Project Scheduling

By

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4D Modeling

- The need
  - Traditional design and construction planning tools, such as 2D drawings and network diagrams, do not support the timely and integrated decision making necessary to move projects forward quickly.
  - They do not provide the information modeling, visualization, and analysis environment necessary to support the rapid and integrated design and construction of facilities.

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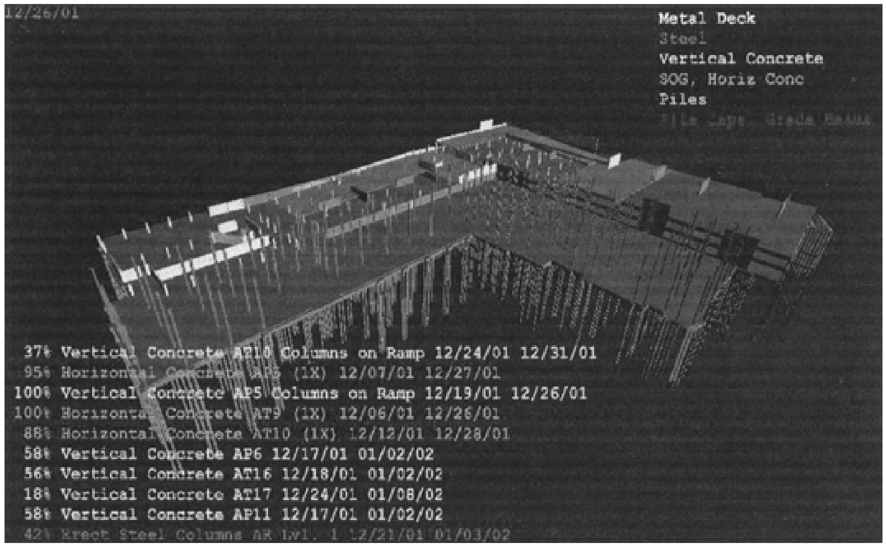


Chapter-Opener (p. 101)

Example of a 4D model.

(Courtesy of M. Fischer, Common Point Technologies, Inc. and DPR Construction, Inc.)

4D Modeling

- Synthesis of construction schedules from design descriptions and integrated evaluation of deign and schedule alternatives are still mainly manual tasks.
- Furthermore, the underlying representations of a design and a construction schedule are too abstract to allow the multiple stakeholders to visualize and understand the cross-disciplinary of design and construction decisions.

4D Modeling

- 4D modeling technologies are now being used by
  - Planners
  - Designers, and
  - Engineers

  to analyze and visualize many aspects of a construction project, from 3D design of the project to the sequence of construction to the relationships among schedule, cost, and resource availability data.

4D Modeling

- These intelligent 4D models support computer-based analysis of schedules with respect to cost, interference, safety, etc., and improve communication of design and schedule information.

The Technology

- Extending the traditional planning tools, visual 4D models combine 3D CAD models with construction activities to display the progression of construction over time.
- However, 4D models are time –consuming to generate manually and cannot currently support analysis program.
- The difficulty and cost of creating and using such models are currently blocking their widespread adoption.

Introduction

- As noted in the previous chapter, time planning is among the most important aspects of successful project management.
- The concept of project scheduling addresses the issues associated with time planning and management.
- Early scheduling methods used simple bar charts or Gannt charts to achieve a very simple and straightforward representation of time and work activity sequencing.

Introduction

- During the pat 40 years network based scheduling methods have become the norm, and many contracts require the use of network based schedules to reflect project progress to owner/client.
- Simply barcharting concepts as well as network scheduling concepts will be introduced in this chapter.

Bar Charts

- The basic modeling concept of the bar chart is the representation of a project work item or activity as a time scaled bar whose length represents the planned duration of the activity.
- The following figure shows a bar representation for a work item requiring four project time units (e.g., weeks).

