing to 1'' thick, not including roofing		6	1.333			34.50		34.50	54	

Figure 9.3

Crews

Crew No.	Bare Costs		Incl. Subs O & P		Cost Per Labor-Hour	
Crew B-35	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Laborer Foreman (out)	$28.00	$224.00	$43.60	$348.80	$31.88	$48.72
1 Skilled Worker	33.65	269.20	52.35	418.80		
1 Welder (plumber)	39.60	316.80	59.45	475.60		
1 Laborer	26.00	208.00	40.50	324.00		
1 Equip. Oper. (crane)	34.80	278.40	52.40	419.20		
1 Equip. Oper. Oiler	29.20	233.60	44.00	352.00		
1 Electric Welding Mach.		77.75		85.55		
1 Hyd. Excavator, .75 C.Y.		458.80		504.70	11.18	12.30
48 L.H. Daily Totals		$2066.55		$2928.65	$43.06	$61.02
Crew B-35A	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Laborer Foreman (out)	$28.00	$224.00	$43.60	$348.80	$31.04	$47.54
2 Laborers	26.00	416.00	40.50	648.00		
1 Skilled Workers	33.65	269.20	52.35	418.80		
1 Welder (plumber)	39.60	316.80	59.45	475.60		
1 Equip. Oper. (crane)	34.80	278.40	52.40	419.20		
1 Equip. Oper. Oiler	29.20	233.60	44.00	352.00		
1 Welder, 300 amp		75.20		82.70		
1 Crane, 75 Ton		1217.00		1338.70	23.08	25.38
56 L.H., Daily Totals		$3030.20		$4083.80	$54.12	$72.92
Crew B-36	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Labor Foreman (outside)	$28.00	$224.00	$43.60	$348.80	$29.46	$45.20
2 Laborers	26.00	416.00	40.50	648.00		
2 Equip. Oper. (med.)	33.65	538.40	50.70	811.20		
1 Dozer, 200 H.P.		863.40		949.75		
1 Aggregate Spreader		41.40		45.55		
1 Tandem Roller, 10 Ton		183.60		201.95	27.21	29.93
40 L.H., Daily Totals		$2266.80		$3005.25	$56.67	$75.13
Crew B-36A	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Labor Foreman (outside)	$28.00	$224.00	$43.60	$348.80	$30.66	$46.77
2 Laborers	26.00	416.00	40.50	648.00		
4 Equip. Oper. (med.)	33.65	1076.80	50.70	1622.40		
1 Dozer, 200 H.P,		863.40		949.75		
1 Aggregate Spreader		41.40		45.55		
1 Roller, Steel Wheel		183.60		201.95		
1 Roller, Pneumatic Wheel		244.60		269.05	23.80	26.18
56 L.H., Daily Totals		$2266.80		$4085.50	$54.46	$72.95
Crew B-36B	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Labor Foreman (outside)	$28.00	$224.00	$43.60	$348.80	$30.13	$45.96
2 Laborers	26.00	416.00	40.50	648.00		
4 Equip. Oper. (medium)	33.65	1076.80	50.70	1622.40		
1 Truck Drive, Heavy	26.45	211.60	40.30	322.40		
1 Grader, 30,000 Lbs,		432.00		475.20		
1 F.E. Loader, crl, 1.5 C.Y.		354.40		389.85		
1 Dozer, 300 H.P.		1099.00		1208.90		
1 Roller, Vibratory		436.80		480.50		
1 Truck, Tractor, 240 H.P.		331.60		364.75		
1 Water Tanker, 5000 Gal.		118.00		129.80	43.31	47.64
64 L.H., Daily Total		$4700.20		$5990.60	$73.44	$93.60

Crew No.	Bare Costs		Incl. Subs O & P		Cost Per Labor-Hour	
Crew B-36C	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Labor Foreman (outside)	$28.00	$224.00	$43.60	$348.80	$31.08	$47.20
3 Equip. Oper. (medium)	33.65	807.60	50.70	1216.80		
1 Truck Driver, Heavy	26.45	211.60	40.30	322.40		
1 Grader, 30,000 Lbs.		432.00		475.20		
1 Dozer, 300 H.P.		1099.00		1208.90		
1 Roller, Vibratory		436.80		480.50		
1 Truck, Tractor, 240 H.P.		331.60		364.75		
1 Water Tanker, 5000 Gal.		118.00		129.80	60.44	66.48
48 L.H. Daily Totals		$3660.60		$4547.15	$91.52	$113.68
Crew B-37	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Labor Foreman (outside)	$28.00	$224.00	$43.60	$348.80	$27.36	$42.33
4 Laborers	26.00	832.00	40.50	1296.00		
1 Equip. Oper. (light)	32.15	257.20	48.40	387.20		
1 Tandem Roller, 5 Ton		108.20		119.20	2.25	2.48
48 L.H. Daily Totals		$1421.40		$2151.00	$29.61	$44.81
Crew B-38	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Labor Foreman (outside)	$28.00	$224.00	$43.60	$348.80	$29.16	$44.74
2 Laborers	26.00	416.00	40.50	648.00		
1 Equip. Oper. (light)	32.15	257.20	48.40	387.20		
1 Equip. Oper. (medium)	33.65	269.20	50.70	405.60		
1 Backhoe Loader, 48 H.P.		207.80		228.60		
1 Hyd. Hammer, (1200 lb)		112.00		123.20		
1 F.E. Loader, (170 H.P.)		438.40		482.25		
1 Pavt. Rem. Bucket		50.00		55.00	20.21	22.23
48 L.H., Daily Totals		$1974.60		$2678.65	$49.37	$66.97
Crew B-39	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Labor Foreman (outside)	$28.00	$224.00	$43.60	$348.80	$27.36	$42.33
4 Laborers	26.00	832.00	40.50	1296.00		
1 Equip. Oper. (light)	32.15	257.20	48.40	387.20		
1 Air Compr., 250 C.F.M		127.60		140.35		
2 Air Tools & Accessories		22.40		24.65		
2-50 Ft. Air Hoses, 1.5" Dia.		10.00		11.00	3.33	3.67
48 L.H., Daily Totals		$1473.20		$2208.00	$30.69	$46.00
Crew B-40	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Pile Driver Foreman (out)	$34.05	$272.40	$56.25	$450.00	$32.63	$52.11
4 Pile Drivers	32.05	1025.60	52.95	1694.40		
1 Equip. Oper. (crane)	34.80	556.80	52.40	838.40		
1 Equip. Oper. Oiler	29.20	233.60	44.00	352.00		
1 Crane, 40 Ton		915.20		1006.70		
1 Vibratory Hammer & Gen.		1403.00		1543.30	36.22	39.84
64 L.H., Daily Totals		$4406.06		$5884.80	$68.85	$91.95
Crew B-41	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Labor Foreman (outside)	$28.00	$224.00	$43.60	$348.80	$26.91	$41.76
4 Laborers	26.00	832.00	40.50	1296.00		
.25 Equip. Oper. (crane)	34.80	69.60	52.40	104.80		
.25 Equip. Oper. Oiler	29.20	58.40	44.00	88.00		
.25 Crawler Crane, 40 Ton		228.80		251.70	5.20	5.72
44 L.H., Daily Totals		$1412.80		$2089.30	$32.11	$47.48

Figure 9.4

02300 | Earthwork

	02315	Excavation and Fill		Crew	Daily Output	Labor-Hours	Unit	2004 Bare Costs				Total Incl O&P	
								Mat.	Labor	Equip	Total		
418	0010	**RIPPING**	R02315 -450										418
	0020	Ripping, trap rock, soft, 300 HP dozer, ideal conditions		B-11S	700	.017	C.Y.		.53	1.67	2.20	2.65	
	1500	Adverse conditions			660	.018			.57	1.77	2.34	2.81	
	1600	Medium hard, 300 HP dozer, ideal conditions			600	.020			.62	1.95	2.57	3.09	
	1700	Adverse conditions			540	.022			.69	2.17	2.86	3.43	
	2000	Very hard, 460 HP dozer, ideal conditions		B-10X	350	.034			1.07	4.21	5.28	6.25	
	2100	Adverse conditions		"	310	.039			1.20	4.75	5.95	7.10	
	2200	Shale, soft, 300 HP dozer, ideal conditions		B-11S	1,500	.008			.25	.78	1.03	1.24	
	2300	Adverse conditions		"	1,350	.009			.28	.87	1.15	1.37	
	2310	Grader, rear ripper, 180 H.P. ideal conditions		B-11L	740	.022			.64	.58	1.22	1.63	
	2320	Adverse conditions		"	630	.025			.76	.69	1.45	1.91	
	2400	Medium hard, 300 HP dozer, ideal conditions		B-11S	1,200	.010			.31	.97	1.28	1.54	
	2500	Adverse conditions		"	1,080	.011			.35	1.08	1.43	1.72	
	2510	Grader, rear ripper, 180 H.P. ideal conditions		B-11L	625	.026			.76	.69	1.45	1.93	
	2520	Adverse conditions		"	530	.030			.90	.82	1.72	2.28	
	2600	Very hard, 460 HP dozer, ideal conditions		B-10X	800	.015			.47	1.84	2.31	2.74	
	2700	Adverse conditions		"	720	.017			.52	2.05	2.57	3.04	
	2800	Till, boulder clay/hardpan, soft, 300 H.P. dozer, ideal conditions		B-11S	7,000	.002			.05	.17	.22	.26	
	2810	Adverse conditions		"	6,300	.002			.06	.19	.25	.29	
	2815	Grader, rear ripper, 180 H.P. ideal conditions		B-11L	1,500	.011			.32	.29	.61	.81	
	2816	Adverse conditions		"	1,275	.013			.37	.34	.71	.94	
	2820	Medium hard, 300 H.P. dozer, ideal conditions		B-11S	6,000	.002			.06	.19	.25	.30	
	2830	Adverse conditions		"	5,400	.002			.07	.22	.29	.35	
	2835	Grader, rear ripper, 180 H.P. ideal conditions		B-11L	740	.022			.64	.58	1.22	1.63	
	2836	Adverse conditions		"	630	.025			.76	.69	1.45	1.91	
	2840	Very hard, 460 H.P. dozer, ideal conditions		B-10X	5,000	.002			.07	.29	.36	.43	
	2850	Adverse conditions		"	4,500	.003			.08	.33	.41	.49	
	3000	Dozing ripped material, 200 HP, 100' haul		B-10B	700	.017			.53	1.23	1.76	2.17	
	3050	300' haul		"	250	.048			1.49	3.45	4.94	6.05	
	3200	300 HP, 100' haul		B-10M	1,150	.010			.32	.96	1.28	1.54	
	3250	300' haul		"	400	.010			.93	2.75	3.68	4.44	
	3400	460 HP, 100' haul		B-10X	1,680	.007			.22	.88	1.10	1.30	
	3450	300' haul		"	600	.020			.62	2.46	3.08	3.65	
424	0010	**EXCAVATING, BULK BANK MEASURE** Commoon earth piled	R02315 -400										424
	0020	For loading onto trucks, add									15%	15%	
	0050	For mobilization and demobilization, see division 02305-250	R02315 -450										
	0100	For hauling, see division 02315-490											
	0200	Backhoe, hydraulic, crawler mtd., 1 C.Y. cap. = 75 C.Y./hr		B-12A	600	.027	C.Y.		.85	.81	1.66	2.18	
	0250	1-1/2 C.Y. cap. = 100 C.Y./hr		B-12B	800	.020			.64	.85	1.49	1.90	
	0260	2 C.Y. cap. = 130 C.Y./hr.		B-12C	1,040	.015			.49	.85	1.34	1.68	
	0300	3 C.Y. cap. = 160 C.Y./hr.		B-12D	1,280	.013			.40	1.54	1.94	2.29	
	0310	Wheel mounted, 1/2 C.Y. cap. = 30 C.Y./hr.		B-12E	240	.067			2.13	1.35	3.48	4.69	
	0360	3 C.Y. cap. = 45 C.Y./hr.		B-12F	360	.044			1.42	1.27	2.69	3.54	
	0500	Clamshell, 1/2 C.Y. cap. = 20 C.Y./hr.		B-12G	160	.100			3.20	3.03	6.23	8.15	
	0550	1 C.Y. cap. = 35 C.Y./hr.		B-12H	280	.057			1.83	2.99	4.82	6.05	
	0950	Dragline, 1/2 C.Y. cap. = 30 C.Y./hr.		B-12I	240	.067			2.13	2.60	4.73	6.05	
	1000	3/4 C.Y. cap. = 35 C.Y./hr.		"	280	.057			1.83	2.23	4.06	5.20	
	1050	1-1/2 C.Y. cap. = 65 C.Y./hr.		B-12P	520	.031			.98	1.82	2.80	3.48	
	1100	3 C.Y. cap. = 112 C.Y./hr.		B-12V	900	.018			.57	1.41	1.98	2.41	
	1200	Front end loader, track mtd., 1-1/2 C.Y. cap. = 70 C.Y./hr.		B-10N	560	.021			.67	.54	1.21	1.60	
	1250	2-1/2 C.Y. cap. = 95 C.Y./hr.		B-10O	760	.016			.49	.71	1.20	1.53	
	1300	3 C.Y. cap. = 130 C.Y./hr.		B-10P	1,040	.012			.36	.73	1.09	1.36	
	1350	5 C.Y. cap. = 160 C.Y./hr.		B-10Q	1,280	.009			.29	.83	1.12	1.35	
	1500	Wheel mounted, 3/4 C.Y. cap. = 45 C.Y./hr.		B-10R	360	.033			1.04	.53	1.57	2.17	
	1550	1-1/2 C.Y. cap. = 80 C.Y./hr.		B-10S	640	.019			.58	.37	.95	1.30	

Figure 9.5

Crews

Crew No.	Bare Costs		Incl. Subs O & P		Cost Per Labor-Hour	
Crew B-10O	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 F.E. Loader, T.M., 2.25 C.Y.		538.00		591.80	44.83	49.32
12 L.H., Daily Totals		$911.20		$1159.40	$75.93	$96.62

Crew B-10P	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 F.E. Loader, T.M., 2.25 C.Y.		761.00		837.10	63.42	69.76
12 L.H., Daily Totals		$1134.20		$1404.70	$94.52	$117.06

Crew B-10Q	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 F.E. Loader, T.M., 5 C.Y.		1061.00		1167.10	88.42	97.26
12 L.H., Daily Totals		$1434.20		$1734.70	$119.52	$144.56

Crew B-10R	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 F.E. Loader, T.M., 1 C.Y.		192.00		1211.20	16.00	17.60
12 L.H., Daily Totals		$565.20		$778.80	$47.10	$64.90

Crew B-10S	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 F.E. Loader, T.M., 1.5 C.Y.		236.20		259.80	19.68	21.65
12 L.H., Daily Totals		$609.40		$827.40	$50.78	$68.95

Crew B-10T	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 F.E. Loader, T.M., 2.5 C.Y.		295.60		325.15	24.63	27.10
12 L.H., Daily Totals		$668.80		$892.75	$55.73	$74.40

Crew B-10U	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 F.E. Loader, T.M., 5.5 C.Y.		674.80		742.30	56.23	61.86
12 L.H., Daily Totals		$1048.00		$1309.90	$87.33	$109.16

Crew B-10V	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 Dozer, 700 H.P.		3047.00		3351.70	253.92	279.31
12 L.H., Daily Totals		$3420.20		$3919.30	$285.02	$326.61

Crew B-10W	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 Dozer, 105 H.P.		434.00		477.40	36.17	39.78
12 L.H., Daily Totals		$807.20		$1045.00	$67.27	$87.08

Crew B-10X	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 Dozer, 410 H.P.		1473.00		1620.30	122.75	135.03
12 L.H., Daily Totals		$1846.20		$2187.90	$153.85	$182.33

Crew B-10Y	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equip. Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 Vibratory Drum Roller		323.60		355.95	26.97	29.66
12 L.H., Daily Totals		$696.80		$923.55	$58.07	$76.96

Crew B-11A	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equipment Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$29.83	$45.60
1 Laborer	26.00	208.00	40.50	324.00		
1 Dozer, 200 H.P.		863.40		949.75	53.96	59.36
16 L.H., Daily Totals		$1340.60		$1679.35	$83.79	$104.96

Crew B-11B	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equipment Oper. (light)	$32.15	$257.20	$48.40	$387.20	$29.08	$44.45
1 Laborer	26.00	238.00	40.50	324.00		
1 Air Powered Tamper		23.50		25.85		
1 Air Compr. 365 C.F.M.		157.60		173.35		
2.50 Ft. Air Hoses, 1.5" Dia.		10.00		11.00	11.94	13.14
16 L.H., Daily Totals		$656.30		$921.40	$41.02	$57.59

Crew B-11C	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equipment Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$29.83	$45.60
1 Laborer	26.00	208.00	40.50	324.00		
1 Backhoe Loader, 48 H.P.		207.80		228.60	12.99	14.29
16 L.H., Daily Totals		$685.00		$958.20	$42.82	$59.89

Crew B-11K	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equipment Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$29.83	$45.60
1 Laborer	26.00	208.00	40.50	324.00		
1 Trencher, 8' D., 16" W.		1310.00		1441.00	81.88	90.06
16 L.H., Daily Totals		$1787.20		$2170.60	$111.71	$135.66

Crew B-11L	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equipment Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$29.83	$45.60
1 Laborer	26.00	208.00	40.50	324.00		
1 Grader, 30,000 Lbs.		432.00		475.20	27.00	29.70
16 L.H., Daily Totals		$909.20		$1204.80	$56.83	$75.30

Crew B-11M	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equipment Oper. (med.)	$33.65	$269.20	$50.70	$405.60	$29.83	$45.60
1 Laborer	26.00	208.00	40.50	324.00		
1 Backhoe Loader, 80 H.P.		230.80		253.90	14.43	15.87
16 L.H., Daily Totals		$708.00		$983.50	$44.26	$61.47

Crew B-11N	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Labor Foreman	$28.00	$224.00	$43.60	$348.80	$28.22	$42.98
2 Equipment Operator (med.)	33.65	538.40	50.70	811.20		
6 Truck Drivers (hvy.)	26.45	1269.60	40.30	1934.40		
1 F.E. Loader, 5.5 C.Y.		674.80		742.30		
1 Dozer, 400 H.P.		1473.00		1620.30		
6 Off Hwy. Tks. 50 Ton		7356.00		8091.60	132.00	145.20
72 L.H., Daily Totals		$11535.80		$13548.60	$160.22	$188.18

Crew B-11Q	Hr.	Daily	Hr.	Daily	Bare Costs	Incl. O&P
1 Equipment Operator (med.)	$33.65	$269.20	$50.70	$405.60	$31.10	$47.30
.5 Laborer	26.00	104.00	40.50	162.00		
1 Dozer, 140 H.P.		542.20		596.40	45.18	49.70
12 L.H., Daily Totals		$915.40		$1164.40	$76.28	$97.00

Figure 9.6

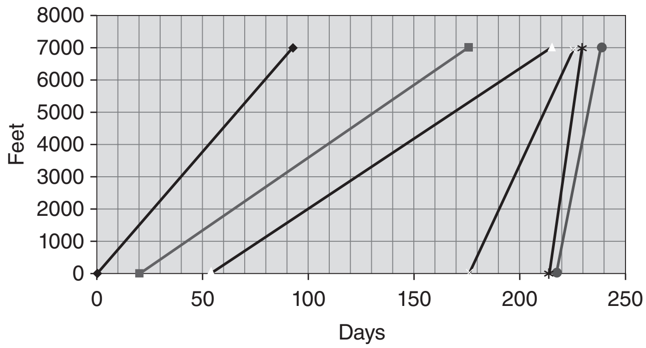


Figure 9.7 LOB Schedule: runway replacement initial plot

Another source of conflict is the fact that some crews work faster than others. This type of conflict falls into two categories: lagging crews and overrunning crews. Consider first the case of a following crew that moves slower than the crew that precedes it. Looking at the first two activities in the sequence, it is apparent that removing old base and subsoil is slower than removing old asphalt (63 days vs. 31 days). In this case, there is no danger that the base and subsoil crew will overrun the asphalt crew, so the only problem is to ensure that the asphalt crew is far enough down the runway to preclude any interference. In this case, it is best to plot the spacing in the manner shown in Figure 9.10, which show two ways of plotting the distance between crews at the beginning. First, the required separation of 1,500 feet can be measured vertically. Also, the time it takes the asphalt crew to move 1,500 feet down the runway can be calculated in days, using the speed of the asphalt crew. This speed is 7,000 ft. / 93 days = 76 feet per day. Using this value, the time separation can be calculated as: 1,500 feet / 76 feet per day = 20 days, which would be rounded to 7 days. If the starts of the old base and subsoil crews are delayed by seven days, the crew will always be at least 1,500 feet behind the asphalt removal. It is also apparent that since the following crew is slower, the distance between them will increase over time.

The third crew that lays and compacts the new subsoil moves at a faster rate than the one removing the old base and subsoil. If there was not enough separation provided when the new subsoil crew began work, it would be in danger of overrunning the crew taking out the old base and subsoil. This problem can be solved by looking at the relationship between the two crews when they finish rather than when they start, as shown in Figure 9.9. In this case, a finishing time has been scheduled for the crew laying the new subsoil so that it will be sure to finish late enough so that the crew ahead of it has had time to finish the last segments of work. Specifically, the progress of the removal crew can be monitored, and when it finishes and moves off, the subsoil crew has only reached Station 55 + 00, some 1,500 feet from completion. A starting time can then be determined for the new subsoil crew by plotting backward from the finish time to a start time that will provide a sufficient start delay to prevent a crew overrun.

Finally, these two cases are illustrated together in Figure 9.10, which shows the first three activities. The first activity's crew to remove the old asphalt moves more quickly than the one removing the old base and topsoil, so we set the separation and time relationship at the start of the two activities. This figure also shows that since the third activity, laying and compacting new subsoil, moves faster than its predecessor, removing old base and subsoil, we can set the time and distance relationship at the end.

Using these techniques, we can then proceed to plot the remainder of the activities as shown in Figure 9.9, and use this to analyze the relationships between all activities. The schedule shows some rather dramatic anomalies: the rates of progress vary considerably, and the overall time is 238 working days, which translates to 48 weeks, or over 11 months to do this simple runway job.

Step 4: Examine the Resulting Plot and Adjust Rates of Progress

In the final step, it is important to look at how the rates of production and resulting times can be adjusted to bring the overall project duration down to a reasonable level. There are several factors that should be optimized when doing this adjustment. Typically they are:

1. Changing the rates of progress can help all activities to move at roughly the same rate. This will result in the least overall time for the project as a whole. Any realistic method can be used that will vary the time accordingly. Usually, this means adding or removing crews or equipment, or using larger or smaller machines.
2. All tasks should start and end at times that ensure that there is no conflict between crews. No conflict means that no two crews will be in the same area at the same time. It also means that there will be enough distance or time between crews to ensure that there is room to work and that factors such as curing and drying have time to take place before a following crew works in the area.

