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# 建筑施工计划与进度

# Construction Planning and Scheduling

Jimmie W. Hinze

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# 序　言

建设管理原是我国土木工程专业中重要的方向，许多土木类院系设有该专业，近年不少综合性大学也设置了该专业。随着我国加入 WTO、中国企业角逐国际工程、国外建筑企业挤入中国市场，使得建设管理专业教育必须提供从内容到语言上能够与国际建筑业接轨的课程。

鉴于这种趋势，清华大学出版社秉承在引进国外原版教材方面的领先地位，与全球高等教育出版巨擘——美国培生教育出版集团——合作，经过清华大学建设管理系专家评审，精选出这套“国外大学优秀教材——建设管理系列（影印版）”教材。

“国外大学优秀教材——建设管理系列（影印版）”适合作为建设管理专业、相关经济类专业和土木工程专业的原版教材，以及具有较好英文基础和专业背景、渴望了解国外相关领域知识的企业界人士学习使用。

“国外大学优秀教材——建设管理系列（影印版）”包括：《房屋设计与施工案例分析》（Case Studies in Building Design and Construction, 1e）、《建筑工程合同》（Construction Contracts, 3e）、《建筑工程估价》（Estimating in Building Construction, 5e）、《建筑工程项目管理（专业版）》（Construction Project Management-Professional Edition, 1e）和《建筑施工计划与进度》（Construction Planning and Scheduling, 1e）。另外，在我社的“清华经济学系列英文版教材”中包括《工程经济学》（Engineering Economy, 12e）、《环境与自然资源经济学》（Environmental and Natural Resource Economics，6e），在“清华管理学系列英文版教材”和“工商管理优秀教材译丛·管理学系列”中包括《面向商务和技术的项目管理》（Project Management for Business and Technology，2e）等教材可配套选用。对清华大学出版社相关教材最新资讯感兴趣的读者，可查询清华大学出版社网站 www.tup.com.cn。

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2004 年 8 月

# Preface

There are perhaps more textbooks on the subject of construction scheduling than on any other specific construction topic. Many of them provide excellent information on a variety of scheduling subjects. Unfortunately, many of these texts omit scheduling subjects that should be addressed. This text is written to provide coverage on all major scheduling subjects.

My first employment with a construction contractor was a summer job in the 1960s. Although I was exposed to many different tasks, I have vivid memories of the arrow diagram network that I was asked to draw by hand. A few years later while working for a different firm, my primary responsibility was scheduling. The scheduling effort was largely focused on the coordination of subcontractors on several different projects for which I used the precedence diagramming method. It was during this period that I developed a strong appreciation for the value of effective scheduling.

The effective use of schedules is based on beginning with a viable network model. The steps to achieve this objective are described in Chapter 1.

Some textbooks address only precedence diagramming, with little or no treatment of arrow diagramming. Many regard precedence diagrams as the most popular and most prudent for use on construction projects. Although I share this general perception, I also feel that some treatment on the subject of arrow diagramming is appropriate. In academic settings, I have found that students can grasp arrow diagramming more easily if they have not already been exposed to precedence diagrams. For this reason, the arrow diagrams are discussed early in the text, in Chapters 2 and 3. Note that the remainder of the text is essentially focused on precedence diagrams, as described in Chapter 4. Regardless of the scheduling technique used, accuracy in the scheduling information is rooted in beginning with accurate time estimates for activity duration as discussed in Chapter 5.

One scheduling topic seldom addressed in scheduling texts, especially in detail, is that of contract provisions related to scheduling. This text devotes an entire chapter to this subject (Chapter 6). The impact of scheduling provisions on cash flow is also addressed (Chapter 8).

Resource leveling and resource allocation are described in Chapter 7. Manual solutions to these problems are discussed. Although such problems are often solved by computer, it is necessary for schedulers to understand the process of arriving at a solution in order to fully comprehend the computer solution.

Schedules are management tools and as such, they should be used. It is through the proper use of schedules that management is able to make informed decisions about scheduling activities. This use includes updating the schedules when the schedule information ceases to be useful for making informed decisions. This is described in Chapter 9.