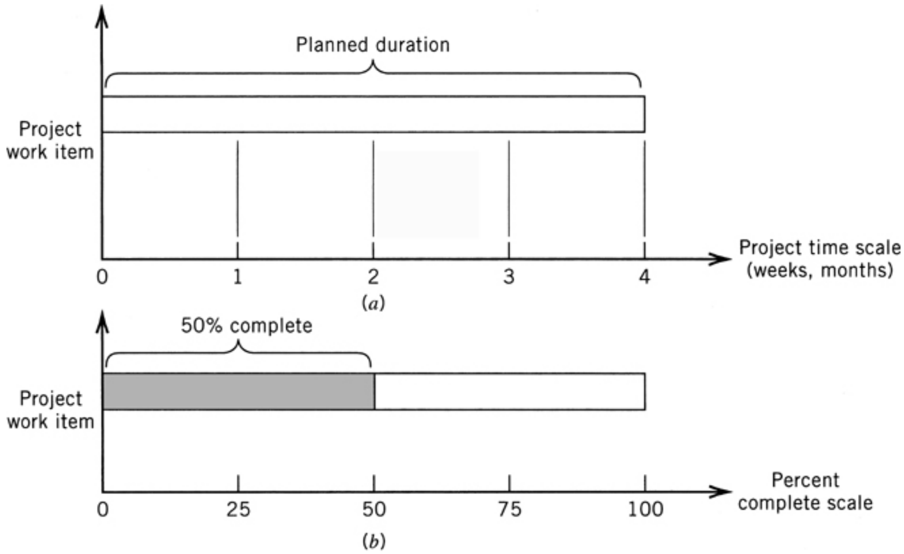


Figure 7.1ab (p. 102)
Bar chart model: (a) plan focus and (b) work focus.

Bar Charts

- The bar is located on a time line to indicate the schedule for planned start, execution, and completion of the work activity.
- In practice the scaled length of the bar is also used as a graphical base on which to plot actual performance toward completion of the project work item as seen in the previous figure Part b.

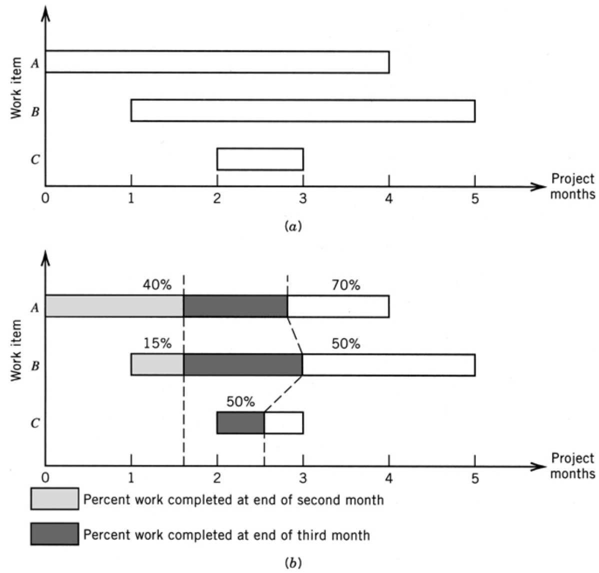
Bar Charts

- In this way the bar chart acts both as planning-scheduling model and as a reporting-control model.
- In this use of the bar chart, the length of the bar has two different meanings:
  1. The physical length of the bar represents the planned duration of the work item.
  2. It also provides a proportionally scaled baseline on which to plot at successive intervals of time, the correct percentage complete.

Bar Charts

- The same figure (part b) shows a bar for a project work item that has been half completed.
- In a situation where the work rate is constant and field conditions permit, this would occur in half the planned duration.
- The following figur (part a) shows a schedule for a project consisting of three activities.

Figure 7.2 (p. 103)
Bar chart project models: (a) bar chart schedule (plan focus) and (b) bar chart updating (control focus).



Bar Charts

- Activity A is to be carried out in the first four months.
- Activity B in the last four month.
- Activity C in the third month.
- Actual progress in the project can be plotted from time to time on these bars as shown in the same figure (part b)

Bar Charts

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

Bar Charts

- Disadvantages
  - One disadvantage of the traditional bar chart is the lack of precision in establishing the exact sequence between activities.
  - This problem can be addressed by using directional links or arrows connecting the bars to give a precise indication of logical order between activities.
  - This connected diagram of bars is calledd a bar-net.

Bar Charts

- A bar-net showing the major activities defined in the preliminary project breakdown diagram for the small gas station of Chapter 6 is shown in the following figure of the next slide.
- The bar positioned in sequence against a time line.
- The sequence or logic between the bars is formalized by connecting the end of the preceding bar to the start of the following bar.