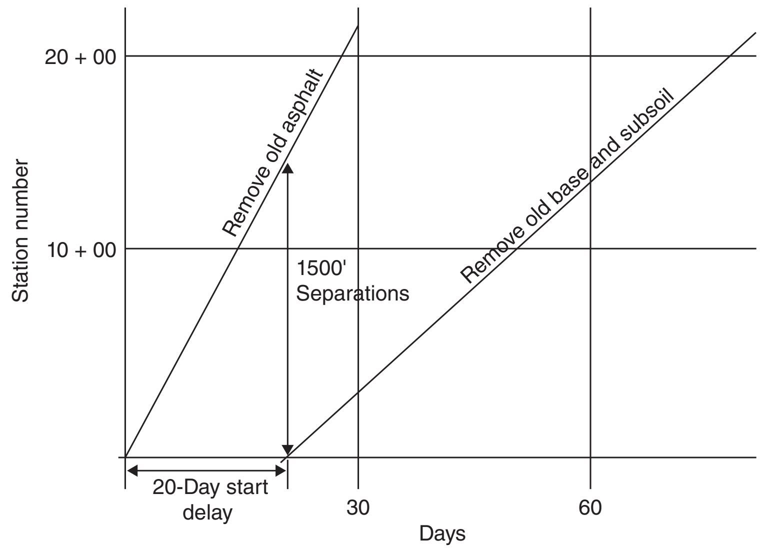


Figure 9.8

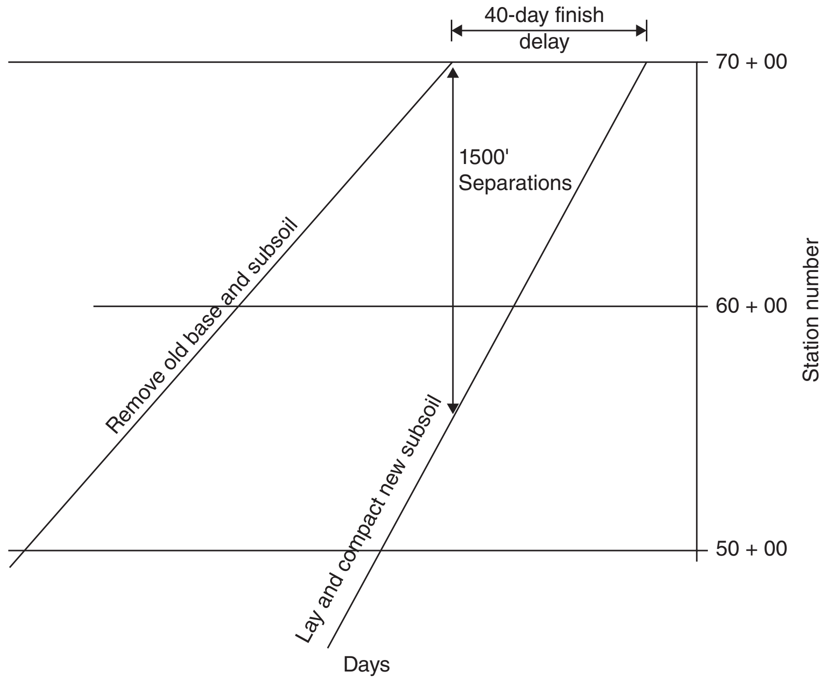


Figure 9.9

There are several options to adjust the activities to achieve the goals of roughly equal rates of progress and reducing project time. In an ideal world, one could optimize the crew mix by doing a detailed productivity analysis of various type and sizes of equipment that will be used, but this option can become quite complex and requires a great deal of experience and detailed knowledge of equipment characteristics.

It is far more common to simply vary the quantity of resources applied to the job by increasing or decreasing the number of crews. In order to clearly demonstrate the basic method and the effect of adjusting activity times, changes will be confined to adjusting the number of crews.

When all activities in the previous step were plotted, it was assumed that a single crew would be used for each activity. As we saw earlier, the diagram clearly shows the adverse result of this simple assumption. The activity times vary a great deal, and there is an overall project time of 106 days.

If we set up a simple table to vary the number of crews in order to adjust the rates of production, we can rapidly arrive at a number of crews to be assigned in each case. Table 9.3 shows the rates of progress that result from using one crew on all activities. The rates vary widely, from a high of 456 lineal feet of runway for paving, to a low of 43 lineal feet for removing the old base and subsoil. Note that the rates of progress are expressed in lineal feet along the runway, not in the original rates of production that used SY and CY. This conversion allows one to work in a common unit of measure for all activities, or, in other words, comparing apples to apples, not apples to pears to oranges.

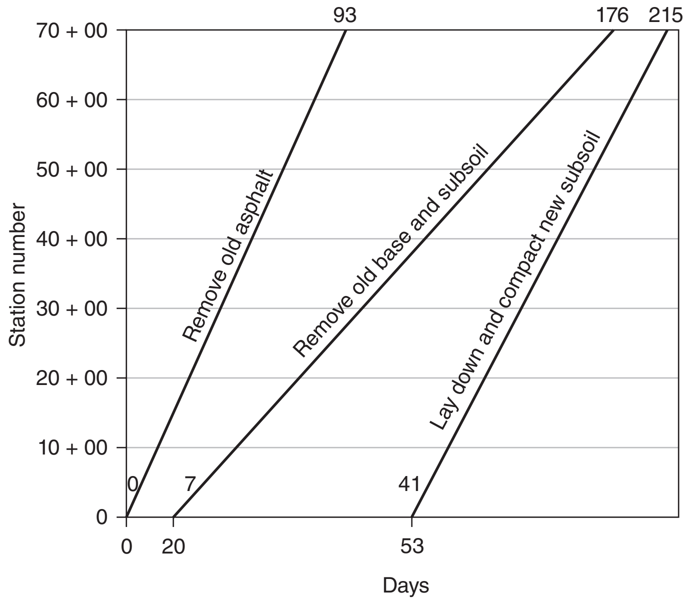


Figure 9.10

Using a table such as Table 9.3 we can easily test the effect of our changes. We can see that the paving activity is the fastest activity, at 15 days and 456 feet per day. Also, this work only uses one crew, so it cannot be slowed down to adjust to slower crews. One can try adding crews to other activities to speed them up to at least keep up somewhat with the paving crew. Table 9.3 shows what additional crews have been added. In some cases, there are as many as three crews on an activity, and two for others. Looking at the figures for the increased rates of work, it can be seen that the progress varies from 173 feet per day to 456 feet per day. This is still a significant variation, but it is considerably better than the previous variation. This process of adjusting crew production rates so that the rates are as alike as possible is called “balancing the crews,” hence the term line of balance schedule.

If we replot the activities as changed, we can see a dramatic improvement in overall time (73 days vs. 238 days previously). Figure 9.11 shows all activities replotted at their new rates of production, as well as the old schedule, so we can easily see the result of balancing the crews.

There is an interesting paradox in this process. It seems counterintuitive that time can be saved by slowing down, but it is true nonetheless. Even if some activities have to be slowed down in order to move all activities along at similar rates of progress, the act of establishing equal rates has a dramatic effect on overall time. This phenomenon occurs primarily because the equal rates of progress allow one to eliminate most start delays, and thus get each activity under way much earlier than would otherwise be the case. To illustrate this point, one can look back at our unadjusted schedule and see major start delays of 33 days, 40 days, and 123 days, whereas looking at the adjusted schedule, the longest start delay is 21 days, and the next longest is 13 days.

Table 9.3 Recalculation of Activity Times

Task	Quantity	Unit	Production Rate — 1 crew Lineal ft/day	Total Days — 1 crew	Revised No. of crews	Revised Production Date	Revised Total Days
Remove old asphalt	38,899	SY	76	93	3	227	31
Remove old base and soil	162,037	CY	45	156	4	180	39
Lay down and compact new subsoil	97,222	CY	43	162	4	173	41
Lay down and compact new gravel base	64,815	CY	140	50	2	281	25
Place and finish new concrete	58,333	SY	456	15	1	456	15
Groove concrete	58,333	SY	330	21	1	330	21

UPDATING A LINE OF BALANCE SCHEDULE

As we noted in Chapter 8, a good plan is essential, but it is not enough to ensure a successful project. Just as was the case with a standard CPM schedule, we must also monitor the work as it proceeds, and if it does not meet our planned objectives, we must take corrective action. Fortunately, performing this task with a line of balance schedule is very simple, much more so than with CPM.

The steps in the process are essentially the same as they were with traditional scheduling, but they are different in detail. To review, in broad terms, those steps are:

1. **Monitor progress:** Collect data on where the work stands at the end of a reporting period.
2. **Compare progress to goals:** Display where the work stands versus where it was planned to be. This is best done on the same chart so that any deviation from plan is crystal clear.
3. **Take corrective action:** As before, a superintendent or project manager must take action to find out the causes of any delays, then take vigorous measures to bring crew progress back into line with the plan.

This technique can best be illustrated using the schedule for our runway, as shown in Figure 9.12. In order to do this, we will plot hypothetical progress week by week, and show how this progress can easily be displayed. For the sake of clarity, we will plot only the first two activities and the first four weeks of work.

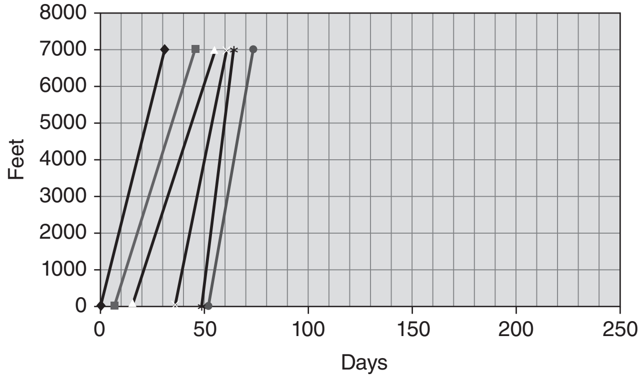


Figure 9.11 LOB schedule: runway replacement final plot

Week 1

The superintendent went out to the job on Friday of the first week, and noted that the crew removing old asphalt had reached Station 15 + 00. If we plot this point on our diagram and draw a dashed line to represent actual progress, we can see that the work is slightly behind. It should have reached Station 22 + 50 and is, therefore, some 7,500 feet behind where it should be. We can easily see this by noting the difference in the slopes of the planned and actual lines, and the gap between where the planned line is at the end of Week 1 and where the actual line is. We can safely assume that the superintendent will soon have a discussion with the foreman of the asphalt removal crew about his crew's rate of progress.

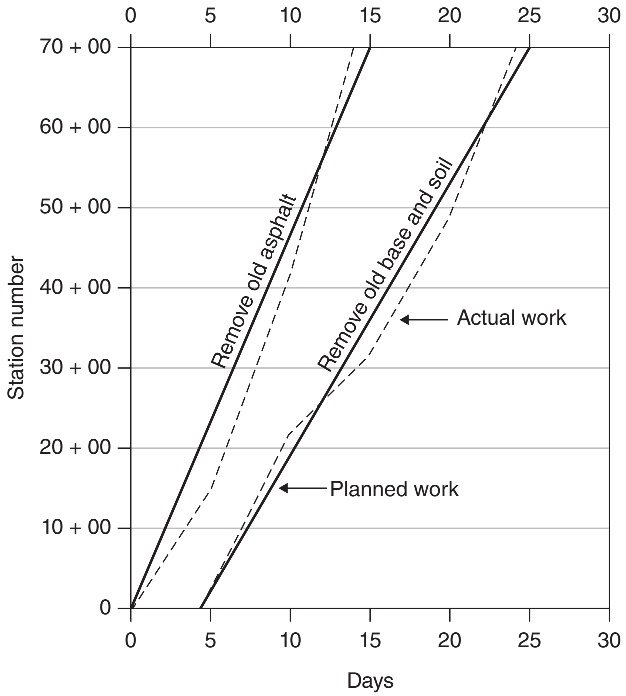


Figure 9.12 Planned vs. actual plot

The second activity, removing old base and subsoil, has barely started, and not enough progress has been observed to make a plot meaningful.

Week 2

By this time, our superintendent sees that the clearing crew has reached Station 42 + 50. Clearly, the superintendent's talk with the foreman had some effect. The crew is now only about 4,500 feet behind the planned line, and we can see from the slope of the actual line, their rate of progress has improved. They are still not on schedule, but appear to be improving and may get back on schedule. Also, we can see that the crew excavating and removing the old base is moving along nicely. In fact, they are slightly ahead of schedule. They were scheduled to reach Station 20 + 00 by the end of Week 2, but have in fact reached Station 22 + 50 and are, therefore 2,500 feet ahead of schedule.

Week 3

At the end of Week 3, the asphalt removal crew has reached Station 70 + 00 and has actually done this one day early. This was achieved by substantially increasing their production during Week 3, which we can easily see in the steeper slope of their actual progress line during their last four days of work.

Looking at the work of removing old soil and base, we can see a problem. Clearly something is wrong with the progress of this crew during Week 3. They have only been able to reach Station 30 + 50, and have fallen behind schedule by some 4,500 feet. There might be any number of causes for this, including finding a subsoil that was much more difficult to excavate, or an equipment breakdown. As is the case with CPM updates, the diagram will not tell us why a delay occurred. The superintendent must go to the field and investigate the actual circumstance, then take appropriate action to solve the problem.

Week 4

From the fact that the actual progress line has the same slope as the planned line, we can see that the base and soil removal crew has been able to speed up somewhat, and has managed to again work at the planned rate. They have not, however, been able to make up the lost time, as they are still some 4,500 feet behind schedule.

Week 5

For the completion of our exercise, we can see that the soil removal crew finished with a flourish, completing their work one day early by doing over 20,000 feet during the last four days.

From this illustration, we can see that this updating process is much simpler and easier than updating a CPM schedule. There are no percents complete to estimate, no remaining durations, and no computer calculations required. Still, the need to regularly monitor progress, update the schedule, and take corrective actions as appropriate is no less important if we are to complete our projects on time.

REVIEW QUESTIONS

1. What kinds of projects would benefit most from line of balance scheduling?
2. Can line of balance scheduling be used in other industries? Hint: line of balance did not originate with the construction industry.
3. What is linear scheduling? How is it different from line of balance scheduling?
4. Which is most important in line of balance scheduling, a fast pace on all crews or an even pace on all crews?
5. What does the term "machine dependent" mean? Give an example of where this would be true and explain why?
6. Could the runway replacement problem in this chapter be done using traditional CPM scheduling? How would you go about doing this?
7. Design a spreadsheet that you can use to plot line of balance schedules and that will allow you to try out different crew sizes and rates of progress for each activity. If you do this and make the spreadsheet automatically determine the separation between crews, your instructor should give you extra credit.

PRACTICE PROBLEMS

1. Pipelaying
   Your task is to lay a 12,000 ft oil pipeline. The pipe is 6 inch welded steel pipe, laid in a trench which averages 5 feet in depth and 3 feet in width. The pipe is laid onto a 1 foot deep layer of compacted crushed stone bedding at the bottom of the trench. The trench is then backfilled.

   The production rates for these tasks are as follows:

Excavate trench	350 feet per day
Lay and compact pipe bedding	500 feet per day
Lay and weld steel pipe	300 feet per day
Backfill trench	600 feet per day

Further restrictions: you must maintain a 5-day buffer between all activities.

Using the preceding information and a sheet of graph or engineering paper, create a line of balance schedule for the job.

2. High-rise sequencing
   Your task is finish out the interior of six-story office building. The work consists of the following phases:

Phase	Days per floor
Rough in ductwork and AHUs	11
Install studs and door frames	5
Rough in electrical, plumbing, sprinklers	12
Float, tape and finish gypsum wall board	7
Rough paint	5
Hang ceiling grid	8
Finish mechanical, electrical, sprinklers	10

Phase	Days per floor
Drop in ceiling tiles	6
Hang doors and hardware	5
Finish flooring	7

Further restrictions:

- Phases must be performed in the order shown. Each crew finishes on one floor, then moves to the next floor up.
- A crew cannot move up to the next floor until the crew before it has moved on.

Using the preceding information, plot the schedule using a CPM network and then with a LOB schedule. After you have plotted the work both ways, compare the results to see if they match and then see if you can find a way to shorten the overall time.

10 PROJECT COST CONTROL

10 Project Cost Control

So far we have concentrated primarily on the methods for keeping a project on schedule. The other half of project management, keeping the project within budget, is the subject of this chapter. Cost control tends to be the priority of many companies. For example, subcontractors who do only one type of work have virtually no need to run scheduling systems; their schedules are set by the general contractor. Cost control, on the other hand, is still of vital importance.

Cost control is typically an easier task for the project manager than time control, but it is no less important. A good part of the project cost control function is performed within the overall accounting system of a construction company, and is not a burden to the project manager. This chapter covers the role of the project manager in the cost control process, and what that individual needs to do and know to effectively control costs.

Construction cost control involves performing the same functions as any business selling a product for a profit. This production cost control is just as critical for construction as it is for other businesses. Cost control for construction has the following additional complications. First, the elements that influence cost variations in construction can be highly volatile. Most manufacturing businesses are not constantly producing a different product; the size of the product relative to the total company size is not so huge as it is in construction; and weather is not the significant factor that it is in construction. These elements are always present in the construction business, and they make an effective, functioning cost control system an absolute necessity.

In construction, cost factors can be broken down into four categories: labor, material, equipment, and subcontractors. Of these four, material and subcontractor costs are relatively easy to control. Material costs tend to be fairly predictable, and subcontractor costs are defined at the time of the bid and job buy-out. Labor and equipment are, however, an entirely different matter. These two factors constitute the greatest risk for large cost overruns and, in many cases, have the potential for bankrupting the project and even the company.

The real key to controlling labor and equipment costs lies in the *feedback* cycle concept described in Chapter 1. To keep costs under control, the project manager must set targets for the various categories, closely monitor the performance of the crews doing the work, and when a deviation in cost performance is found, he must act positively and quickly to bring about corrective action. This monitoring must be done at the job site. The principle of being close to the work is a basic tenet of management, and nowhere more valid than in construction. The emphasis must be on aggressive job site tracking and follow-up, not monitoring from the home office. The Project Control Cycle described in Chapter 1 provides the basis for operating a cost system, just as it does for scheduling.

PROJECT COST CODING SYSTEMS

All cost control systems depend on a *project cost code.* This system of classifying costs and types of work is essential if the numbers collected in the job tracking process are to be useful to the project manager. The key to keeping informed of job progress is the comparison of actual performance to the targeted progress. The project manager should be able to look at a specific category of work separate from all others, and make meaningful judgments about cost and performance. This is not possible if he cannot clearly isolate finish work from concrete work.

Information on cost and performance is collected and represented in the form of lots of numbers—labor-hours worked, dollars spent, cubic yards of concrete placed, etc. Consequently, there should be a means of classifying the numbers into categories meaningful to the project manager. A coding system provides such a means and ensures that "apples are compared to apples." When a labor-hour is expended on concrete work, that labor-hour will be recorded as an expense of concrete work and will not be assigned to some other category of work. When an accounting of expenditures has been made, the totals and other information can then accurately be compared to the target figure.

Elements of a Project Coding System

Every project coding system must serve a number of functions. Over the years, systems have evolved to meet these various needs. While there is no such thing as one standard project cost coding system, most numbering schemes contain all or most of the following elements.

Project Number

All systems identify each project as being a separate entity. Usually the project number corresponds to a specific contract that the company has undertaken. The project number also frequently includes a number identifying the year in which the project was started. These two elements are derived from tax accounting requirements (based on the requirements of the I.R.S.) i.e., the need to identify income and expenditures by project and fiscal year. A typical project number might be 8823. This designation might indicate the company's 23rd job, started in fiscal year 1988. Some companies simply number projects sequentially from the first job obtained, keeping a list of when each job started. In this case, job number 435 would be the 435th job since the company started.

Area, Job Type, or Other Subclassification Code

If the company's geographic spread or variation in types of work is significant, a code might be added to clarify these distinctions. For example, say a company does union work in the Midwest and in California, but (through a subsidiary) does work in the Sunbelt that is non-union. Clearly, each division or subsidiary is affected by different cost factors. Since it would not be advisable to compare costs from one area to the other, each area would have a separate code. Another example is a company with different divisions performing very different types of work in the same geographic area. Power plant work, for example, is significantly different from building construction and should be recorded separately. If such variations do not exist, then this part of the overall project cost code may not be necessary. A contractor working only in the Los Angeles Basin would probably not need to distinguish between overall conditions of work in El Segundo and Orange County.

Work Type

This is probably the most essential part of the code from the standpoint of detailed project cost control. It is this number that separates different materials and trades on the job. It also furnishes the basis for identifying crews and ongoing work tasks, and for determining whether or not these controllable areas need attention. The starting point for a work type code is almost always the classifications of the MasterFormat system. The code is hierarchical, e.g., under *concrete* there are subcategories such as *concreting procedures, concrete formwork,* etc. These subdivisions are broken down further into more detailed classifications. *Concrete formwork,* for example, further subdivides into *wood forms* and *formwork accessories.* One point to note, however, is that the MasterFormat classifications may not precisely cover all possible situations. A case in point is if the contractor wishes to make a distinction between *erecting and stripping forms,* additional categories must be developed. *Type of Expense Category* Finally, each expenditure should be recognized as one of the four types of spending: labor, material, equipment, and subcontractor costs. These classifications are sometimes called *cost distributions.*

Detail in a Cost Code System

How much detail should be built into the system? On the one hand, more detail provides more information about precisely where cost overruns are occurring. On the other hand, a greater amount of detail makes the system bureaucratic and heavy with paperwork. If the system is too detailed, the likelihood of error actually increases. A system that demands excessive detail may be resented by the field personnel who have to fill in the forms that provide the system with its input. The answer to the problem is that it is better to have a system that works well and accurately, even at the expense of slightly less precise information. A tremendously detailed system may sound great from the standpoint of telling everything there is to know about the project, but it is no good if it is not accurate. Simple and complex cost coding systems show the kinds of extremes which are possible on coding system detail.