Chapter 10 addresses computer applications. This chapter is not a user's manual, nor is it a proponent for any particular scheduling software. The more widely used software programs are described to some extent, but this is not to be construed as an endorsement of any particular product. The purpose of the chapter is to familiarize the reader with some of the basic scheduling concepts that are addressed by computer software.

Chapter 11 describes earned value concepts. Project schedules are generally adversely impacted by changes in the project. Chapter 12 provides information for quantifying such impacts. Such information is often required when a claim is prepared. Chapter 13 presents a brief discussion of the value of schedules in litigations.

Short-interval schedules are addressed in Chapter 14. This treatise is far more extensive than any known writings or papers on the subject. The use of short-interval schedules is vital to the successful completion of many construction projects. Although concepts of their use and application are simple, the subject warrants a discussion in any serious text on scheduling.

Linear scheduling (discussed in Chapter 15) is a relatively new scheduling technique used in the construction industry. Linear scheduling is a very viable method on a variety of projects that would otherwise be difficult to schedule. Schedulers should consider the use of linear scheduling on projects that lend themselves to this technique. The use of probabilistic duration estimates is described in Chapter 16. Although the use of PERT is perhaps minimal in the construction industry, the basic concepts should be understood.

It is perhaps rare for a text to be written entirely by one person. I certainly can make no such claim. Others have provided valuable assistance in helping me compile all the information for this text. Of particular note are the contributions of Dr. John Gambatese, who helped review the entire text and who wrote Chapter 10. Dr. Ian Flood also offered valuable comments as the text was being finalized. The efforts of Bruce Jamieson were instrumental in compiling the information on short-interval scheduling. A considerable amount of the material on linear scheduling was developed by Greg Hanby, Phil Nelson, Brendan Kennedy, and H. C. Phillips. Dr. Robert Shawcroft contributed to the scheduling class notes that eventually evolved into this text, a major contribution. In addition, his help and advice are reflected to varying degrees in a majority of the chapters. I gratefully acknowledge the contributions of all of these individuals and of the reviewers of the book: Narayan Bodapati, Southern Illinois University at Edwardsville; Hal Johnston, California Polytechnic State University; and David A. Wahlstrom, Universtiy of Houston.

# Contents

# Introduction

*It's about time.*

Planning can be thought of as determining "what" is going to be done, "how," "where," by "whom," and "when." In construction projects the "plans" (blueprints) and specifications for the project generally define both the end product and, often, the general time frame in which to complete the project. However, they normally do not specifically identify the individual steps, their order, and the timing followed to achieve the end product. Thus, when we discuss planning in the construction process, we must address the "how" and, therefore, the "what," "when," "where," and "who."

When we discuss scheduling, we are usually interested in some aspect of the time element of the plan. In essence, a schedule is a timetable of activities, such as of "what" will be done or "who" will be working. Such a timetable can be looked at in two ways: The first is focusing on an activity, such as determining "when" a certain task will be performed relative to other activities. The second is concentrating on a specified time frame and then ascertaining "who" will be working (or needed) or "what" should be occurring at a particular time. All of us are involved in planning and scheduling on an ongoing basis. The degree to which we carry it out and the techniques we use vary depending upon the complexity of our situations and our needs and objectives.

We all do planning and scheduling on a regular, albeit informal basis. For whatever undertaking, we mentally determine a plan and schedule, such as what we will do in the next half-hour or how and when we will accomplish that task, such as a homework assignment. Often it is necessary for us to go a step beyond this level by creating a "to-do list." None of us can retain the organization of all the tasks we have to do on a daily basis, so we document what needs doing by writing down the information. This is also helpful if we are coordinating with other parties. By writing down the list of items, and perhaps copying and distributing it, we have documented a basis of agreement. We may also prioritize this list by writing the items in the order in which they will be done.

As the number of items increase and/or the time frame expands, we find we have to put our to-do list in the context of time. Normally, we do this using an appointment book or calendar. The driving forces typically are to avoid scheduling multiple things at the same time, to ensure that we allow sufficient time to prepare for an event, and/or to provide a record of what activities we undertook and when and how long we spent on them.