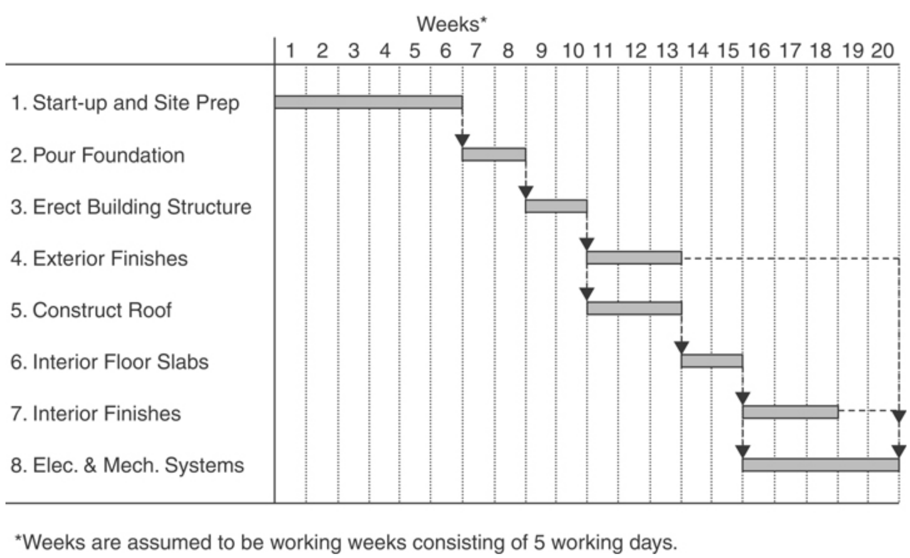


Figure 7.3 (p. 104)
Preliminary Bar-Net Schedule for the Small Gas Station.

Bar Charts

- For instance, the end of bar 3.
- Erect Building Structure is connected using a directional link or arrow to the two activities that follow it (Activities 5 and 4).
- The use of directional arrows to connect preceding and following activities leads to the development of a preliminary scheduling document called a bar-net.

Bar Charts

- This is a schedule that combines the graphical modeling features of the bar (e.g., length to indicate duration, and scaling to a time line) with the sequencing features or directional arrows.
- Positioning the eight activities as bars in their logical sequence using the arrow connectors against a time line plotted in weeks allows us to visually determine that the duration of the entire project is roughly 20 weeks.

Bar Charts

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

Bar Charts

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

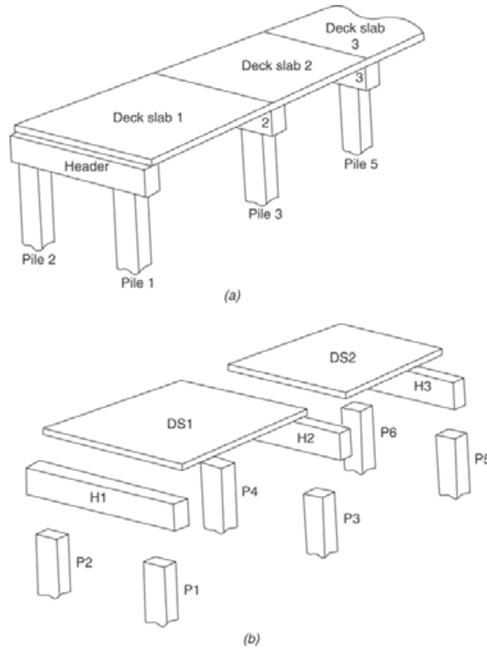
Scheduling Logic

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

Scheduling Logic

- A schematic view of a portion of the pier is shwon in the following figure of next slide.
- The various physical components of the pier have been identified and labeled.
- An exploded view of the pier is shown in the figure in part b, which shows each physical component individually separated but in the same relative position.

Figure 7.4 (p. 105)
Simple schematic models.
(a) Schematic view of pier.
(b) Exploded view of pier.
(Antill and Woodhead, 1982).



Scheduling Logic

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

Scheduling Logic

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

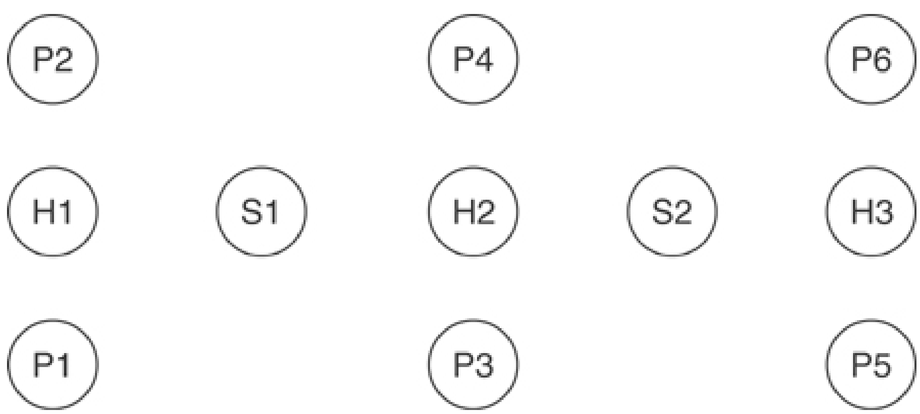


Figure 7.5 (p. 106)
Conceptual Model of Pier Components.