Simple Cost Coding System

031.00 Formwork

031.10 Formwork material and accessories
031.20 Fabricating, erecting, stripping and moving formwork
  031.21 Foundations
  031.22 Slabs on grade
  031.23 Columns
  031.24 Walls
  031.25 Elevated slabs

032.00 Reinforcing

032.10 Reinforcing materials and accessories
032.20 Sorting and placing reinforcements
  032.21 Foundations
  032.22 Slabs on grade
  032.23 Columns
  032.24 Walls
  032.25 Elevated slabs

033.00 Placing and Finishing

033.10 Materials and accessories
033.20 Sorting and placing reinforcements
  033.21 Foundations
  033.22 Slabs on grade
  033.23 Columns
  033.24 Walls
  033.25 Elevated Slabs
033.30 Concrete Finishes
  033.31 Horizontal
  033.32 Vertical
  033.33 Curing

Complex Coding System

031.000 Concrete formwork

031.1000 Fabricating and erecting

031.1100 Foundations
  031.1110 Spread footings
  031.1120 Pile caps
  031.1130 Equipment pads
031.1200 Slabs on grade
  031.1210 Sidewalks
  031.1220 Stairs on grade
  031.1230 Exterior curb and gutter
  031.1240 Concrete paving
  031.1250 Special finishes
031.1300 Columns
  031.1310 Conventionally formed
  031.1320 Prefabricated forms
  031.1330 Disposable forms

031.1400 Walls
031.1410 Conventional forming
031.1411 Straight walls
031.1412 Curved walls
031.1420 Gang formed
031.1421 Straight walls
031.1422 Curved walls
031.1430 Special surface finish formwork
031.1500 Elevated slabs
031.1510 Flat slabs
031.1520 Drop panel slabs
031.1530 Pan or dome slabs
031.1540 Flying forms
031.1550 Metal deck forming systems

031.2000 Stripping, cleaning, and moving

031.2100 Foundations
031.2110 Spread footings
031.2120 Pile caps
031.2130 Equipment pads
031.2200 Slabs on grade
031.2210 Sidewalks
031.2220 Stairs on grade
031.2230 Exterior curb and gutter
031.2240 Concrete paving
031.2250 Special Finishes
031.2300 Columns
031.2310 Conventionally formed
031.2320 Prefabricated forms
031.2330 Disposable forms
031.2400 Walls
031.2410 Conventional forming
031.2411 Straight walls
031.2412 Curved walls

Complex Coding Systems (cont.)

031.2420 Gang formed
031.2421 Straight walls
031.2422 Curved walls
031.2430
031.2500 Elevated slabs
031.2510 Flat slabs
031.2520 Drop panel slabs
031.2530 Pan or dome slabs
031.2540 Flying forms
031.2550 Metal deck forming systems

032.0000 Concrete reinforcing

032.1000 Standard reinforcing
032.2000 Masonry reinforcing
032.3000 Epoxy coated reinforcing

(*Continued*)

032.4000	Prestress tendon reinforcing
032.5000	Welded wire fabric
032.6000	Glass fiber reinforcing
032.7000	Stainless steel reinforcing
032.8000	Unloading and sorting
032.9000	Reinforcing ideas
033.0000	**Concrete placing and finishing**
033.1000	Concrete materials
033.1100	Standard concretes
033.1200	Lightweight concretes
033.2000	Placing labor and equipment
033.2100	Foundations
033.2200	Slabs on grade
033.2300	Columns
033.2400	Walls
033.2500	Elevated slabs
033.2600	Exterior curb and gutter
033.2700	Concrete paving
033.3000	Finishing
033.3100	Rubbing wall surfaces
033.3200	Float and trowel finding
033.3300	Curing
033.3400	Sandblasting/bush hammer
033.3500	Surface toppings

Other Points about Cost Codes

Several practical points should be noted by the company or project manager considering a new cost system, or changing an old one. First, make sure the system fits the company's needs. This is often a major factor for a company buying a new computer and accounting system, as the code system may be changed at the same time. In fact, if the present code system works fine and the computer system is being changed for capacity reasons, then a strong case should be made for keeping the old classification system. A coding system is a lot more effective when company personnel are used to using it, and changing them over entails significant risk and cost. When upgrading, the direction to take is evolutionary, not revolutionary.

Second, the coding system should be well explained in the company's field operations manual. Each code should be thoroughly and clearly explained, and the manual should be readily available to everyone who has to use it.

SPECIFIC TASKS IN PROJECT COST CONTROL

The specific steps or tasks that the project manager and his team must undertake fit within the schematic of the Project Control Cycle described in Chapter 1. The sequence for cost control is shown in Figure 10.1. These steps are described in detail as follows.

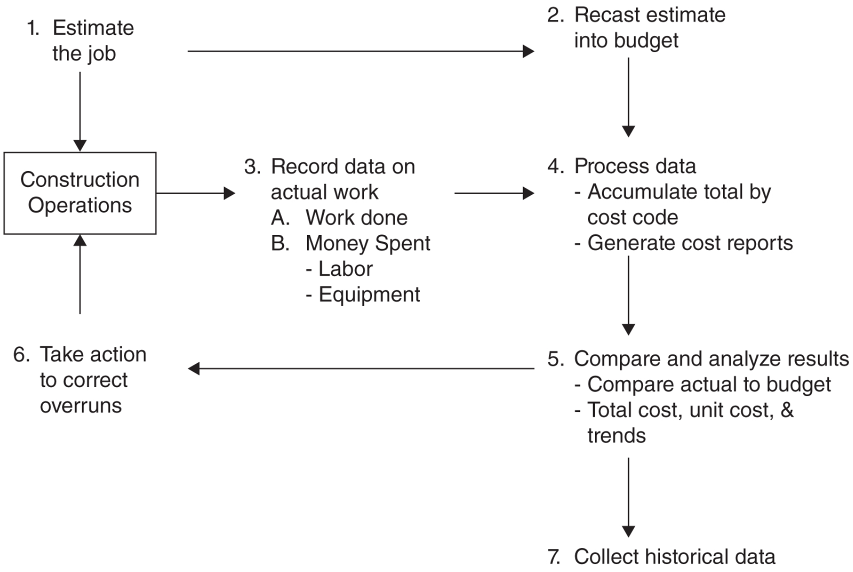


Figure 10.1 Project Control Cycle (Applied to Cost)

Estimate the Job

The estimate is the basis for the project's cost goals. As such, it represents the limits of spending which must be met by the project manager if the project is to realize the profit anticipated at the time the contract was obtained.

Unfortunately, estimates are usually not arranged in a manner immediately suitable to cost control purposes. The problem is one of classification of work subcategories. In an estimate, the job is broken down in such a way as to simplify the complications of bid day. It is not designed as an aid to control work in the field. The estimate may be more or less detailed than the cost code system of the company, but in any case, must almost always be reworked to make the information useful for cost control.

Recast Estimate into Budget

In reworking the information in the estimate, the project or cost engineer (or whoever is assigned the task) must ensure that the budget does several things. First, it must break the job down into groups of work that are recognizable and meaningful entities. Fortunately, a company with a working cost code system probably already has taken care of this organization process with a system that has evolved over time and proven workable. If not, the project manager must ensure that the categories established are neither too broad nor too narrow to be useful. Second, each category must contain two elements: (1) a quantity of work to be done and (2) the resources to cover that work.

To do this, we must first consult our estimate. A short example of recasting a budget into an estimate is shown in Figure 10.2 and 10.3 and Table 10.1. Figure 10.2 shows how an estimate might appear when received from an estimator. As with most estimates, ours contains quantities and unit prices, plus extensions that show total cost of each item.

CONSOLIDATED ESTIMATE

SHEET NO. 1

PROJECT Sample Extension of Est. for Foundation Walls & Waffle Slabs | CLASSIFICATION | ESTIMATE NO.

LOCATION | ARCHITECT | DATE

TAKE OFF BY DP | QUANTITIES BY DP | PRICES BY DP | EXTENSIONS BY | CHECKED BY

DESCRIPTION	NO.	DIMENSIONS		QUANTITIES				MATERIAL		LABOR		EQUIPMENT		TOTAL	
		LH/unit	Total LH		UNIT		UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
Form work:															
Foundation Walls		0.122	1126	9226	SFCA			.54	4982	3.91	36074		0	4.45	41056
Waffle Slab		0.102	1858	18220	SFCA			2.26	41177	3.29	59944		0	5.55	101121
Reinforcing:															
Foundation Walls		10.67	101	9.49	TN			540	5125	395	3749		0	935	8873
Waffle Slab		11.03	260	23.59	TN			605	14272	410	9672		0	1015	23944
Place Concrete:															
Foundation Walls		0.582	136	233	CY			76.50	17825	12.75	2971	5.50	1282	94.75	22077
Waffle Slab		0.457	254	555	CY			76.50	42458	16.25	9019	7.00	3885	99.75	55361
Finishing:															
Waffle Slab		0.012	227	18900	SF			0	0	.35	6615		0	.35	6615

Figure 10.2 Consolidated Estimate

PERCENTAGE COMPLETE ANALYSIS

PAGE

PROJECT Sample Project DATE

ARCHITECT BY FROM TO

NO.	DESCRIPTION	ACTUAL OR ESTIMATED	TOTAL PROJECT	THIS PERIOD		PERCENT TOTAL TO DATE										
				QUANTITY	%	QUANTITY	10	20	30	40	50	60	70	80	90	100
031 1411	Form Walls	ACTUAL	8672	1730												
		ESTIMATED														
032 1000	Reinf. Walls	ACTUAL	8.8	1.7												
		ESTIMATED														
033 2400	Place Walls	ACTUAL	175	29												
		ESTIMATED														
031 1530	Form Slab	ACTUAL	11843	3800												
		ESTIMATED														
032 1000	Reinf. Slab	ACTUAL	11.8	4.9												
		ESTIMATED														
033 2500	Place Slab	ACTUAL	185	—												
		ESTIMATED														
033 3200	Fin. Slab	ACTUAL	6300	—												
		ESTIMATED														
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Figure 10.3 Percentage Complete Analysis

Table 10.1 Labor Budget Foundation Concrete

Item	Cost Code	Unit	# of Units	LH/unit	Total LH	$/Unit	Total $
Form Walls	031.24	SFCA	9,226	0.122	1,126	$ 3.91	$ 36,074
Reinforce Walls	032.24	TNS	9.49	10.67	101	395.00	3,749
Place Walls	033.24	CY	233	0.582	136	16.25	3,786
Form Waffle Slab	031.25	SFCA	18,220	0.102	1,858	3.29	59,944
Reinforce waffle slab	032.25	TNS	23.59	11.03	260	410.00	9,672
Place waffle slab	033.25	CY	555	0.457	254	12.75	7,076
Finish waffle slab	033.31	SF	18,900	0.012	227	0.35	6,615
					3,962		$126,915

In order to turn this information into something that is useful for cost control, a cost engineer or project manager must ensure that all costs are classified or sorted into a cost code, and that all the quantities of work and associated resources are accurate. Looking at the first item in our estimate, formwork for foundation walls (shown in Figure 10.2), we can see that there are 9,226 SFCA to be done, and the estimated unit labor price is $3.91 per SFCA. If we then consult our simple cost coding system, we find that the cost code for wall formwork is 031.24. Also, we note that the labor-hour per SFCA is 0.122 labor-hours per SFCA. Some estimates will contain this information, most will not. If that is the case, the project manager must obtain that data from other sources, either the company accounting data, or from a source such as RSMeans *Building Construction Cost Data*.

The exact format for the information that will go into the accounting system will often be defined by the company's accounting system itself, but Table 10.1 is typical. For the work item, Form Walls, cost code 031.24, the quantity of work to be performed is 9,226 SFCA, and the resources necessary to perform that work are 1,126 labor-hours and $36,074. Furthermore, the resources listed are further broken down into labor-hour per unit and dollars per unit.

Once the quantity of work and associated labor-hours and dollars have been established for all our work, they are then entered into the accounting system, and would appear on a labor-hour cost report, as shown in Table 10.2

We should note, however, that not all estimate information can be directly and conveniently classified into a specific cost code, such as if our company used a complex cost code, as illustrated in the sample code list earlier. In this case, the work of forming walls is subdivided into much greater detail than a simple line item in the estimate. In our complex code system, forming walls is divided into two cost codes, one for fabricating and erecting—031.1411, and stripping, cleaning, and moving—031.2411. This presents a problem for the project manager—how to realistically distribute a single category of work into two.

In order to do this, the project manager must call on his or her professional judgment, and calculate accordingly. If, for example, the project manager knows that fabricating and erecting wall formwork is typically about 80% of the total labor-hours, and stripping cleaning and moving is 20%, then the single value of 0.122 labor-hours per SFCA could be divided accordingly. Cost code 031.1411 would then

Table 10.2 Example Weekly Labor Cost Report (Sample Office Building Foundation Concrete)

Estimated quantities and costs								work done this week			budget to date		total costs and labor hours					unit costs and labor hours				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Item		**Unit**	**# of Units**	**LH/Unit**	**Total LH**	**$/Unit**	**Total $**	**This week**	**To Date**	**% comp**	**LH**	**$**	**Total**	**Total**	**Total**	**Total**		**Unit**	**Unit**	**Unit**	**Unit**	
								(units)	(units)				LH	LH	$	$	$	LH	LH	$	$	percent
													this week	to date	this week	to date	over/ under	this week	to date	this week	to date	deviation
Form walls	031.24	SFCA	9226	0.122	1,126	$ 3.91	$36,074	1,730	8,672	94%	1,058	$33,908	216	1119	$ 6,920	$35,902	$ 1,994	0.125	0.129	$ 4.00	4.14	106%
Reinforce walls	032.24	TN	9.49	10.67	101	$395.00	$ 3,749	1.7	8.8	92%	93	$ 3,456	17	89	$ 646	$ 3,110	$ (346)	10.00	10.171	$380.00	355.43	90%
Place walls	033.24	CY	233	0.582	136	$ 16.25	$ 3,786	29	175	75%	102	$ 2,844	18.65	122	$ 486	$ 3,520	$ 676	0.64	0.697	$ 16.76	20.11	124%
Form waffle slab	031.25	SFCA	18220	0.102	1,858	$ 3.29	$59,944	3,800	11,843	65%	1,208	$38,963	445	1340	$11,475	$34,429	$(4,534)	0.117	0.113	$ 3.02	2.91	88%
Reinforce waffle slab	032.25	TN	23.59	11.03	260	$410.00	$ 9,672	4.9	11.8	50%	130	$ 4,838	61	155	$ 1,911	$ 5,612	$ 774	12.45	13.136	$390.00	475.59	116%
Place waffle slab	033.25	CY	555	0.457	254	$ 12.75	$ 7,076	–	185	33%	85	$ 2,359	0	97	$ –	$ 2,736	$ 377	–	0.524	$ –	14.79	116%
Finish waffle slab	033.31	SFCA	18900	0.012	227	$ 0.35	$ 6,615	–	6300	33%	76	$ 2,205	0	78	$ –	$ 2,250	$ 45	–	0.012	$ –	0.36	102%
					3,962		$16,915			69%	2,751	$88,573				$87,559	$(1,014)					99%

have a budgeted labor-hour figure of 0.80 times 0.122, or 0.098 labor-hours per SFCA, and 031.2411 would be 0.20 times 0.122, or 0.024 labor-hours per SFCA. The dollars per SFCA would also be divided in the same way.

It is very likely that each estimate-to-budget conversion will involve a variety of these situations, going both ways. The estimate must be revised, point by point, and judgment applied to make the conversion. Ideally, all estimators and field managers should work from the same set of cost code numbers. Unfortunately, such is not the case at the present time, although some companies are developing systems to solve this problem.

Record Data on Actual Work

As the project is proceeding, the project management staff must collect data as the resources are expended to accomplish the work. Material and subcontractor payments are not normally difficult to control.

While it is important to ensure against overuse of material and overpayments to subcontractors, it is not necessary to treat these issues with the same aggressiveness as should be directed toward careful monitoring of labor and equipment on the actual construction. The recording of expenditures for material does not take on the same urgency as that for labor and equipment, and it is often done by persons other than direct project management personnel.

Recording and tracking labor and equipment costs is the direct concern of the project manager and anyone else who is involved in controlling the production process. Specifically, these individuals must record three primary categories of information: work performed, labor expended, and equipment used.

Recording Work Performed

In order to determine how much money—or labor—should have been spent at any point in the project, it is necessary to know how much work has been accomplished. For example, if the labor budget for wall formwork is $36,074.00, but not all the formwork has been erected, then it is clear that not all of the money should have been spent. The money should be spent at a rate proportional to the rate of work being done. To determine this rate, the project manager should know how much work has been accomplished.

Unfortunately, calculating the work completed can be a difficult task. Again, the judgment of the project manager (or other person calculating the values) is a key factor. There are several general approaches to the problem. The one that works best should be used for each individual item on the job. The first is *direct measurement of work*. This approach involves someone physically measuring what has been installed. This system is typically used on jobs where extensive surveying is done anyway. An example is roadwork, where a state surveyor typically provides control points and profiles for the contractor.

The second method uses the same quantity survey techniques used in estimating. If the project manager can see by looking at a building how far up and along a wall the brick work has gone, then the quantities complete can be calculated using the plans and a scale and calculator, and standard quantity surveying factors, such as number of bricks per square foot.

A third method is to use the recording of activities completed in the scheduling system, especially if the calculation of activity times was done using methodologies such as those described in Chapter 4. Finally, it should be noted that for many types of work it is virtually impossible to calculate work done with significant precision, and a certain amount of approximation has to be accepted. An example is *reinforcing steel.* It may be possible to work from the shop drawings, or physically count bars and then calculate lengths and multiply by bar weights per lineal foot, but by the time a cost engineer has completed the task, the reporting period would be over.

Whatever degree of precision is accepted, and whatever method is used, some attempt should be made to establish work complete. When the progress has been calculated, it should be recorded as shown in Figure 10.5. This example shows how a typical week's progress for the waffle slab work might be recorded.

Recording the Resources Expended

Recording the actual expenditures of labor is done using daily or weekly labor time cards. Filling out these cards is fairly self-explanatory. Examples of each are shown in Figure 10.4 and 10.5. Each is filled out for a representative day or week for the small waffle slab illustrated in this chapter. The foreman enters the appropriate data based on the specific work performed by the crew. Absolute precision may not be possible, but if the time is recorded promptly at the end of the day, or notes made as the work progresses, a conscientious supervisor should be accurate to within the nearest one half hour.

DAILY TIME SHEET

PROJECT Sample Project

FOREMAN Rodger

WEATHER CONDITIONS Fair - Cool

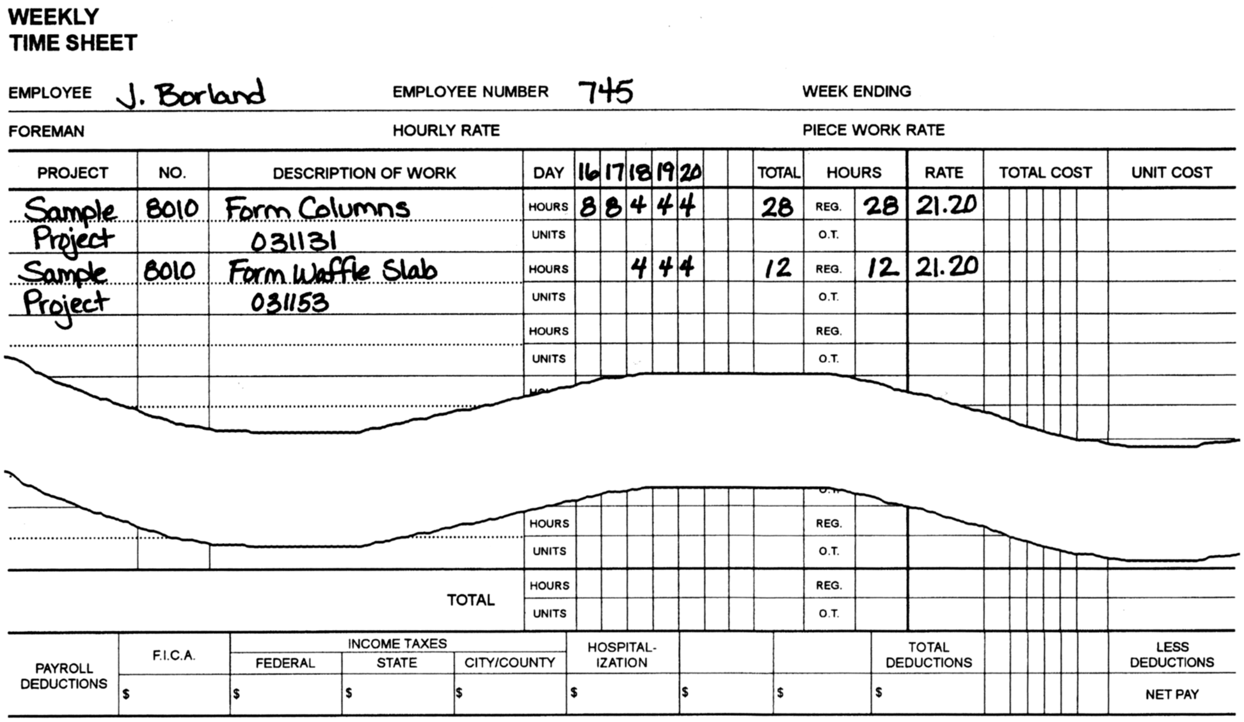
TEMPERATURE 58°F

DATE

SHEET NO.

NO.	NAME	DESCRIPTION OF WORK									TOTALS REG-ULAR	TOTALS OVER-TIME	RATES REG-ULAR	RATES OVER-TIME	OUTPUT	
	J. Kubasok	HOURS	8								8		21.20			
		UNITS													SEE	
	J. Borland	HOURS	4	4							8		21.20		PROGRESS	
		UNITS														
	N. Morris	HOURS	8								8		21.20		REPORT	
		UNITS														
	J. Emmack	HOURS	4	4							8		21.20			
		UNITS														
		HOURS														
		UNITS														
		HOURS														
		UNITS														
		HOURS														
		UNITS														

Figure 10.4 Daily Timesheet



WEEKLY
TIME SHEET

EMPLOYEE J. Borland EMPLOYEE NUMBER 745 WEEK ENDING

FOREMAN HOURLY RATE PIECE WORK RATE

PROJECT	NO.	DESCRIPTION OF WORK	DAY	16	17	18	19	20			TOTAL	HOURS		RATE	TOTAL COST	UNIT COST
Sample Project	8010	Form Columns 031131	HOURS	8	8	4	4	4			28	REG.	28	21.20		
			UNITS									O.T.				
Sample Project	8010	Form Waffle Slab 031153	HOURS			4	4	4			12	REG.	12	21.20		
			UNITS									O.T.				
			HOURS									REG.				
			UNITS									O.T.				
			HOURS									REG.				
			UNITS									O.T.				
		TOTAL	HOURS									REG.				
			UNITS									O.T.				