# BAR CHARTS

In 1917 Henry Gantt developed a method of relating a list of activities to a time scale in a very effective manner, by drawing a bar (or Gantt) chart such as those shown in Figures I.1 and I.2. Activities are represented as bars on the chart, while across the top or bottom of the chart is a time line. For each activity, a bar is drawn from the activity's starting time until its ending time. The Gantt chart has been widely used in depicting schedules for construction projects and has some very useful characteristics. Its primary advantage is that its simple graphic representation allows one to grasp schedule information quickly and easily.

Bar charts are simple presentations that show how major work activities are scheduled. A major advantage is that they are easily prepared as time-scaled presentations. Bar charts are the most commonly employed and readily recognized scheduling models in use today. In recognition of their creator, the terms *bar chart* and *Gantt chart* are used interchangeably by many schedulers.

The widespread use of bar charts can best be attributed to the ease with which they can be understood with only a cursory examination. The bar chart in Figure I.1 is a good example: the activity sequencing is apparent, and one can surmise easily when each activity is to begin and when it is to be completed. This simple example shows at a glance how the different activities relate to each other. Note that the activities are time-scaled and that they have been superimposed over a calendar.

With the time-scale presentation, a bar chart shows operations and the time consumed by each operation. In addition, it can show the scheduled versus actual