Scheduling Logic

- For example, an indication of the adjacency of physical components or relational contact of physical components may be required.
- A model to portray these properties requires a modeling element (say a line) to indicate that property exists.
- Assuming the modeling rationale of the following figure (a), the various nodes of the previous figure can be joined by a series of lines to develop a graph structure portraying the physical component adjacency or contact nature of the pier.

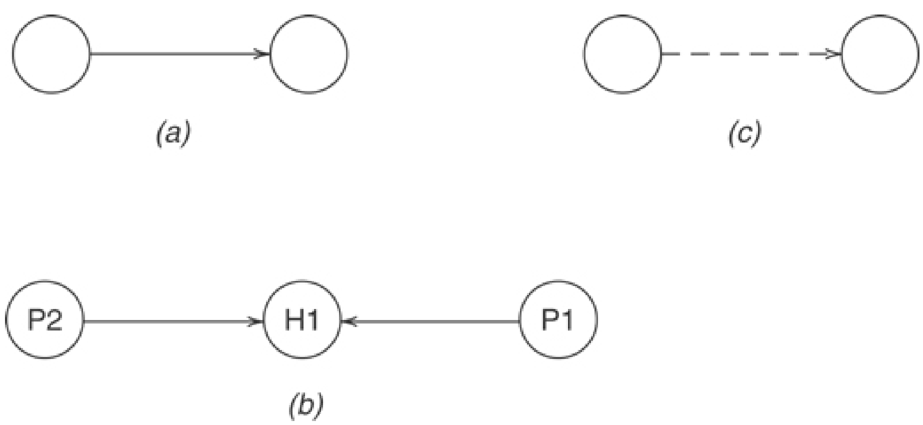


Figure 7.6 (p. 106)
Logical modeling rationales. (a) Adjacency of contact modeling. (b) Physical structure order modeling. (c) Physical construction order modeling.

Scheduling Logic

- If the idea of contact is expanded to indicate the order in which elements appear and physical contact is established, a directed modeling rationale may be used, as shown in the figure in part b.
- Using this conceptual modeling rule, The following figure of the next slide can be developed.

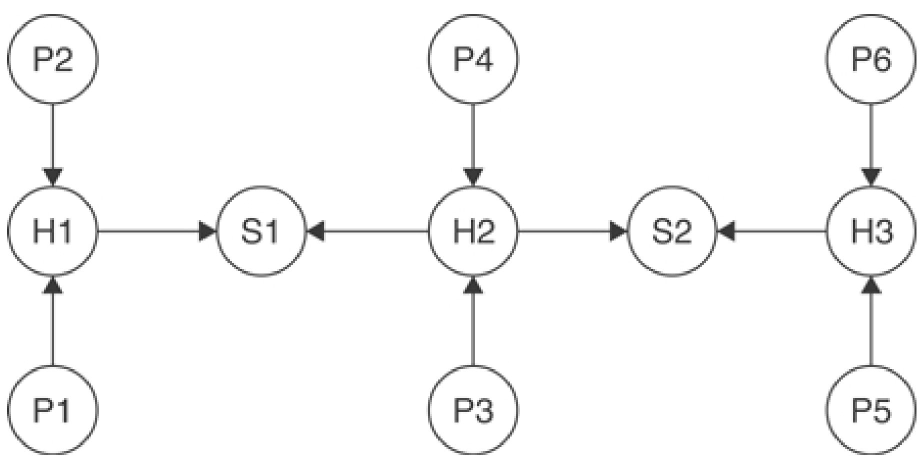


Figure 7.7 (p. 107)
Conceptual model of pier component relationships.