PAYROLL DEDUCTIONS	F.I.C.A.	INCOME TAXES FEDERAL	STATE	CITY/COUNTY	HOSPITAL-IZATION			TOTAL DEDUCTIONS		LESS DEDUCTIONS
	$	$	$	$	$	$	$	$		NET PAY

Figure 10.5 Weekly Timesheet

In general, using daily time cards is a more accurate method than using weekly time sheets. The time is recorded while it is still fresh in the mind of the foreman or other person responsible for filling out the card. Whichever method is used, the responsibility for recording and checking the data should be firmly established in the job site procedures. Cards should be checked daily for accuracy of work categories and hours recorded, and for human error.

The time card system should be designed for ease of use by the people in the field who must fill them out. For example, the time card can be computer generated with as much information as possible already recorded, such as job number, date, etc. Many companies generate time cards in advance with the employee's job assignment, and other basic information. These cards are then transmitted to the site for use. Such measures for reducing administrative workload can significantly improve the accuracy of the system, as well as the degree to which it is accepted in the field.

Finally, the job labor cost system should be tied in with the payroll system of the company; the time card should serve both needs. Since the same information must be collected for both functions, the savings in overhead from using one recording form can be considerable.

Collecting costs on equipment can be done using the same form of cards. Again, daily records are better than weekly ones, for the same reasons. It should be noted that it is often not possible to assign equipment costs to precise categories of work. A case in point would be a large crane used to lift formwork and reinforcing into place, but also used on occasion to move interior materials to the upper floors of a building. In this case, it may be better to record the crane costs in a general job cost category, making sure that the budget is set up to reflect that fact.

Process Data

This step is not the responsibility of the project manager. It involves feeding the data into the accounting system, by hand or machine. The accumulations and totals are developed, and the reports printed for the project manager's use. Only in the case of very large projects is this process carried out on the job site.

The job cost system is part of the overall financial accounting system of a construction company. Every construction company must have the standard parts of an accounting system—general ledger, accounts payable, accounts receivable, etc. These are derived to some degree from the job cost system since all transactions begin with construction work done. However, these parts of the accounting system only affect the project manager in a peripheral way. The key to job site success, and the success of the company, rests with the control of production costs, and this must occur at the job site.

Another issue is whether the job cost system should be kept by hand or by computer. The fact is, there are almost no circumstances where hand systems make sense. The few cases they might be better are those in which all work is subcontracted and no significant company labor is used. These situations do not reflect true job cost control, but rather issues of cash flow management. Further, the quality of construction accounting cost control systems has greatly improved in the recent past. Some very good systems are available for reasonable prices. Besides, a computer used for an accounting system can also serve many other purposes, further reducing the cost of the system.

It should be noted, however, that there are vendors of computer systems who do not know the construction business and try to sell systems adapted from other fields. These systems may not work at best, and may cause a lot of damage at worst. As is true of any purchase of a major capital item, the contractor must do the necessary investigation to ensure that the system fits a specific situation.

Compare and Analyze the Results

Once the weekly summary reports have been received, the project manager must analyze the information presented to determine the status of the job at the end of the reporting period. The information generated should contain several elements, all of which are important to determine where action needs to be taken. If the system does not include all of the elements, further analysis of raw data, or of the information contained in the reports generated may also be necessary.

Information Needed First, the information must be timely. After the labor and equipment cost data has been collected and turned into the accounting department, it should be processed and returned to the field within a few days at most. Promptness is absolutely essential if control is to be maintained over the production process. Labor and equipment costs can quickly overrun due to the volatile nature of the construction processes. Fast action is essential.

Second, there are several types of information that have proven useful in identifying the source and extent of overruns. Table 10.2 is an example of a fairly comprehensive type of labor cost summary containing most of the types of information needed. The key elements to look at are:

1. Unit costs relative to budget
2. Total costs relative to budget (particularly relative magnitude of overruns)
3. Trends in costs

Reviewing the report for the above elements—section by section—reveals the information of value. The first two sections (Columns 1-8) remain constant throughout the life of the job, barring changes in scope of work or price. Each item is identified by cost code. The budget information is presented for the work to be done, in terms of budgeted labor-hours and budgeted dollars. Labor-hours and dollars are presented in both *totals* and *cost per unit of work*.

The third section (Columns 9–11) contains the information about work performed during the period covered by the report, and the total work done to date on the job. These figures are also converted to a percent complete for each category of work. The fourth section (Columns 12–13) provides information on budgeted labor-hours and costs to date. These figures represent the maximum amount that should have been spent accomplishing the work reported and recorded in the previous section. The budgeted expenditures are determined by multiplying the percent complete in Column 11 times the original budgeted amounts in Columns 6 and 8.

The last two sections provide the project manager with information on accumulated costs and comparisons with the budgeted amounts. Section 5 (Columns 14–18) contains information on total labor-hours and dollars; Section 6 (Columns 19–23) offers the same information on unit labor-hours and dollars. Note that both sections provide information about the period just covered (*this week* columns), and the total progress so far (*to date* columns). Also presented are columns that “summarize” the sections by giving over/under figures and percent deviation figures.

What the Information Reveals

A review of the example weekly labor cost report (Table 10.2) informs the project manager about a number of issues. From the total in Column 18, it can be seen that the job is $1,014 under budget at this point, and approximately 69% of the work has been completed (total budgeted cost = $126,915, and budgeted cost for all work completed so far = $88,573). The report also shows that several areas of the job are significantly over budget, while others are significantly under. This is very typical of many jobs, the performance in individual kinds of work will vary considerably from that of the job as a whole. It is therefore necessary to look at the detail to find areas that need attention in order to bring the overall performance of the crews back into profitability.

The analysis shown in Table 10.3 of what the report reveals about performance of specific crews will highlight those areas that would benefit from management attention. The analysis will focus on overall performance to date and the trend as shown in the most recent week's performance. This data can be found by looking at either the dollars or labor-hours per unit. These detail indexes may vary slightly, but both will usually show the same performance to date and the recent trend.

Table 10.3 Labor Cost Performance Analysis

Work Category	Overall Performance to Date	Trend of Recent Performance	Overall Progress to Date
Forming walls	Total cost is some 6% over budget. The budgeted unit cost is $3.91 per SFCA, but the crew has spent $4.14 per SFCA.	Last week's performance was better than the overall date ($4 vs. $4.14). It is still above the original budget of $3.91.	This forming work is about 94% complete, and it appears that the loss on this item will be considerable—over $2,000.
Reinforcing walls	Performance to date is excellent—$355.43 per ton vs. a budget of $395 per ton.	The trend is still improving. Last week's unit cost, which is well below budget and even better than the overall to date.	The reinforcing operation is 92% complete. It appears this task will make some money—at least $350.
Placing walls	Performance to date is poor—approximately 24% over budget ($20.11 vs. a budget of $15.25 per cubic yard).	Last week's performance was an overall improvement—$16.76 vs. budget cost of $16.25. This improved performance is still not up to budget standards, however.	The placing work is 75% complete, and the loss will probably exceed $700.
Forming waffle slab	Total cost is about 5% under budget. Unit cost to date is $2.91 per SFCA vs. a budget of $3.06.	Last week's performance was not as good as to date, but it still under budget—$3.02 vs. $2.91 to date.	The work is 65% complete. If trends continue, this task will earn at least $4,600.
Reinforcing waffle slab	This work is significantly over budget—$475.59 per ton, vs. a budget of $410 per ton.	The performance trend is definitely better. Last week's work was done for $390 per ton, even lower than the budget of $410 per ton.	The work is only 50% complete, and there is some possibility of recovery.
Placing waffle slab	Total cost to date is small, but is over budget nonetheless. The unit cost to date is $14.29 per cubic yard, while budgeted cost is $12.75.	There was no work last week, so it is not possible to measure a trend.	Placement is 33% so far. Considerable work remains, but improvement is still
Finish waffle slab	The performance of the placement is just about on budget—$0.36 per SF vs. a budget of $0.35.	There was no work last week, so it is not possible to measure a trend.	Placement is only 33% so far. Considerable work remains.

Take Action to Correct Overruns

While labor and equipment cost reports identify the location of the problem, they do not reveal the cause of the problem. In order to do this, the Project Manager or Superintendent must go out into the field, talk to the foreman, observe the operation, and do whatever else it takes to determine why a type of work is not as efficient as it should be.

The report can, however, show them what work should be the target of scrutiny. The management personnel on the job should analyze the information that the cost report gives them and decide where they can realistically change things for the better.

Looking at our sample case, several things are clear. First, there are five crews that are over budget: forming walls, placing walls, reinforcing waffle slabs, place waffle slabs, and finishing waffle slabs. Looking at each in turn, we can see the following:

Forming Walls

This item is a large portion of the overall cost. It is 6% behind, and will result in a substantial loss. Unfortunately, the work is 94% complete, which means that there is little work left to change. It is impossible at this point to regain lost ground here. A reconsideration of the bid price on the next project might be in order, however. It may be that $3.91 is too low to cover the costs of this work. Unfortunately, this particular item will be the greatest money loser on the project.

Placing Walls

This, too, is over budget, but is also nearly finished. The loss is not nearly as great, however.

Reinforcing Waffle Slabs

This work is over budget by some 16% and half the work has yet to be done. However, the performance last week was a great improvement over the performance to date; in fact it was even better than budgeted. It would appear that this work is well on the way to recovery, and perhaps to a profit. A pat on the back for this crew is in order, and they should be encouraged to continue the good work.

Placing and Finishing Waffle Slabs

So far, only 33% of this work has been completed. The placement is over budget, while the finishing crew has done reasonably well. Much remains to be done, however, and there is a chance to improve performance enough to bring the work back into line. The Project Manager and Superintendent should devote considerable attention to improving performance on the remaining two placements.

Finally, it is worth noting that two crews, reinforcing walls and forming the waffle slab, have done quite well. The rodmen are about to finish their work and will make some money for the company. The carpenters of the slab crews will do even better. They have done most of the work on one of the largest items on the job, and are bringing it in under budget. They will be the largest profit contributors to this job and their work should be noted.

It is worth noting again that once the areas of concern have been identified, aggressive follow-up is essential to a successful cost control process. The technical causes of overruns must be determined and corrected and this can only be done by talking to people in the field. The manner in which these individuals are approached about a problem can have a significant effect on its resolution. If they perceive any sort of a threat to their jobs, they may provide a biased version of the facts. Such distortion only complicates the task of bringing costs back into line. The Project Manager should instead approach the superintendents and foremen with an attitude of joint problem solving. If he conveys a desire to work with them to jointly solve the problems, their responses will be much more positive and productive.

OTHER COST CONTROL ISSUES

Equipment Cost Records and Reports

The task of recording, collecting, and reporting equipment costs is very similar to the process applied to labor. The time cards, report formats, and information that the project manager must obtain from the reports are essentially the same as those covered in the section on labor cost control.

There are some special considerations involved in recording and reporting equipment costs. First is the issue of hourly rates to be charged to the job for various pieces of equipment. In the case of labor, the project manager has very little input. The requirements of the contract, especially on any kind of public work, and the hiring policies of the company (union or non-union) govern the hourly wage to be paid to employees. Also, the calculation of total pay is handled through the payroll system. This is not the case with equipment. Sometimes the project manager has the authority to choose where to obtain equipment based on cost to the job, and the resulting cost must be properly recorded in the project cost system.

Three methods for determining the cost to be charged to the job are commonly used in the industry. The first is to charge the actual cost. This is unusual, however, since the issue of how to determine cost is clouded by the issue of how to charge depreciation. This method tends to be used only on very large jobs where the entire useful life of an individual piece of equipment is to be used on the one specific project to which it is charged.

The second and most common method is to keep all cost records for owning, running, and maintaining the individual pieces of equipment in a cost account separate from the cost of the overall job. The total costs of owning the equipment can then be calculated. An hourly rate is determined and that rate charged against the job for each hour it is used. The hourly rate for equipment takes into account all depreciation, interest, fuel, repairs, and other expenses. At the end of the fiscal year, the *actual* hourly cost of the equipment can be determined. The company then knows if the equipment cost more per hour than it "earned" from being charged to jobs, and can make an intelligent decision about whether or not it is good company policy to own the individual equipment or to rent or lease from outside sources.

Another variation of the separate account method is charging the project for company equipment. The rate charged is based on the local market rate for that type of equipment, and calculated as cost per hour. If the equipment "earnings" from the job do not exceed the actual costs for the equipment, then clearly, the company should instruct the project manager to rent from outside sources.

The third method covers equipment rented from outside sources. In this case, the equipment is charged at the actual rate which has to be paid to the vendor.

Whatever method is used to determine the hourly rate or cost, the project manager should try to ensure that equipment costs are charged to the type of work for which the equipment is actually used. Some companies take the view that all equipment should be charged to one central account on the project, but this is not good practice. As is the case with labor, equipment cost is a volatile item, easily subject to overruns, and should be controlled by means of specific cost codes or identification of types of work. If the project manager charges equipment costs to a single account on the job, he gives up any possibility of identifying *where* equipment costs are out of control, should such an event occur. Small tools (saws, drills, temporary electrical distribution equipment, etc.) are the only exception to this rule, and need not be charged to each specific work activity for which they are used.

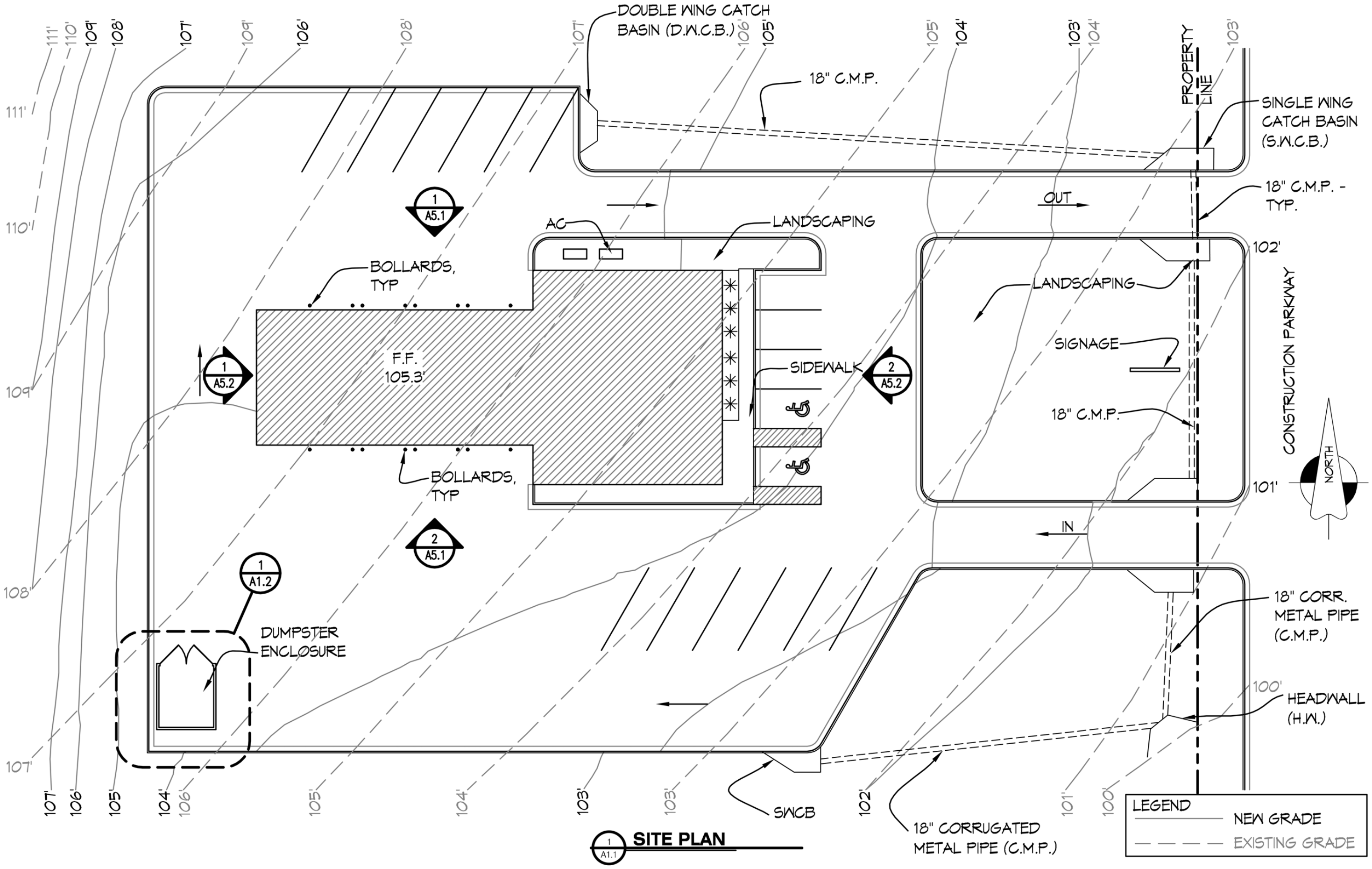
Collect Historical Data

While complete coverage of estimating is beyond the scope of this book, it should be noted that the best single source of acccurate data for estimating future jobs is the company's own cost and productivity records. These records reflect the company's actual performance and, as such, are the best predictor of future performance.

The problem with using company data is the fact that very few firms have a formal feedback system to consult historical costs for the development of estimates. Even less likely is access to a computer system designed for easy retrieval of this historical data. More often than not, the "system" consists of someone digging through past job reports to find unit costs or productivities to fit the specific job being bid. Even when a similar job is found, the cost variation can often be substantial. The estimator must apply judgment in adjusting the unit cost to make an accurate prediction for future work.

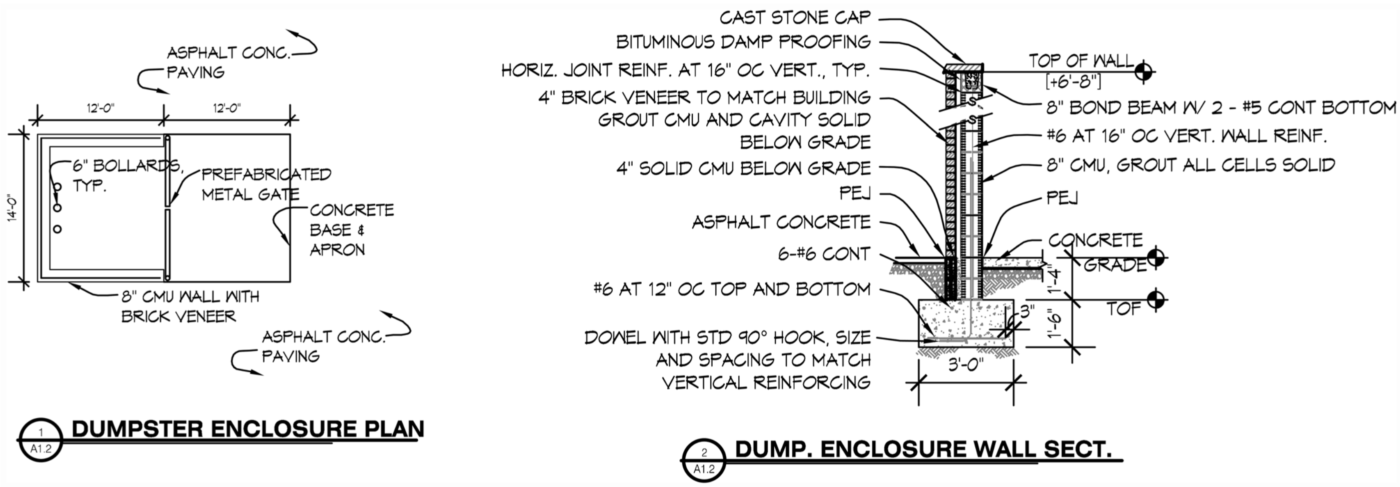
APPENDICES

Appendix A: Vehicle Maintenance Facility Drawings

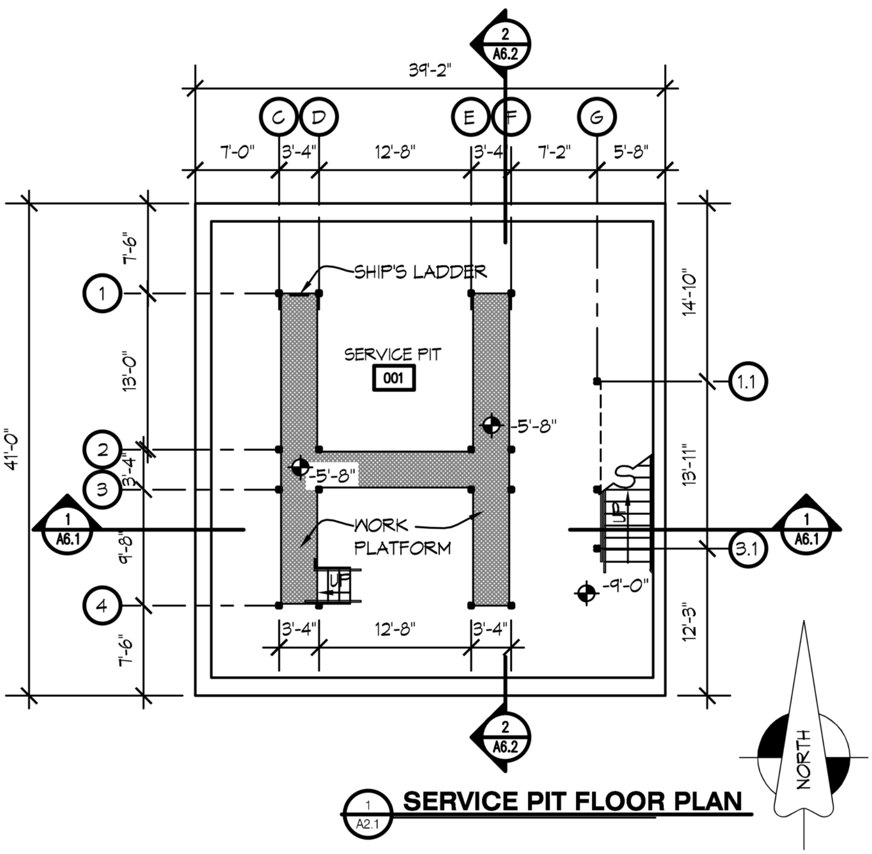


DOUBLE WING CATCH BASIN (D.W.C.B.)
18" C.M.P.
SINGLE WING CATCH BASIN (S.W.C.B.)
PROPERTY LINE
18" C.M.P. - TYP.
OUT
LANDSCAPING
AC
BOLLARDS, TYP
F.F. 105.3'
SIDEWALK
LANDSCAPING
SIGNAGE
18" C.M.P.
CONSTRUCTION PARKWAY
NORTH
BOLLARDS, TYP
IN
DUMPSTER ENCLOSURE
18" CORR. METAL PIPE (C.M.P.)
HEADWALL (H.W.)
SWCB
18" CORRUGATED METAL PIPE (C.M.P.)
SITE PLAN
LEGEND
NEW GRADE
EXISTING GRADE