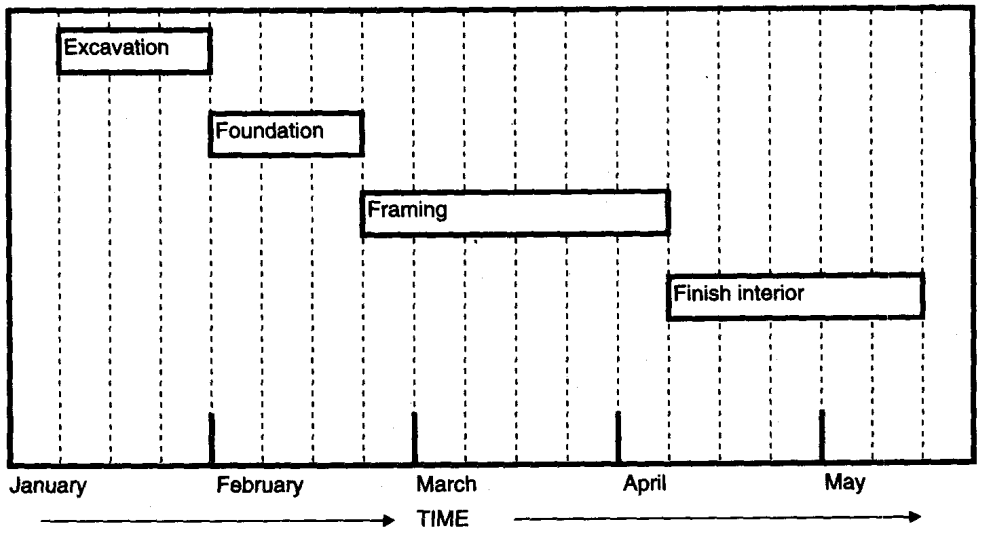


Figure I.1 Bar Chart Showing General Construction Work Tasks

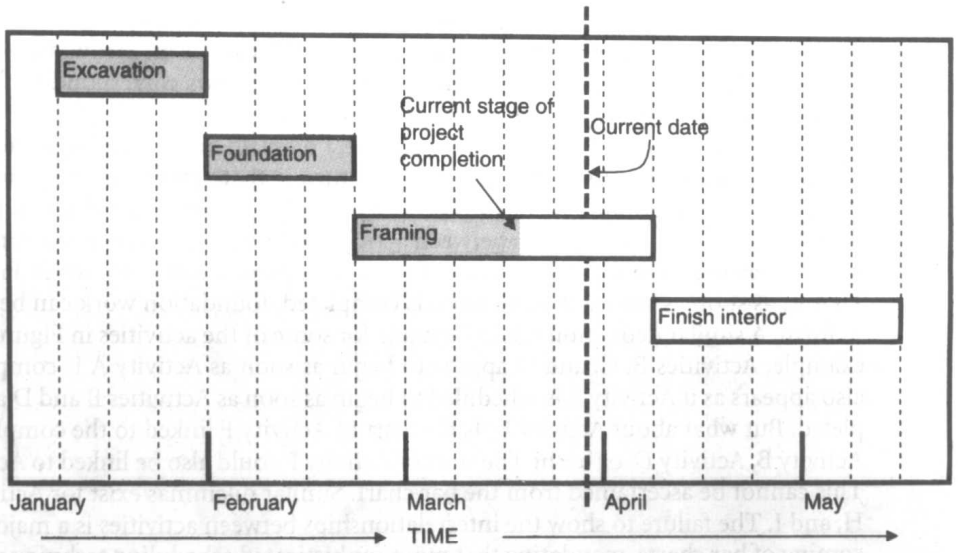


Figure I.2 Bar Chart Showing Scheduled Versus Actual Performance

progress. This is demonstrated in Figure I.2. The heavy dashed vertical line represents the current date, and the shaded portions of the activities indicate the amount of work that has been completed by the current date. It is obvious that the project is slightly behind schedule. The progress on the framing activity has not met expectations. Adjustments to the schedule may be warranted if the delay in project completion (about one week) is not acceptable. In this simple depiction, it is evident that the project can be completed on time by accelerating the work effort on framing, finishing interiors, or both. This information is easy to grasp from this bar chart, and there is little chance of misinterpretation.

## Shortcomings of Bar Charts

Despite the wide usage and appeal of bar charts, they do possess some features that make them difficult to use in certain settings. It is particularly when projects become more complex that bar charts begin to fail to provide the type of information that is often so valuable for planning and scheduling. An example with a bar chart will illustrate some of these shortcomings. First, consider the simple schedule shown in Figure I.1. It can easily be shown in network form; see Figure I.3.

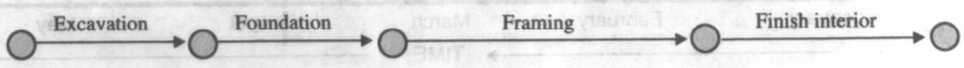


Figure I.3 Simple Arrow Diagram of a Project Showing Activity Sequences

It is simple to see the relationship between the bar chart shown earlier and the same information presented in network form, in this case as an arrow diagram. This diagram is also time-scaled in that the lengths of the arrows correspond to the durations of the activities they represent.

The bar chart in Figure I.4 shows a project overlaid on a calendar, similar to the bar chart already discussed. Its additional feature is that several of the activities are shown as occurring simultaneously. The first general criticism of bar charts is that they do not show clear dependencies between activities. In the previous bar chart, most observers may presume that the activities follow in sequence, just as shown in Figure I.3. That is, as soon as the excavation work is completed, foundation work can begin, and so forth. A similar deduction might be made for some of the activities in Figure I.4. For example, Activities B, C, and D appear to begin as soon as Activity A is completed. It also appears as if Activity E is scheduled to begin as soon as Activities B and D are completed. But what about Activity F? Is the start of Activity F linked to the completion of Activity B, Activity D, or both? The start of Activity F could also be linked to Activity C. This cannot be ascertained from the bar chart. Similar dilemmas exist for Activities G, H, and I. The failure to show the interrelationships between activities is a major shortcoming of bar charts, mandating that more sophisticated scheduling techniques be utilized on complex projects.

The bar chart shown in Figure I.4 shows the relative status of completion. Note that Activity G is ahead of schedule and Activity F is on schedule, but Activity E is behind schedule by about a week. While the relative schedule status of each activity can be determined from the bar chart, the actual status of the project cannot be readily