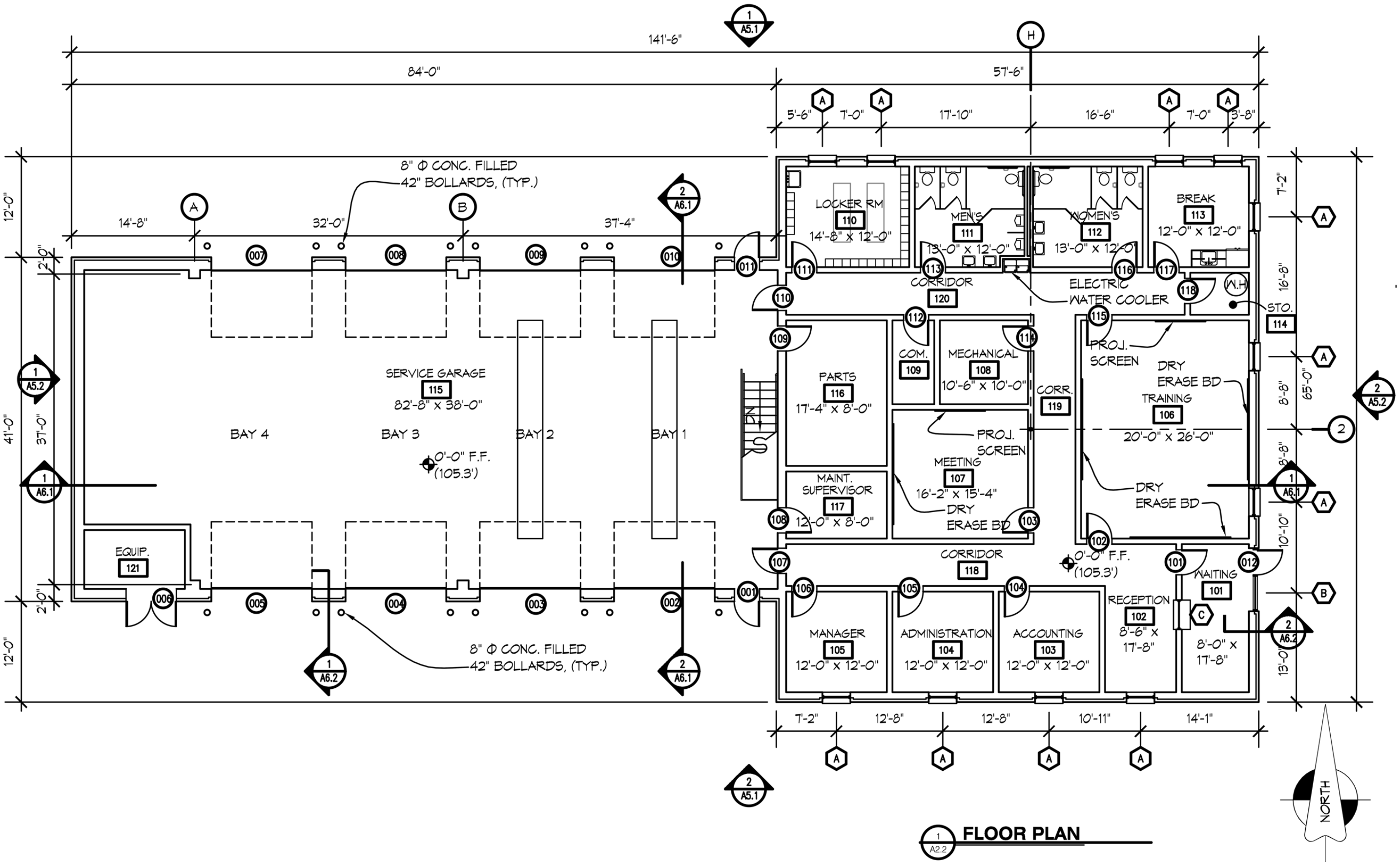
Site plan



Dumpster details



Service pit floor plan

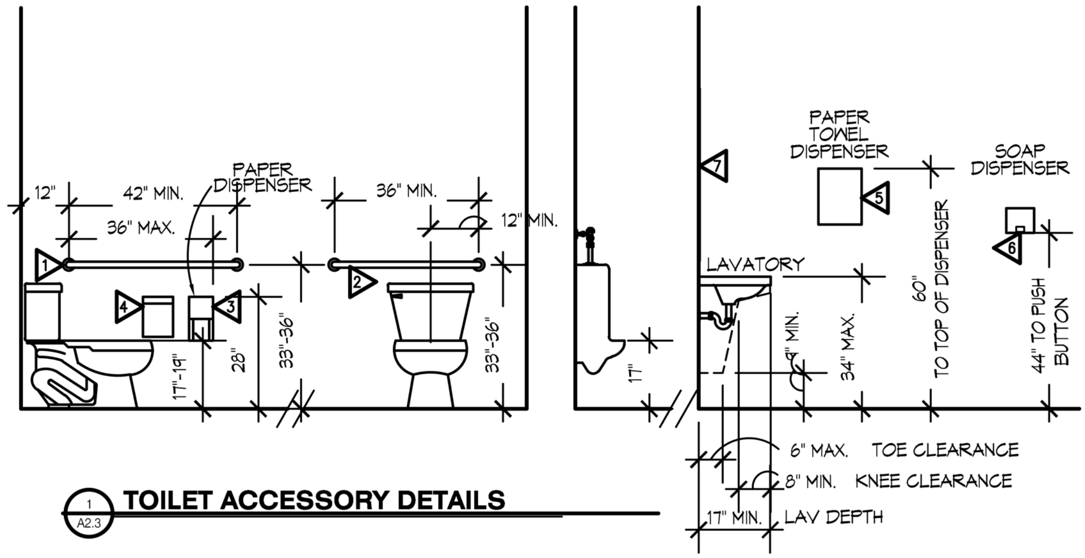

FLOOR PLAN
SERVICE GARAGE
115
82'-8" x 38'-0"
BAY 4
BAY 3
BAY 2
BAY 1
EQUIP.
121
8" Φ CONC. FILLED
42" BOLLARDS, (TYP.)
LOCKER RM
110
14'-8" x 12'-0"
MEN'S
111
WOMEN'S
112
BREAK
113
12'-0" x 12'-0"
CORRIDOR
120
ELECTRIC
WATER COOLER
STO.
114
PARTS
116
17'-4" x 8'-0"
COM.
109
MECHANICAL
108
10'-6" x 10'-0"
CORR.
119
TRAINING
106
20'-0" x 26'-0"
PROJ.
SCREEN
DRY
ERASE BD
MEETING
107
16'-2" x 15'-4"
MAINT.
SUPERVISOR
117
12'-0" x 8'-0"
CORRIDOR
118
0'-0" F.F.
(105.3')
MANAGER
105
12'-0" x 12'-0"
ADMINISTRATION
104
12'-0" x 12'-0"
ACCOUNTING
103
12'-0" x 12'-0"
RECEPTION
102
8'-6" x
17'-8"
WAITING
101
8'-0" x
17'-8"
141'-6"
84'-0"
57'-6"
NORTH

Floor plan

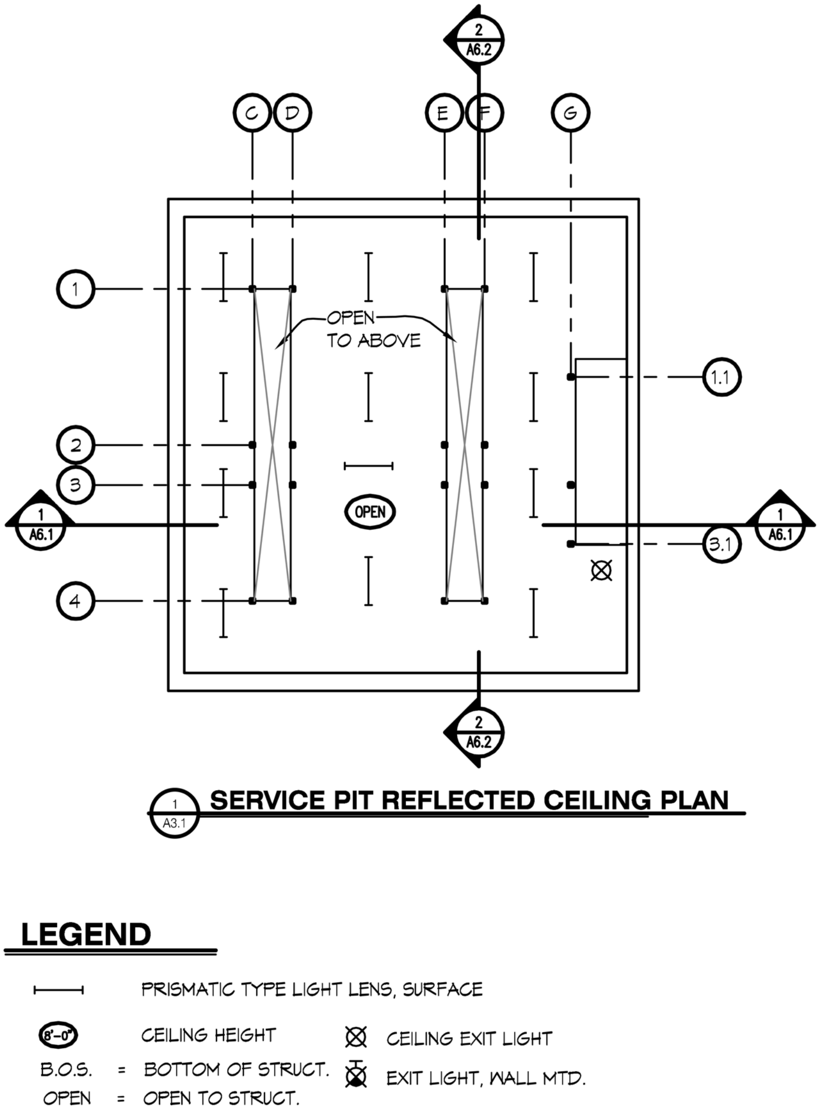
ACCESSORY SCHEDULE

MK	DESCRIPTION	REMARKS
1	42" GRAB BAR	ONE @ EACH ACCESSIBLE STALL
2	36" GRAB BAR	ONE @ EACH ACCESSIBLE STALL
3	TOILET TISSUE DISPENSER	ONE @ EACH WATER CLOSET
4	SANITARY NAPKIN DISPOSAL	ONE @ EACH WOMEN'S RR W.C., SURFACE MOUNTED
5	PAPER TOWEL DISPENSER	ONE NEXT TO EACH LAVATORY
6	SOAP DISPENSER	ONE @ EACH LAVATORY, ABOVE BACKSPLASH
7	PLATE GLASS MIRROR, 1/4" *	SEE NOTE 3
8	PIPE INSULATION	AT EACH H.C. ACCESSIBLE LAVATORY

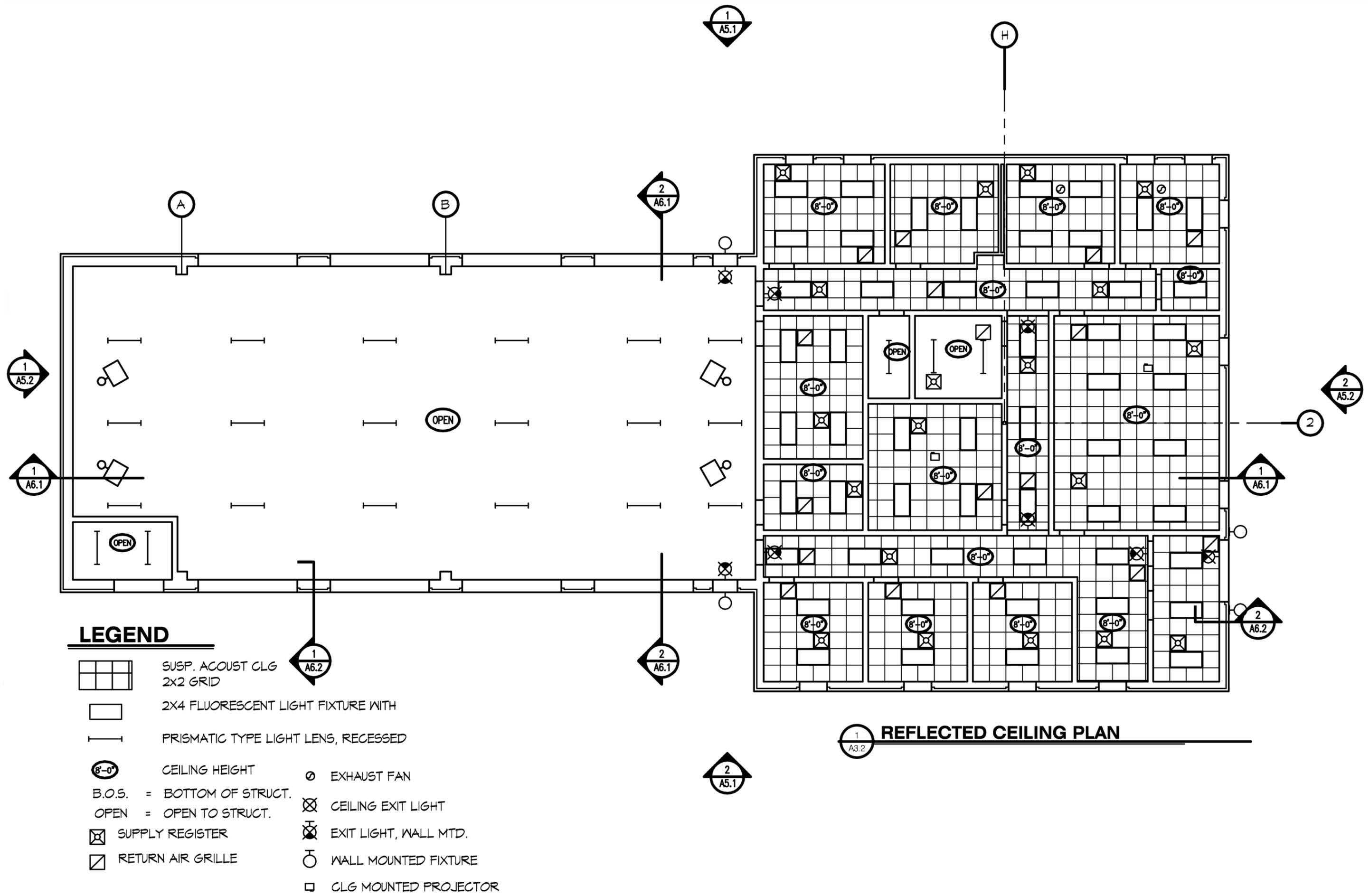
NOTES:
1) SEE 1/A2.3 FOR ALL MOUNTING HEIGHTS
2) PROVIDE THRU-BOLT ATTACHMENT FOR PARTITION MOUNTED ACCESSORIES, TYPICAL.
3) PLATE GLASS MIRROR SHALL BE FULL HEIGHT FROM TOP LEDGE OF BACKSPLASH TO 6'-8" A.F.F.



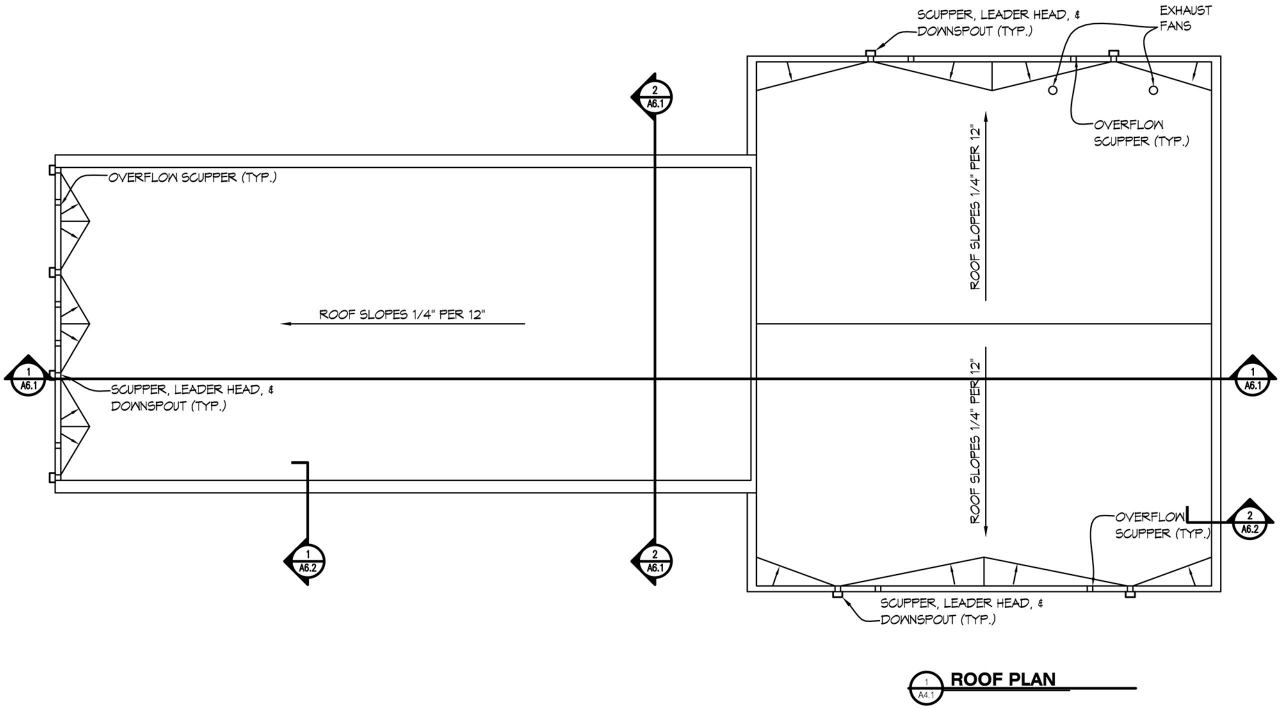
Accessory schedule and details



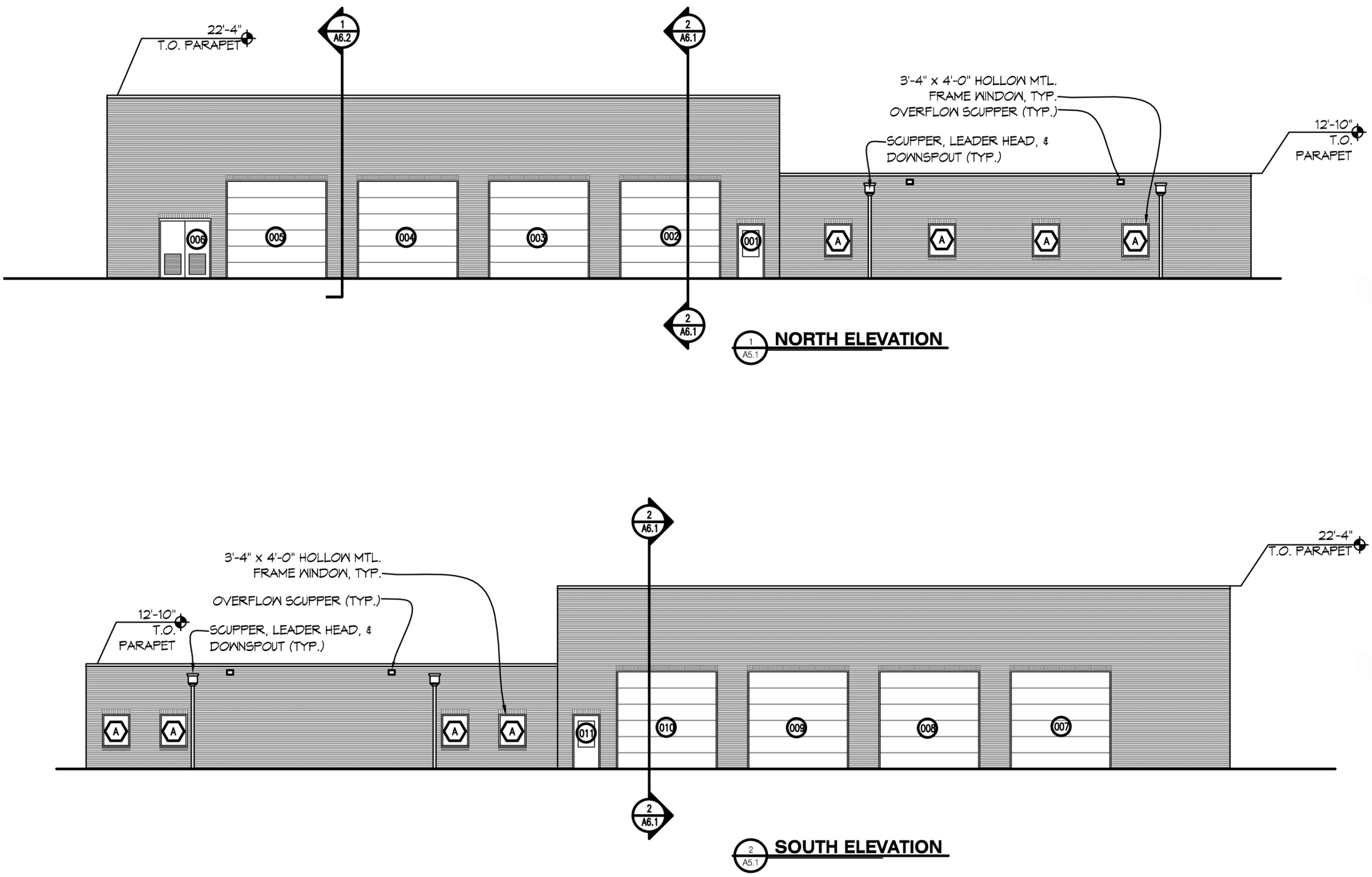
Service pit reflected ceiling



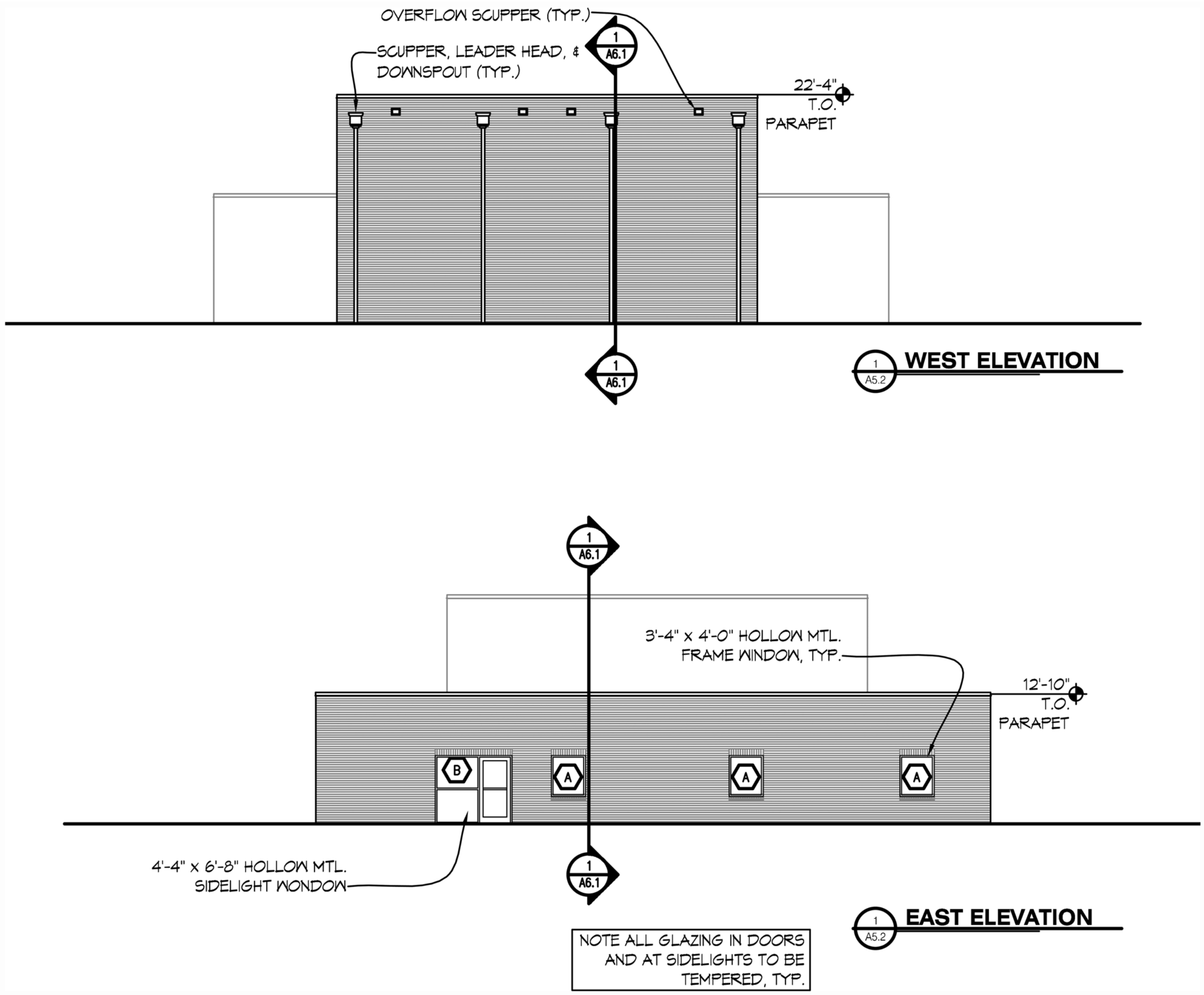
Reflected ceiling plan


SCUPPER, LEADER HEAD, &
DOWNSPOUT (TYP.)
EXHAUST
FANS
OVERFLOW
SCUPPER (TYP.)
OVERFLOW SCUPPER (TYP.)
ROOF SLOPES 1/4" PER 12"
ROOF SLOPES 1/4" PER 12"
SCUPPER, LEADER HEAD, &
DOWNSPOUT (TYP.)
ROOF SLOPES 1/4" PER 12"
OVERFLOW
SCUPPER (TYP.)
SCUPPER, LEADER HEAD, &
DOWNSPOUT (TYP.)
ROOF PLAN

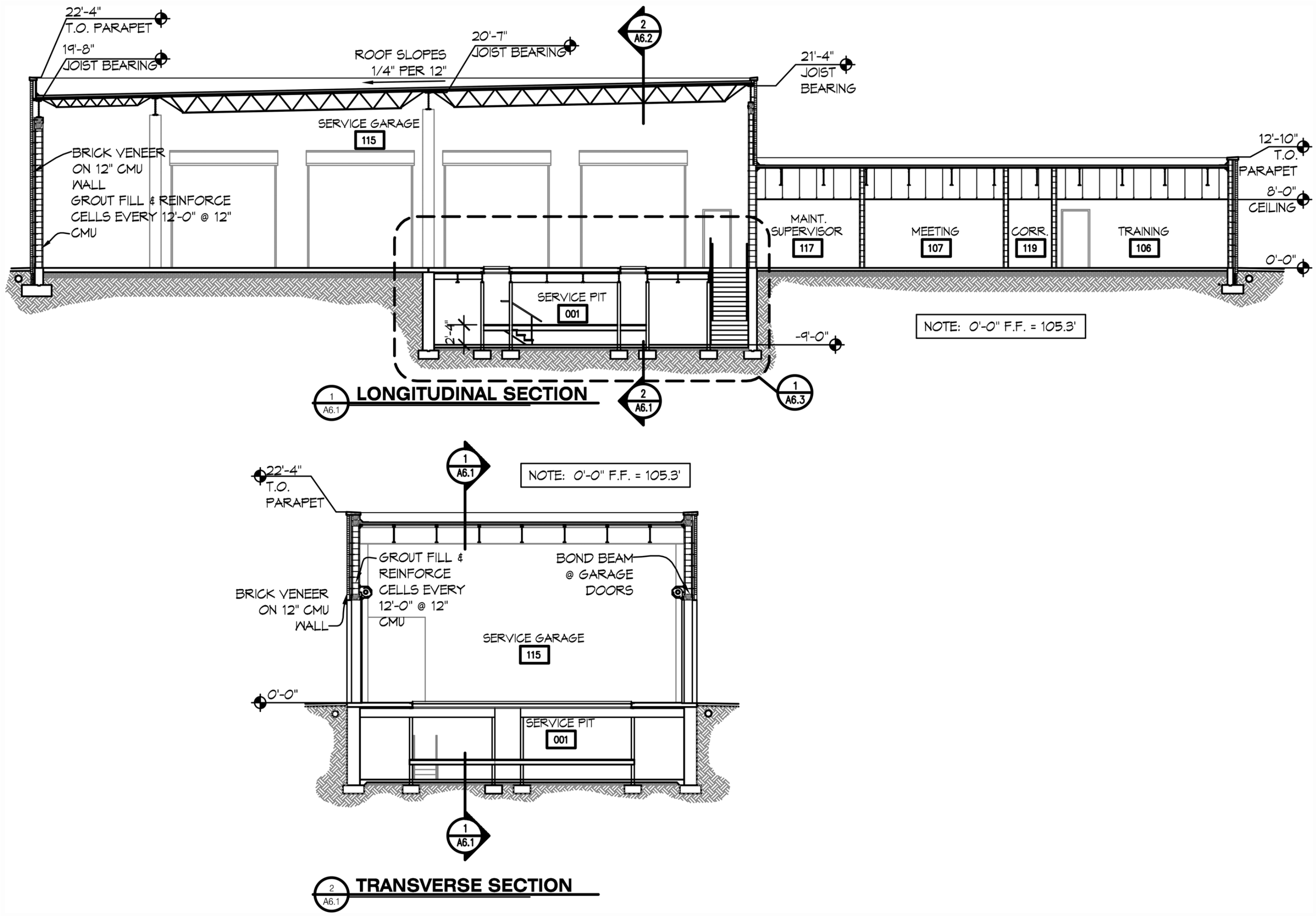
Roof plan



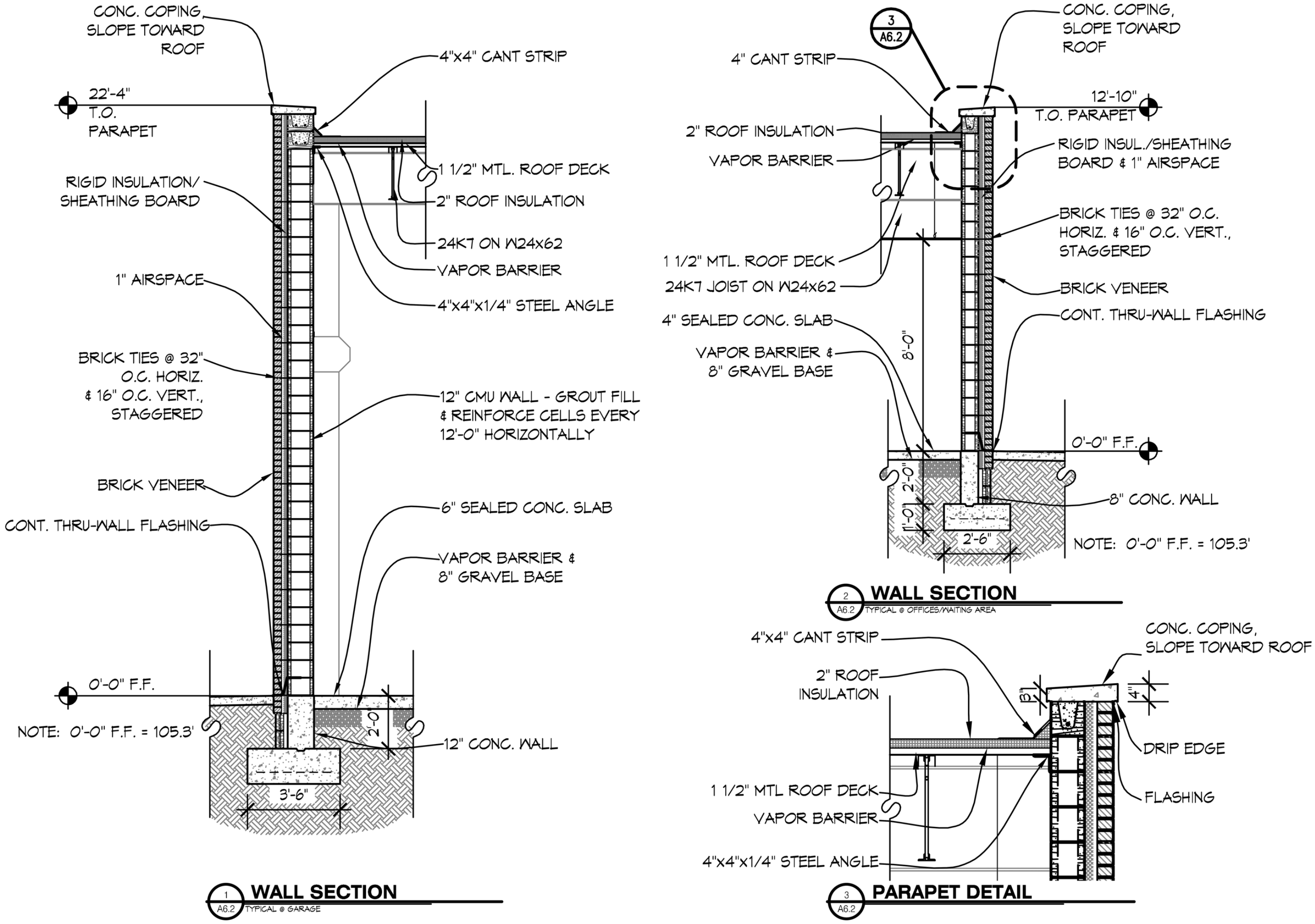
North and south elevations



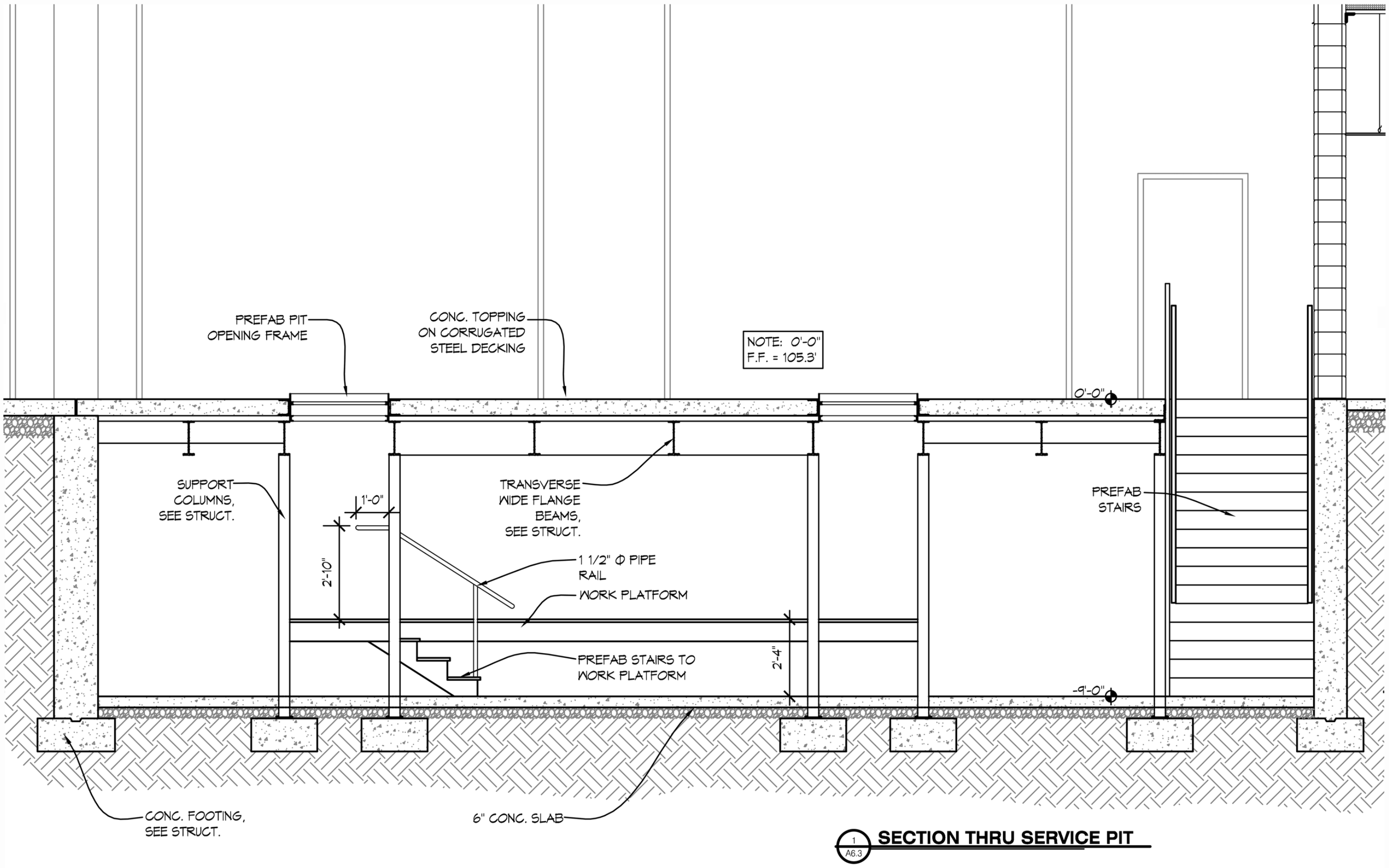
West and east elevations



Longitudinal and transverse sections



Wall and parapets sections



Section through service pit

DOOR SCHEDULE								
DOOR							FRAME	
NO.	DOOR	SIZE	TH.	MAT.	FINISH	REMARKS	MAT.	FINISH
001	SERVICE BAY ENTRANCE	3'-0" x 6'-8"	1 3/4"	HM	PAINT	2'-0" x 3'-2" TEMPERED WDW. ON LOCK SET SIDE OF DOOR	HM	PAINT
002	SERVICE BAY ACCESS	16'-0" x 12'-0"	--	STEEL	FACTORY	ROLL-UP GARAGE ACCESS	--	---
003	SERVICE BAY ACCESS	16'-0" x 12'-0"	--	STEEL	FACTORY	ROLL-UP GARAGE ACCESS	--	---
004	SERVICE BAY ACCESS	16'-0" x 12'-0"	--	STEEL	FACTORY	ROLL-UP GARAGE ACCESS	--	---
005	SERVICE BAY ACCESS	16'-0" x 12'-0"	--	STEEL	FACTORY	ROLL-UP GARAGE ACCESS	--	---
006	AIR COMPRESSOR ACCESS	PR 3'-0" x 6'-8"	1 3/4"	STEEL	FACTORY	DUAL DOOR - CENTER OPENING, LOUVERED LOWER PANELS	HM	PAINT
007	SERVICE BAY ACCESS	16'-0" x 12'-0"	--	STEEL	FACTORY	ROLL-UP GARAGE ACCESS	--	---
008	SERVICE BAY ACCESS	16'-0" x 12'-0"	--	STEEL	FACTORY	ROLL-UP GARAGE ACCESS	--	---
009	SERVICE BAY ACCESS	16'-0" x 12'-0"	--	STEEL	FACTORY	ROLL-UP GARAGE ACCESS	--	---
010	SERVICE BAY ACCESS	16'-0" x 12'-0"	--	STEEL	FACTORY	ROLL-UP GARAGE ACCESS	--	---
011	SERVICE BAY ENTRANCE	3'-0" x 6'-8"	1 3/4"	HM	PAINT	2'-0" x 3'-2" TEMPERED WDW. ON LOCK SET SIDE OF DOOR	HM	PAINT
012	MAIN ENTRANCE	3'-0" x 6'-8"	1 3/4"	ALUM	ANODIZED	TEMPERED PLATE GLASS GLASS IN STOREFRONT FRAME	ALUM	ANODIZED
101	RECEPTION	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
102	TRAINING	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
103	MEETING ROOM	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
104	ACCOUNTING	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
105	ADMINISTRATION	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
106	MANAGER	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
107	TO SERVICE BAYS	3'-0" x 6'-8"	1 3/4"	HM	PAINT	--	HM	PAINT
108	MAINT. SUPERVISOR	3'-0" x 6'-8"	1 3/4"	HM	PAINT	2'-0" x 3'-0" TEMPERED GLASS IN TOP PANEL	HM	PAINT
109	PARTS	3'-0" x 6'-8"	1 3/4"	HM	PAINT	--	HM	PAINT
110	TO SERVICE BAYS	3'-0" x 6'-8"	1 3/4"	HM	PAINT	--	HM	PAINT
111	LOCKER ROOM	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
112	COMMUNICATION	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
113	MEN'S RESTROOM	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
114	MECHANICAL	3'-0" x 6'-8"	1 3/4"	HM	PAINT	--	HM	PAINT
115	TRAINING	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
116	WOMEN'S RESTROOM	3'-0" x 6'-8"	1 3/4"	SC	STAIN	--	HM	PAINT
117	BREAK ROOM	3'-0" x 6'-8"	1 3/4"	SC	PAINT	2'-0" x 3'-0" TEMPERED GLASS IN TOP PANEL	HM	PAINT
118	STORAGE	3'-0" x 6'-8"	1 3/4"	HM	PAINT	--	HM	PAINT

LEGEND

HM	Hollow Metal	STAIN	Blonde Stain on Wood Surface
FACTORY	Factory Applied Paint Finish	SC	Solid Core Wood

Door schedule

FINISH SCHEDULE							
NO. / ROOM	FLOOR	BASE	WALLS	WAINSCOT	CEILING	CLG. HT.	REMARKS
001 SERVICE PIT WORK AREA	CONC	--	CONC	--	--	OPEN	NO BASE REQUIRED, CONCRETE TO BE SEALED.
101 WAITING AREA	CPT	VNYL	GWB	--	ACT	8'-0"	--
102 RECEPTIONIST	CPT	VNYL	GWB	--	ACT	8'-0"	--
103 ACCOUNTING OFFICE	CPT	VNYL	GWB	--	ACT	8'-0"	--
104 ADMINISTRATION OFFICE	CPT	VNYL	GWB	--	ACT	8'-0"	--
105 MANAGER'S OFFICE	CPT	VNYL	GWB	--	ACT	8'-0"	--
106 TRAINING	CPT	VNYL	GWB	--	ACT	8'-0"	--
107 MEETING	CPT	VNYL	GWB	--	ACT	8'-0"	--
108 MECHANICAL	CONC	--	GWB	--	--	OPEN	NO BASE REQUIRED
109 COMMUNICATION	CONC	--	GWB	--	--	OPEN	NO BASE REQUIRED
110 LOCKER ROOM	VCT	VNYL	GWB	--	ACT	8'-0"	--
111 MEN'S RESTROOM	CT	CT	GWB	CT	ACT	8'-0"	TOP OF CERAMIC TILE WAINSCOT = 5'-0" A.F.F.
112 WOMEN'S RESTROOM	CT	CT	GWB	CT	ACT	8'-0"	TOP OF CERAMIC TILE WAINSCOT = 5'-0" A.F.F.
113 BREAK ROOM	CPT	VNYL	GWB	--	ACT	8'-0"	--
114 STORAGE	CONC	--	GWB	--	--	OPEN	NO BASE REQUIRED
115 SERVICE BAYS	CONC	--	CMU	--	--	OPEN	NO BASE REQUIRED, CONC. TO BE SEALED
116 PARTS STORAGE	CONC.	--	GWB	--	ACT	8'-0"	NO BASE REQUIRED
117 MAINTENANCE SUPERVISOR	CONC.	--	GWB	--	ACT	8'-0"	NO BASE REQUIRED
118 CORRIDOR	CPT	VNYL	GWB	--	ACT	8'-0"	--
119 CORRIDOR	CPT	VNYL	GWB	--	ACT	8'-0"	--
120 CORRIDOR	CPT	VNYL	GWB	--	ACT	8'-0"	--
121 EQUIPMENT ROOM	CONC	--	CMU	--	--	OPEN	NO BASE REQUIRED, CONC. TO BE SEALED