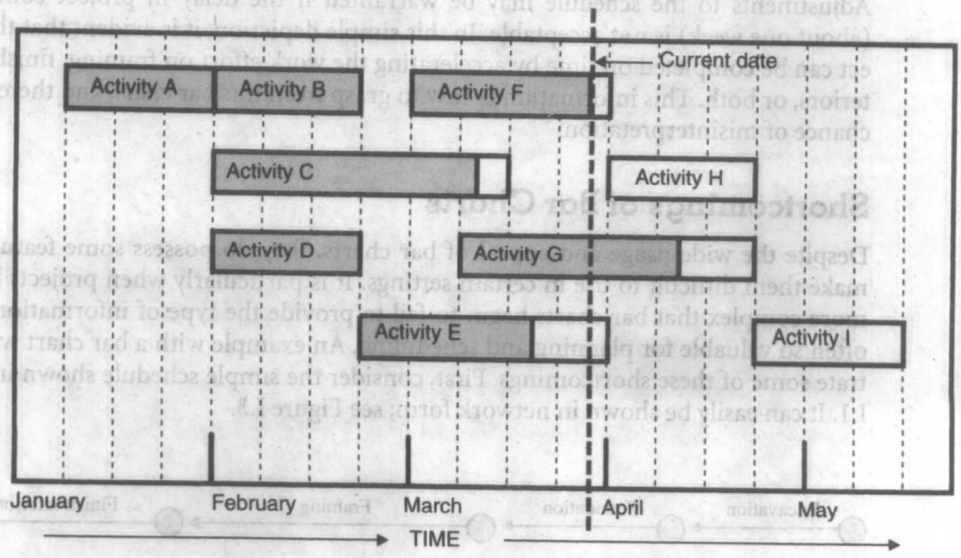


Figure I.4 Bar Chart Showing General Construction Work Tasks

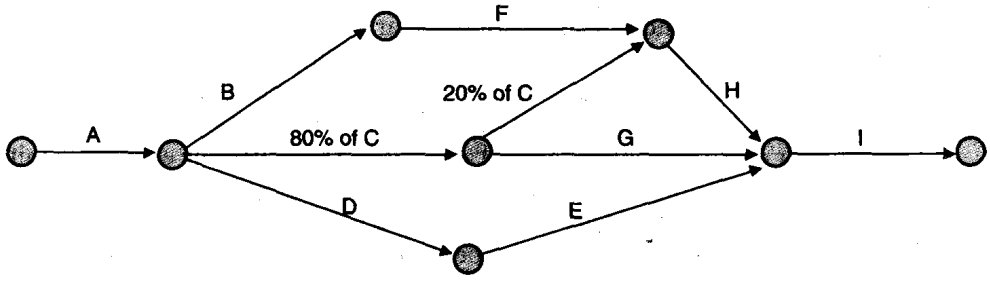


Figure I.5 Arrow Diagram of the Project Shown Earlier in Bar Chart Form

determined. The big question for the scheduler would be, "Does the behind-schedule status of Activity E compromise project completion?" This cannot be determined from the bar chart. Therein lies another shortcoming of bar charts: although the status of individual activities can be readily ascertained, the overall status of a project cannot be determined when some activities are not on schedule. This makes it difficult to assess the need for making scheduling adjustments, and it also makes it difficult to determine the appropriate activities to target for acceleration.

Even a change in the logical sequencing of the activities in a bar chart cannot be readily made, especially when many activities are involved. The information shown in the bar chart in Figure I.4 is shown in the arrow diagram in Figure I.5. Note that the relationships of the activities are consistent with the information shown in the bar chart, but the arrow diagram could not have been, with certainty, developed solely from the bar chart. The arrow diagram is not time scaled. While one can see the relationships between the information shown in the bar chart and the arrow diagram, it is not generally necessary to develop both types of schedules. Many of the computer scheduling programs available today readily enable the conversion (automatic) of network information into bar charts.

## Value of Bar Charts

Despite their shortcomings, the value of bar charts cannot be underestimated. Their usefulness is not eliminated by their deficiencies. While bar charts make it difficult to maintain accurate schedules and make significant schedule changes, one of their major strengths is the ability to clearly and quickly present the status of a project. The key to the use of bar charts is that details and complexity are not readily compatible with the use of most bar charts. Instead, bar charts can be used to convey—often to upper management—the overall status of a project. The details of what is to take place on a given day are generally of little concern to upper management. Rather, they want to establish a quick sense of how a project is doing. The same type of information might also be conveyed to a subcontractor. The subcontractor may not be concerned with those activities that are unrelated to the work in question, but he or she may focus only on the work related to a particular specialty trade. This might be shown quite well on a bar chart.