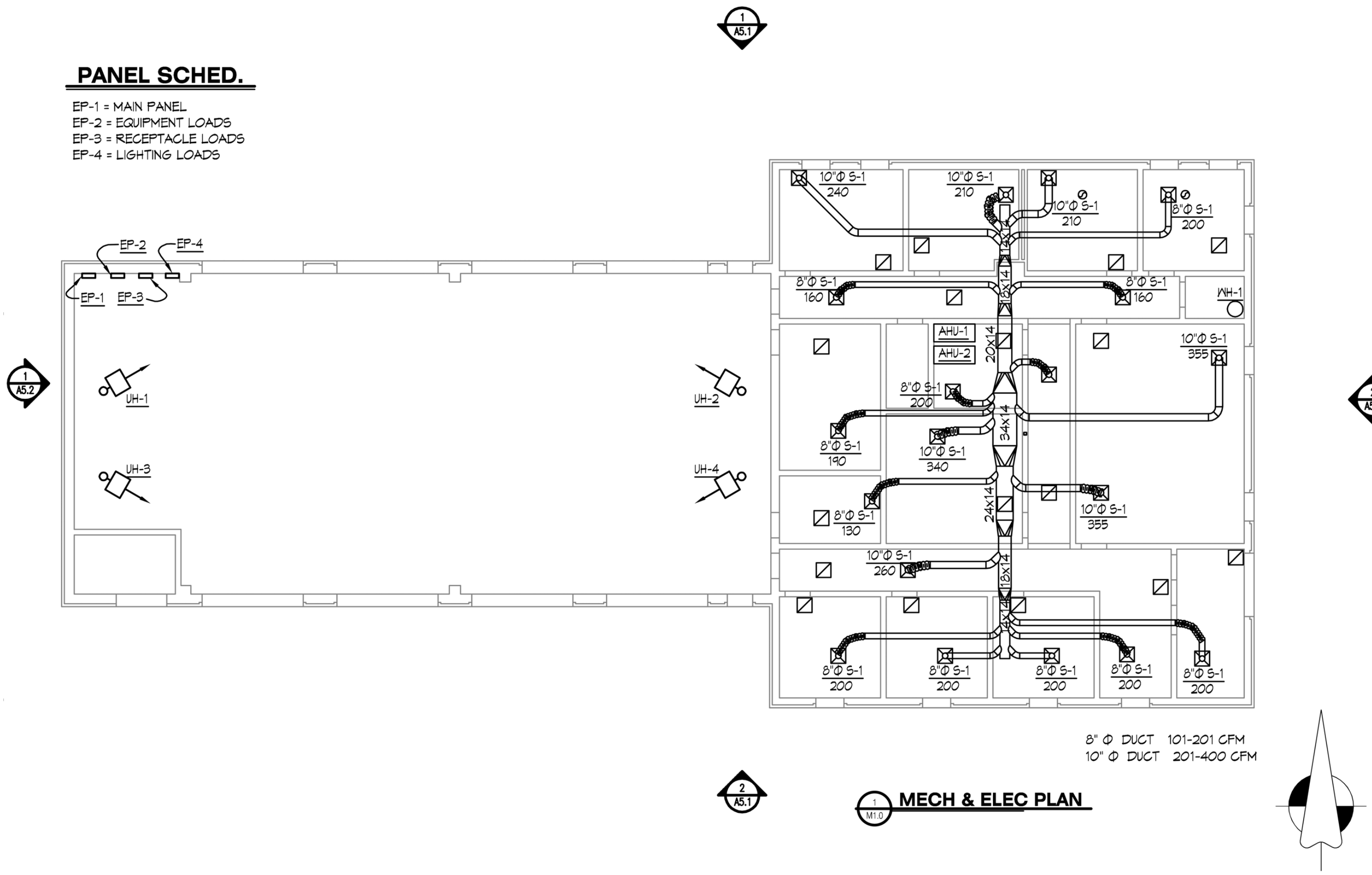
LEGEND

GWB	Gypsum Wall Board
CMU	Concrete Masonry Unit
CONC	Concrete
CPT	Carpet
VCT	Vinyl Composition Tile
CT	Ceramic Tile
VNYL	Vinyl
ACT	Acoustical Ceiling Tile

NOTES:

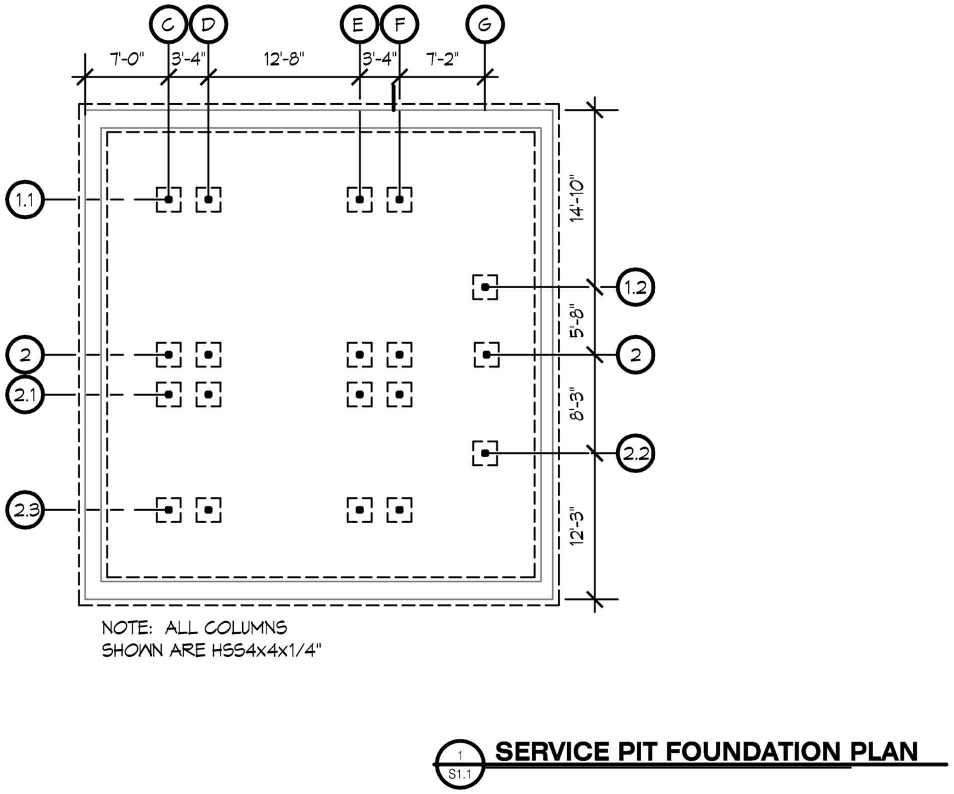
1) All GWB to be painted with matte finish latex paint, colors to be selected by owner.
2) Ceramic tile colors & patterns to be selected by owner.
3) CMU to be painted with gloss finish latex paint.
4) All carpet to be commercial grade with colors and pattern selected by owner.
5) Vinyl Composition Tile pattern and color to be selected by owner.

Finish schedule



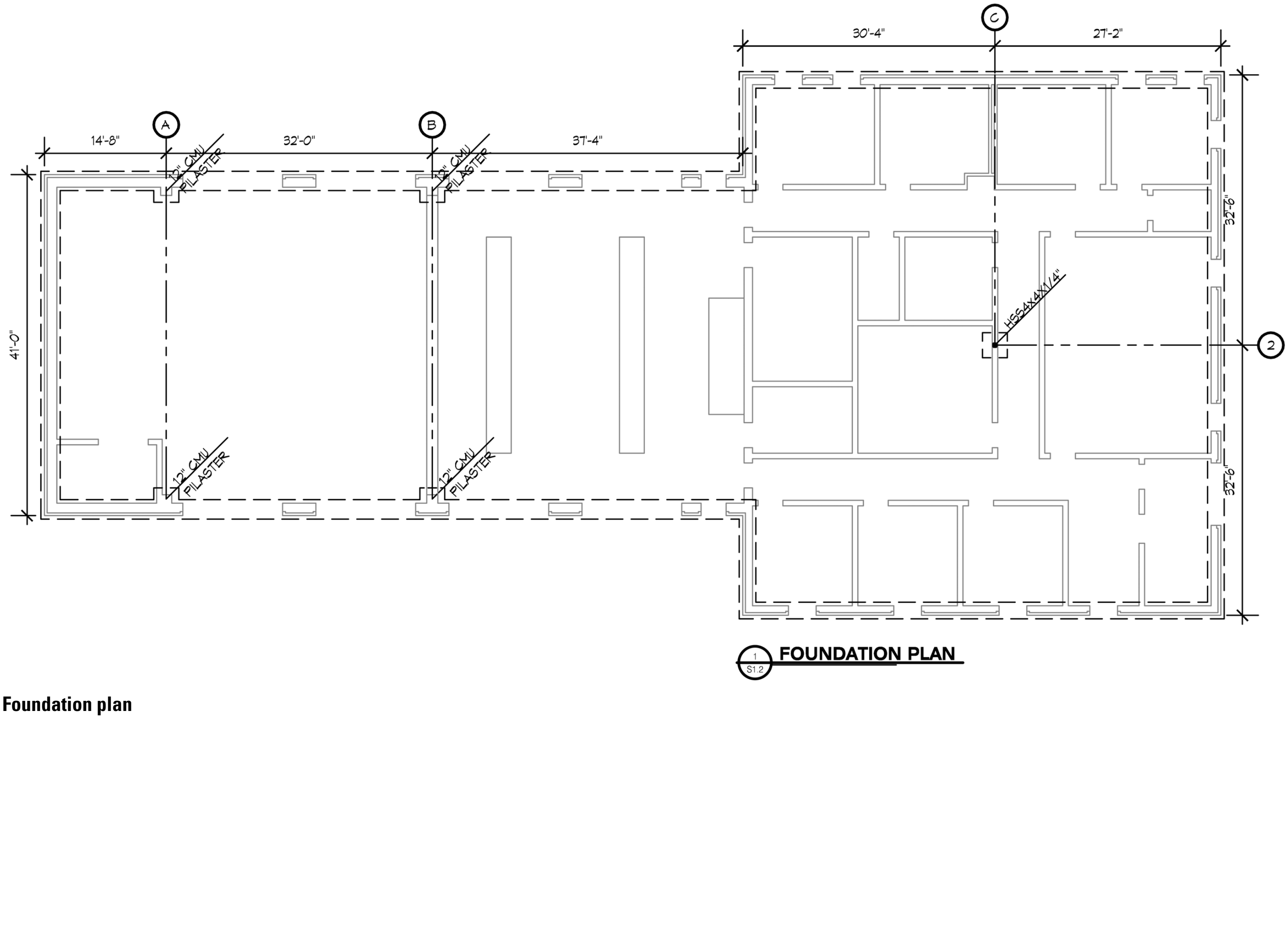
Mechanical and electrical plan

REINFORCING NOTES	
PAD FOOTINGS	#5 @ 1'-0" O.C. EACH WAY
STRIP FOOTINGS	3 - #5 LONGITUDINALLY @ 1'-0"
PIT WALLS	#5 @ 1'-0" O.C. EACH WAY, EACH FACE
SOG	6-6 10/10 WWF
CONCRETE TOPPING OVER SERVICE PIT	6-6 10/10 WWF

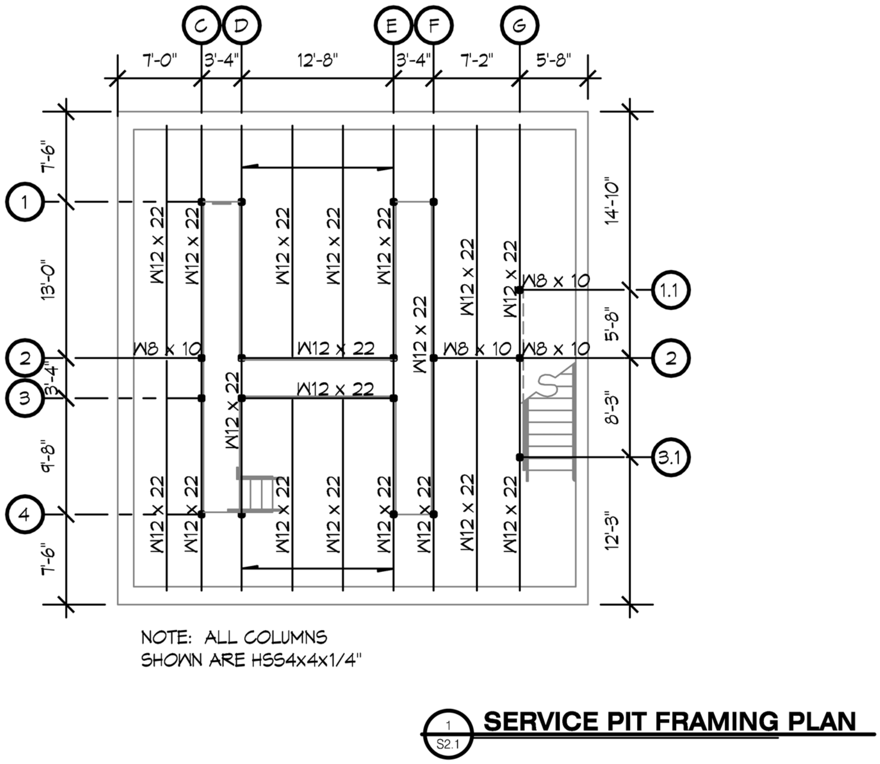


Service pit foundation plan

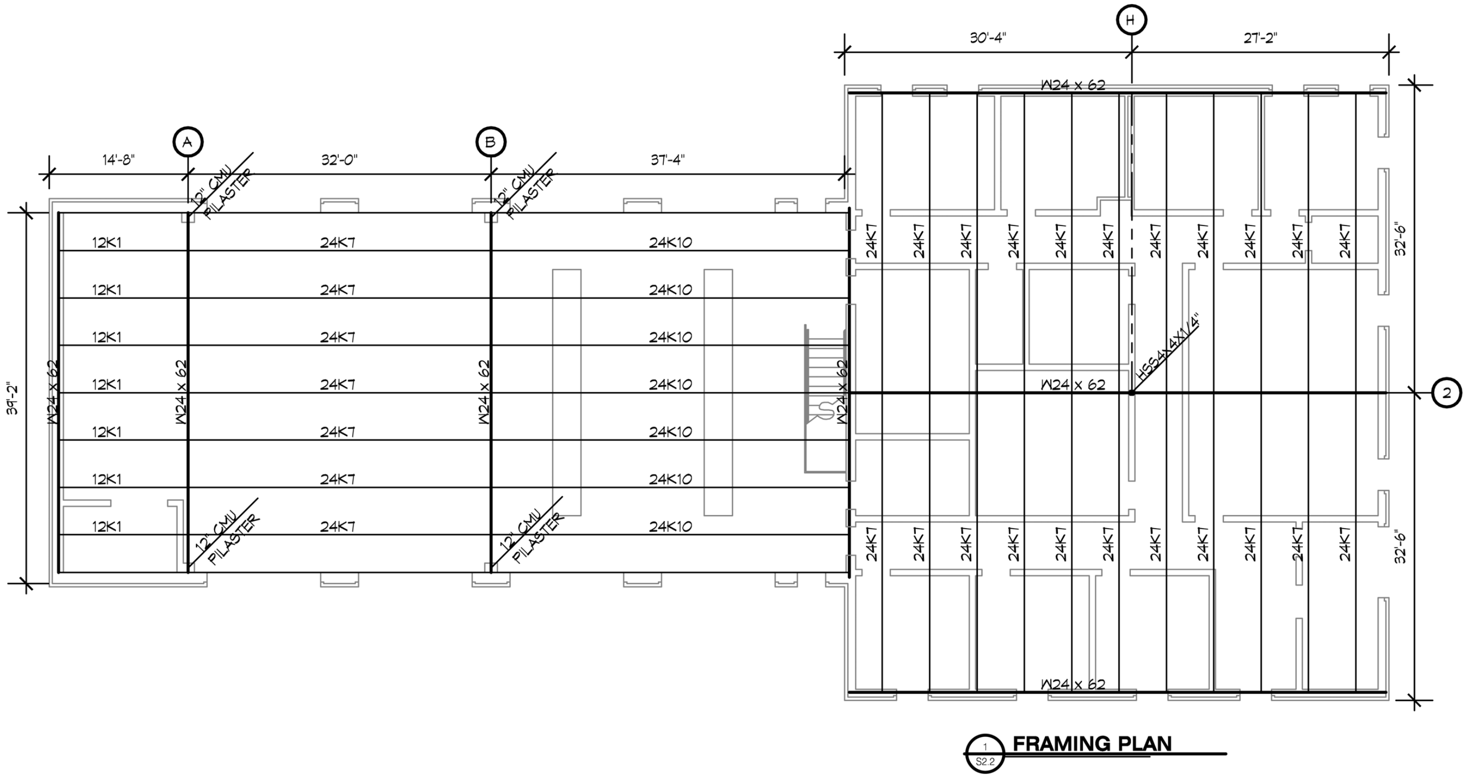
REINFORCING NOTES	
PAD FOOTINGS	#5 @ 1'-0" O.C. EACH WAY
STRIP FOOTINGS	3 - #5 LONGITUDINALLY @ 1'-0"
PIT WALLS	#5 @ 1'-0" O.C. EACH WAY, EACH FACE
SOG	6-6 10/10 WWF
CONCRETE TOPPING OVER SERVICE PIT	6-6 10/10 WWF



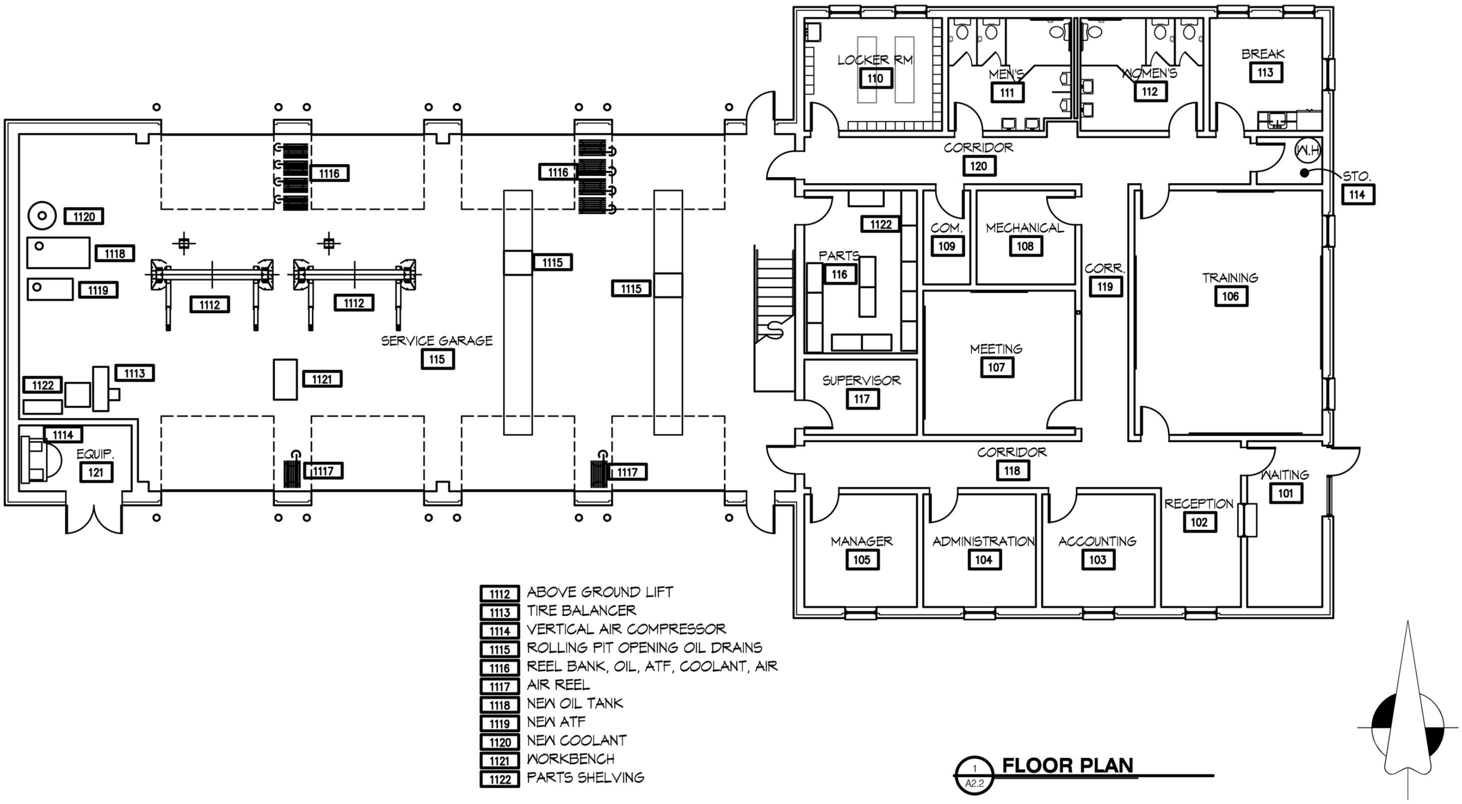
Foundation plan



Service pit framing plan



Framing plan



Automotive service equipment layout

Appendix B: Vehicle Maintenance Facility: Activities, Logic, Codes, and Cost Data

Table B.1 Vehicle Maintenance Facility: Activity Codes

ID	Name	Orig Durn	Phase	Subcontractor	Predecessors
1	**Project Management**	**5 days**			
2	Receive NTP	0 days	SETUP	CM	
3	Set up erosion control	5 days	SETUP	EROSION	2
4	Mobilize General Conditions items	5 days	SETUP	CM	2
5	Bonds and Permits	2 days	SETUP	CM	2
6	**Initial Site Work**	**18 days**			
7	Clear & grub site	3 days	INITSW	SITE	3,4,5
8	Rough grade site	5 days	INITSW	SITE	7
9	Install storm drains	10 days	INITSW	UNDRGR	8
10	**Foundation**	**41 days**			
11	Excavate for Service Pit	3 days	FNDNPIT	SITE	8
12	FRPS Service Pit footings	5 days	FNDNPIT	CONC	11
13	FRPS Service Pit Walls	11 days	FNDNPIT	CONC	12
14	Backfill around Service Pit	2 days	FNDNPIT	SITE	13
15	Install steel columns in Service Pit	1 day	FNDNPIT	STEEL	14
16	Prep and place SOG in Service Pit	3 days	FNDNPIT	CONC	15
17	Install work platform in Service Pit	1 day	FNDNPIT	STEEL	16
18	Install access stair in Service Pit	1 day	FNDNPIT	STEEL	17
19	Install WF support beams in Service Pit	2 days	FNDNPIT	STEEL	18
20	Lay corrugated steel decking over Service Pit	2 days	FNDNPIT	STEEL	19
21	Prep and place concrete topping over Service Pit	3 days	FNDNPIT	CONC	20
22	Excavate for footings – Service Bays	2 days	FNDNMAIN	SITE	14
23	FRPS footings – Service Bays	4 days	FNDNMAIN	CONC	22
24	FRPS foundation walls – Service Bays	5 days	FNDNMAIN	CONC	23

(*Continued*)

Table B.1 (*Continued*)

ID	Name	Orig Durn	Phase	Subcontractor	Predecessors
25	Backfill around foundation walls – Service Bays	2 days	FNDNMAIN	SITE	24
26	Prep and place SOG – Service Bays 3 & 4	3 days	FNDNMAIN	CONC	25
27	Excavate for footings – Office Area	2 days	FNDNMAIN	SITE	14
28	FRPS footings - Office Area	5 days	FNDNMAIN	CONC	27
29	FRPS foundation walls – Office Area	6 days	FNDNMAIN	CONC	28
30	Install U/G plumbing – Office areas	3 days	FNDNMAIN	PLUMB	28
31	Install U/G electrical conduit – Office Area	2 days	FNDNMAIN	ELEC	28
32	Prep and place SOG – Office Area	4 days	FNDNMAIN	CONC	30,31,33
33	Backfill foundation walls – Office area	3 days	FNDNMAIN	SITE	29
34	Complete Foundation	0 days	FNDNMAIN	CM	32,21,26
35	**Structure and Envelope**	**59 days**			
36	Erect roll-up door frames	4 days	STRUC	SPEC	34
37	Erect HM door frames – Service Bays	1 day	STRUC	CARP	36
38	Erect 12″ CMU walls – Service Bays	15 days	STRUC	MASON	37
39	Erect Brick Veneer – Service Bays	8 days	STRUC	MASON	52
40	Hang roll-up doors – Service Bays	8 days	STRUC	SPEC	39
41	Hang exterior HM doors – Service Bays	2 days	STRUC	CARP	39
42	Erect 8″ CMU walls – Office Area	12 days	STRUC	MASON	38
43	Erect brick Veneer – Office Area	6 days	STRUC	MASON	53
44	Install exterior windows - Office Area	2 days	STRUC	CARP	43
45	Install storefront at main entrance – Office Area	5 days	STRUC	STORE	43
46	Erect structural steel and joists – All areas	5 days	STRUC	STEEL	38,39,43
47	Lay corrugated steel roof decking – All areas	2 days	STRUC	STEEL	46
48	Lay rigid roof insulation – All areas	2 days	STRUC	ROOF	47
49	Install cold process roofing and flashing – All areas	5 days	STRUC	ROOF	48
50	Install precast concrete coping at parapets – All areas	4 days	STRUC	MASON	49
51	Building Dry-in	0 days	STRUC	CM	49,50,40,45,41,44
52	Install rigid insulation board – Service Bays	3 days	STRUC	INSUL	38
53	Install rigid insulation board – Office Area	3 days	STRUC	INSUL	42
54	**Interiors – Office Area**	**69 days**			
55	Hang ductwork and install AHUs – Office Area	10 days	OFFROUGH	MECH	47
56	Erect HM door frames – Office Area	3 days	OFFROUGH	CARP	55
57	Erect steel studs – Office Area	5 days	OFFROUGH	CARP	56
58	Rough in panels, conduit and wiring – Office Area	8 days	OFFROUGH	ELEC	57

ID	Name	Orig Durn	Phase	Subcontractor	Predecessors
59	Rough in Plumbing – Office Area	5 days	OFFROUGH	PLUMB	57
60	Rough in HVAC control system – Office Area	5 days	OFFROUGH	MECH	57
61	Rough in fire alarm system – All Areas	5 days	OFFROUGH	FIRE	57
62	Rough in voice/data system - Office Area	3 days	OFFROUGH	IT	57
63	Hang and tape GWB	8 days	OFFFINISH	GWB	58,60,61,62,44,45,51,59,57
64	Rough paint	4 days	OFFFINISH	PAINT	63
65	Hang ceiling grid	7 days	OFFFINISH	CEILING	64
66	Install lighting fixtures in ceiling grid – Office Area	4 days	OFFFINISH	ELEC	65
67	Install registers and grilles in ceiling grid – Office Area	5 days	OFFFINISH	MECH	65
68	Install ceiling tiles in grid	3 days	OFFFINISH	CEILING	66,67
69	Lay ceramic tile in restrooms	5 days	OFFFINISH	CERAMIC	64
70	Install plumbing fixtures in restrooms – Office Area	3 days	OFFFINISH	PLUMB	69
71	Install toilet partitions in restrooms	3 days	OFFFINISH	CARP	70
72	Install toilet accessories in restrooms	2 days	OFFFINISH	CARP	71
73	Install wash basin in locker room – Office Area	2 days	OFFFINISH	PLUMB	68
74	Install lockers and benches in locker room	3 days	OFFFINISH	FURN	73
75	Install casework in break room	2 days	OFFFINISH	CARP	68
76	Install appliances in break room – Office Area	2 days	OFFFINISH	MECH	75
77	Install VCT and base	5 days	OFFFINISH	FLOOR	82,83,80,81
78	Install carpet and base	3 days	OFFFINISH	FLOOR	77
79	Hang doors and hardware	5 days	OFFFINISH	CARP	78,72
80	Finish mechanical – Office Area	3 days	OFFFINISH	MECH	68
81	Finish electrical – Office Area	2 days	OFFFINISH	ELEC	68
82	Install projectors in meeting and training rooms	2 days	OFFFINISH	TRAIN	68
83	Hang screens and whiteboards in meeting and training rooms	2 days	OFFFINISH	TRAIN	68
84	Complete interior buildout – Office Area	0 days	OFFFINISH	CM	79,45,41,74,76
85	**Service Bays**	**30 days**			
86	Paint interior walls – Service Bay and Pit	10 days	SVCBYINT	PAINT	51,21
87	Install main electrical panels – Service Bay	5 days	SVCBYINT	ELEC	92
88	Rough in electrical – Service Bay and Pit	5 days	SVCBYINT	ELEC	87
89	Install lighting fixtures – Service Bay and Pit	5 days	SVCBYINT	ELEC	88
90	Install heating fixtures – Service Bay	4 days	SVCBYINT	MECH	92

(*Continued*)

Table B.1 (*Continued*)

ID	Name	Orig Durn	Phase	Subcontractor	Predecessors
91	Install piping for heating fixtures – Service Bay	5 days	SVCBYINT	MECH	90
92	Seal concrete floors – Service Bay and Pit	5 days	SVCBYINT	CONC	86
93	Install auto service tubing	2 days	SVCBYINT	AUTO	92
94	Install auto service tanks	2 days	SVCBYINT	AUTO	93
95	Install auto service equipment	3 days	SVCBYINT	AUTO	94
96	Install auto service reels and dispensers	2 days	SVCBYINT	AUTO	95
97	Install vehicles lifts	2 days	SVCBYINT	AUTO	96
98	Install workbenches and shelves	5 days	SVCBYINT	FURN	92
99	Complete Service Bay buildout	0 days	SVCBYINT	CM	89,91,93,94,95,96,97,98,92
100	**Final Site Work**	**29 days**			
101	Lay concrete pads for transformers and AC equipment	3 days	FNLSW	CONC	43
102	Set external transformer	2 days	FNLSW	ELEC	101
103	Set external AC units	2 days	FNLSW	MECH	101
104	Install footings – dumpster enclosure	2 days	FNLSW	CONC	110
105	Erect masonry walls – dumpster enclosure	4 days	FNLSW	MASON	106
106	Install bollards – dumpster enclosure	2 days	FNLSW	CONC	104
107	Install concrete pad – dumpster enclosure	2 days	FNLSW	CONC	105
108	Install gate – dumpster enclosure	2 days	FNLSW	MASON	107
109	Install bollards at roll-up doors	4 days	FNLSW	CONC	39
110	Fine grade for parking lot	3 days	FNLSW	SITE	109,9
111	Place curb and gutter – parking lot	6 days	FNLSW	PAVE	110
112	Spread and compact GAB	4 days	FNLSW	PAVE	111
113	Lay AC base course – parking lot	4 days	FNLSW	PAVE	112
114	Lay AC wearing course – parking lot	3 days	FNLSW	PAVE	113
115	Stripe parking lot and install signage	5 days	FNLSW	STRIPE	114
116	Install sidewalks at building entrance	3 days	FNLSW	LANDSCAPE	113
117	Landscaping	5 days	FNLSW	LANDSCAPE	116
118	Erect main entrance sign	5 days	FNLSW	SIGN	114
119	Complete Final Site Work	0 days	FNLSW	CM	108,115,117,118
120	**Project Closeout**	**30 days**			
121	Test and balance AC system – Office Area	5 days	CLOSE	MECH	102,103,89,91,80
122	Final cleanup	5 days	CLOSE	CM	119,99,84,118,108
123	Final inspection	2 days	CLOSE	CM	121,122,99,80
124	Punchlist work	5 days	CLOSE	CM	123
125	Substantial Completion	0 days	CLOSE	CM	124
126	Obtain Certificate of Occupancy	5 days	CLOSE	CM	125
127	Project Completion	0 days	CLOSE	CM	126

Table B.2 Vehicle Maintenance Facility: Activity Dollar Values

ID	Name	Activity Value
1	**Project Management**	
2	Receive NTP	$ -
3	Set up erosion control	$ 5,000
4	Mobilize General Conditions items	$ 17,300
5	Bonds and Permits	$ 24,500
6	**Initial Site Work**	
7	Clear & grub site	$ 12,500
8	Rough grade site	$ 8,840
9	Install storm drains	$ 25,475
10	**Foundation**	
11	Excavate for Service Pit	$ 1,573
12	FRPS Service Pit footings	$ 4,916
13	FRPS Service Pit Walls	$ 19,848
14	Backfill around Service Pit	$ 1,206
15	Install steel columns in Service Pit	$ 3,989
16	Prep and place SOG in Service Pit	$ 2,440
17	Install work platform in Service Pit	$ 2,440
18	Install access stair in Service Pit	$ 6,675
19	Install WF support beams in Service Pit	$ 18,750
20	Lay corrugated steel decking over Service Pit	$ 6,369
21	Prep and place concrete topping over Service Pit	$ 8,573
22	Excavate for footings – Service Bays	$ 1,593
23	FRPS footings – Service Bays	$ 7,438
24	FRPS foundation walls – Service Bays	$ 9,090
25	Backfill around foundation walls – Service Bays	$ 1,950
26	Prep and place SOG – Service Bays 3&4	$ 11,209
27	Excavate for footings – Office Area	$ 1,547
28	FRPS footings – Office Area	$ 6,569
29	FRPS foundation walls – Office Area	$ 8,027
30	Install U/G plumbing – Office areas	$ 3,100
31	Install U/G electrical conduit – Office Area	$ 11,582
32	Prep and place SOG – Office Area	$ 24,318
33	Backfill foundation walls – Office area	$ 1,500
34	Complete Foundation	$ -
35	**Structure and Envelope**	
36	Erect roll-up door frames	$ 4,000
37	Erect HM door frames – Service Bays	$ 900
38	Erect 12″ CMU walls – Service Bays	$ 59,068
39	Erect Brick Veneer – Service Bays	$ 79,585
40	Hang roll-up doors – Service Bays	$ 28,000
41	Hang exterior HM doors – Service Bays	$ 9,060
42	Erect 8″ CMU walls – Office Area	$ 19,976

(*Continued*)

Table B.2 (*Continued*)

ID	Name	Activity Value
43	Erect brick Veneer – Office Area	$ 19,693
44	Install exterior windows – Office Area	$ 5,940
45	Install storefront at main entrance – Office Area	$ 1,564
46	Erect structural steel and joists – All areas	$ 41,893
47	Lay corrugated steel roof decking – All areas	$ 28,107
48	Lay rigid roof insulation – All areas	$ 11,451
49	Install cold process roofing and flashing – All areas	$ 11,520
50	Install precast concrete coping at parapets – All areas	$ 18,160
51	Building Dry-in	$ -
52	Install rigid insulation board - Service Bays	$ 4,046
53	Install rigid insulation board - Office Area	$ 2,617
54	**Interiors – Office Area**	
55	Hang ductwork and install AHUs – Office Area	$ 42,500
56	Erect HM door frames – Office Area	$ 3,150
57	Erect steel studs – Office Area	$ 6,819
58	Rough in panels, conduit, and wiring - Office Area	$ 26,060
59	Rough in Plumbing - Office Area	$ 4,500
60	Rough in HVAC control system - Office Area	$ 4,250
61	Rough in fire alarm system - All Areas	$ 17,374
62	Rough in voice/data system - Office Area	$ 18,821
63	Hang and tape GWB	$ 14,600
64	Rough paint	$ 4,200
65	Hang ceiling grid	$ 7,988
66	Install lighting fixtures in ceiling grid – Office Area	$ 21,717
67	Install registers and grilles in ceiling grid – Office Area	$ 4,250
68	Install ceiling tiles in grid	$ 8,516
69	Lay ceramic tile in restrooms	$ 6,591
70	Install plumbing fixtures in restrooms – Office Area	$ 14,800
71	Install toilet partitions in restrooms	$ 4,920
72	Install toilet accessories in restrooms	$ 2,239
73	Install wash basin in locker room - Office Area	$ 2,500
74	Install lockers and benches in locker room	$ 7,722
75	Install casework in break room	$ 500
76	Install appliances in break room - Office Area	$ 2,125
77	Install VCT and base	$ 709
78	Install carpet and base	$ 12,416
79	Hang doors and hardware	$ 27,810
80	Fiinish mechanical – Office Area	$ 2,125
81	Finish electrical – Office Area	$ 7,239
82	Install projectors in meeting and training rooms	$ 2,000
83	Hang screens and whiteboards in meeting and training rooms	$ 2,910
84	Complete interior buildout – Office Area	$ -

ID	Name	Activity Value
85	**Service Bays**	
86	Paint interior walls – Service Bay and Pit	$ 1,488
87	Install main electrical panels – Service Bay	$ 13,030
88	Rough in electrical – Service Bay and Pit	$ 10,135
89	Install lighting fixtures – Service Bay and Pit	$ 11,582
90	Install heating fixtures – Service Bay	$ 8,500
91	Install piping for heating fixtures – Service Bay	$ 8,500
92	Seal concrete floors – Service Bay and Pit	$ 5,638
93	Install auto service tubing	$ 1,660
94	Install auto service tanks	$ 5,260
95	Install auto service equipment	$ 17,680
96	Install auto service reels and dispensers	$ 5,960
97	Install vehicles lifts	$ 9,960
98	Install workbenches and shelves	$ 1,500
99	Complete Service Bay buildout	$ -
100	**Final Site Work**	
101	Lay concrete pads for transformers and AC equipment	$ 800
102	Set external transformer	$ 7,239
103	Set external AC units	$ 8,500
104	Install footings – dumpster enclosure	$ 9,120
105	Erect masonry walls – dumpster enclosure	$ 5,980
106	Install bollards – dumpster enclosure	$ 940
107	Install concrete pad – dumpster enclosure	$ 2,355
108	Install gate – dumpster enclosure	$ 500
109	Install bollards at roll-up doors	$ 13,840
110	Fine grade for parking lot	$ 16,363
111	Place curb and gutter – parking lot	$ 19,023
112	Spread and compact GAB	$ 18,168
113	Lay AC base course – parking lot	$ 8,450
114	Lay AC wearing course – parking lot	$ 17,697
115	Stripe parking lot and install signage	$ 2,500
116	Install sidewalks at building entrance	$ 3,000
117	Landscaping	$ 15,000
118	Erect main entrance sign	$ 10,000
119	Complete Final Site Work	$ -
120	**Project Closeout**	
121	Test and balance AC system – Office Area	$ 4,250
122	Final cleanup	$ 2,500
123	Final inspection	$ -
124	Punchlist work	$ 10,000
125	Substantial Completion	$ -
126	Obtain Certificate of Occupancy	$ -
127	Project Completion	$ -
	Total Project Cost	$ 1,162,366

Appendix C: Notes on Schedule Sequencing

The following “rules” are included to help the reader visualize some typical sequences of construction. They should be regarded as suggestions, not hard and fast requirements.

Always Schedule the Physical Dependencies First

Physical dependencies are those that cannot be changed and, therefore, must have priority in schedule. These dependencies are often so obvious that they are simply assumed, but they must be shown in the schedule nonetheless.

Typical examples are:

- A footing cannot be installed until a space is excavated for it.
- Concrete placement has to occur after reinforcement is installed.
- Wiring cannot be pulled until conduit has been installed.
- A column cannot be built until the footing upon which is rests is in place.

One of the best ways to start establishing dependencies is to look at the details in the drawing, for example, the wall sections of a building. Looking at these details from the bottom up will often make the necessary sequence of events obvious.

However, sometimes what depends on something else something else is not readily apparent, especially one item is shown in the one sets of drawings, while another, dependent item is shown in a different set of drawings. For example, electrical conduit is often embedded in a concrete slab. The conduit’s general location is shown in the electrical drawings, but these drawings may not show its elevation within the slab. Also, the location relative to the reinforcing steel may not be obvious from drawings. Creating a schedule that accurately reflects the correct order of work may mean talking to the superintendent and various foreman in order to determine the reality in the field.

Architectural Work

Sometimes the architectural detail will determine which goes first. For example:

- In commercial work, hollow metal frames must be set before gypsum wall board (GWB) is hung.
- In residential work, prehung frames and doors cannot be set until after GWB is in.
- The difference is in the way the door frames fit with the GWB. The fit shown on the drawing detail will govern.

Items that go inside something must be installed after the enclosing item is built in position.

- Items that go in a wall and depend on the wall for alignment and location—conduit, rough plumbing, cabling, insulation, etc.—can go in only after the studs are up.
  Note: GWB can be hung only after the items inside the wall are installed.

Look at the wall sections for a basic sequence.

Example of a carpentry sequence for residential construction:

- Sill
- Joists
- Subfloor
- Bottom plate, studs, top plate
- Sheathing
- Rafters (or trusses)
- Roof decking

Example of a structural concrete sequence:

- Footings
- Foundation walls
- First floor slab
- Columns to second floor
- Second floor slab

Basic Interior Sequencing

Everything above the ceiling goes in first. Least flexible items go first.

- Air-handling equipment
- Ductwork
- Piping—includes fire protection, HVAC piping, and any plumbing
- Electrical conduit
- Flexible wiring (such as computer cabling or control wiring), including cable trays, supports, and the like

Install ceiling grid.

Install everything that rests in the grid:

- Light fixtures
- HVAC registers and grilles
- Sprinkler heads, etc.

Install the ceiling tiles.

Install finishes in the rooms below the ceiling grid, for example, cabinetry, finish carpentry, carpet, and so on.

Note: Some superintendents prefer to put the ceiling tile in as the last thing before floor finishes so damage to fragile ceiling tiles is minimized.

Some General Rules for Interior Work

Bathrooms:

- Tile goes first, since most things rest on it.
- Cabinets must go in before lavatories, etc.
- Finish plumbing fixtures go in after tile since they rest on the tile.
- Accessories and toilet partitions go in last.

Other interior work ideas:

- Door jambs go in with studs; doors themselves go in later.
- Look at the details to determine order:
  - If item A butts up against item B, then B goes in first, followed by A, for example, vinyl wall covering must be fitted to cabinetry.
  - It is a good idea to do the finish flooring last to prevent damage by other trades.

Rules about Concurrence

Usually, two activities can go on at the same time if they're not in the same space. For example:

- External siding on a house can be installed while electricians put in panels and wiring inside.
- Landscaping can go on while interior finishes are being done.

Workers cannot work over others if a hazard is possible. For example:

- Do not install roofing while external siding is being installed. The roofers can drop things, which could injure the carpenters below.

Two activities can take place in the same space if they do not interfere with each other. For example:

- Often mechanical, electrical, and plumbing rough-ins can occur on the same floor if the area is large enough so that workers will not interfere.
- Some activities just can't have other work going on at the same time in the same space, for example, rough painting using sprayers.

Underground Work

- Generally, bring the site to grade, then put in underground systems (storm drains, water piping, etc.)
- Never do earthwork on top of installed underground items if you can help it.
- Elevation almost always rules—deepest first.

Mechanical Work

- Install vessels first, then pipe to the vessel. For example, set air-handling units, boilers, and chillers first, then run the piping lines between them.
- Use the same concept with HVAC equipment and ductwork, although the rule is not as hard and fast.
- Ductwork installers like to have a clear floor, with no studs or other building elements in the way, because ductwork is large, heavy, and difficult to handle. Also, it cannot be altered in the field.
- Look for pieces of equipment so large that they must be installed first, then have the building built around them and sequence accordingly—for example, mechanical equipment in basements or penthouse structures.
- The work of a mechanical sub is often intermittent. Early work such as roughing in is done, then the sub will leave the site while architectural or other work is done, then return to do finishes. The only time this will not be true is when the job is very large.

Electrical

- Like mechanical work, electrical work is often intermittent. The sub moves on and off the job as various phases are done.
- Electrical work can usually be divided in two ways, one simple and one detailed. The simple sequence is equipment–rough-ins–finishes. The complex breakdown is underground distribution equipment–overhead work–lighting systems–trim.

Dealing with Subs

- Negotiating with subs on schedule details is always better than dictating times.
- Always ask the subs how they would to see their work sequences broken out is the schedule. It doesn't cost anything to add a few extra activities to the schedule, and any sub will be happier if he is consulted. beforehand.
- Be prepared to give the sub something if you want something from him. For example, perhaps he will guarantee that he will show up with a specific crew if you will guarantee that he won't have other subs interfering with his work.

Other Suggestions

- Always have a single starting node and a single ending nodes in any network. In fact, most scheduling specifications will require this anyway.
- Don't forget to include inspections. An inspection can be scheduled as either a milestone or an activity, but in either case, the appropriate inspector must be

notified in advance and have time on the schedule to carry out the actual task of inspecting.

- Any activities which have very large float values probably are not connected properly to successors.
- Be careful with using float. Large float values can be misleading, and they often disappear if other parts of the job are delayed.
- Also, if possible, build in some extra time in individual activities to give the superintendent some opportunity to work out the inevitable unexpected small delays that occur on every job.
- Avoid putting too many crews in the same space at the same time. Overcrowded jobs are less efficient, and subs are less happy and, therefore, may be less cooperative.
- If the job is large, break the schedule down into areas or individual floors. Displaying the work this way can help avoid stacking trades.

Critical Points

- NEVER give anyone an optimistic time as to when an activity will be completed. This is not a technical rule, but rather a common sense rule of project management. Owners and project managers are seldom upset when an activity finishes earlier than projected, but they are almost always upset when it finishes later than projected.
- Beware of very tight schedules that have many SS and FF relationships. These kinds of networks often reflect overly optimistic thinking.
- First schedules should always be conservative. If the overall project duration meets the contract deadline, then all is well and the project has a better chance of on-time completion..
- If the overall time does not meet the contract requirements, then judicious rescheduling is in order. However, everyone should understand where the schedule has been trimmed and specifically what has to be done to make that happen.
- Always make your schedule show what the superintendent says he is going to do. You can make the schedule show something else, but most superintendents are going to do it their way, regardless.

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