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Scheduling Logic

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

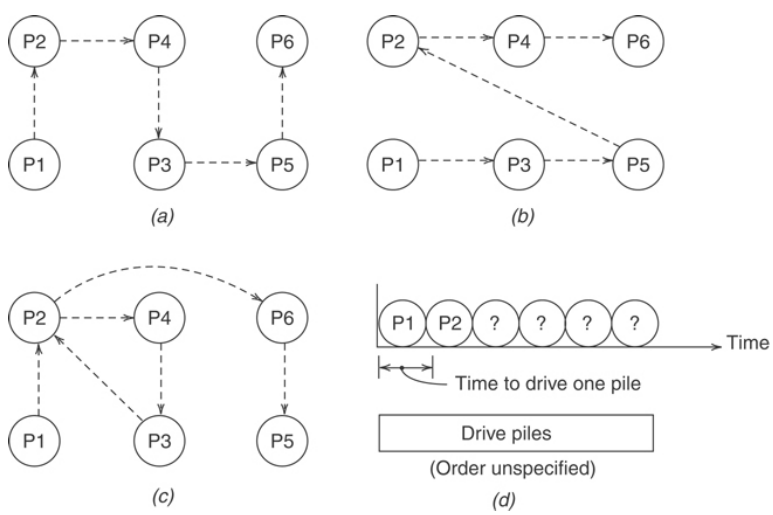


Figure 7.8 (p. 107)
Construction sequence and activity modeling. (a) Alternate row pile driving. (b) Sequential row pile driving. (c) Field mishap alteration to pile driving sequence. (d) Bar chart model of pile driving operation. (Antill and Woodhead, 1982).

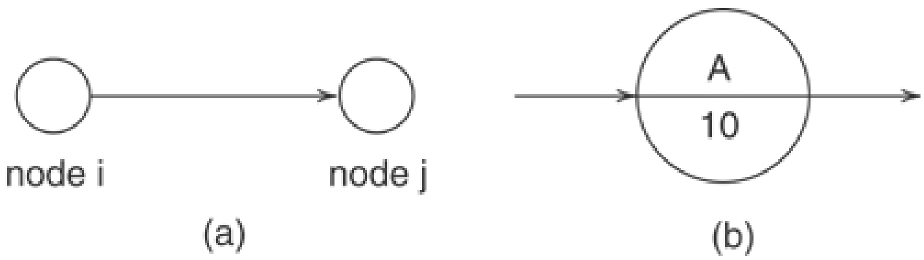


Figure 7.9 (p. 108)

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

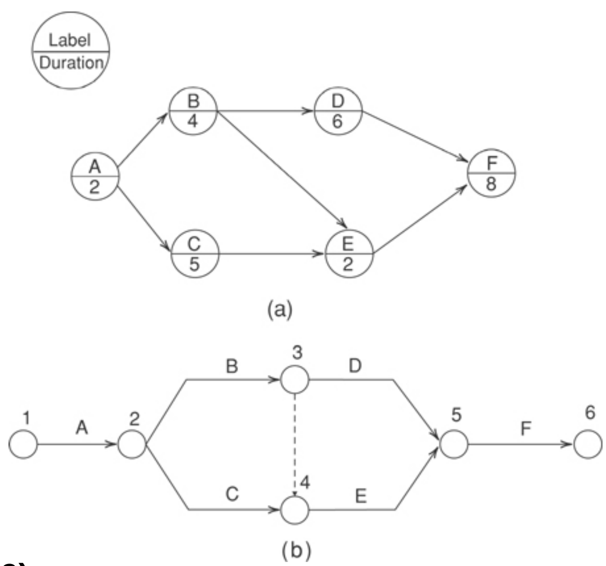


Figure 7.10 (p. 109)

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

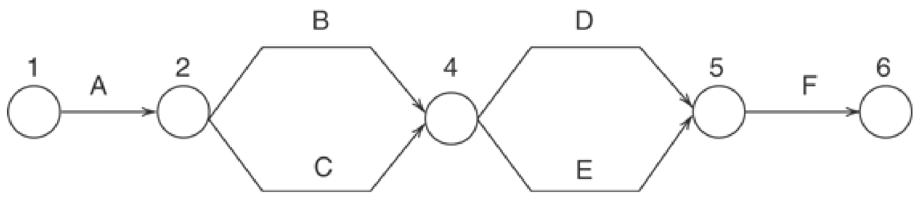


Figure 7.11 (p. 109)
Mistake in Logical Sequence.

Figure 7.12 (p. 110)
Elements of an arrow network. (After Antill and Woodhead, 1982).

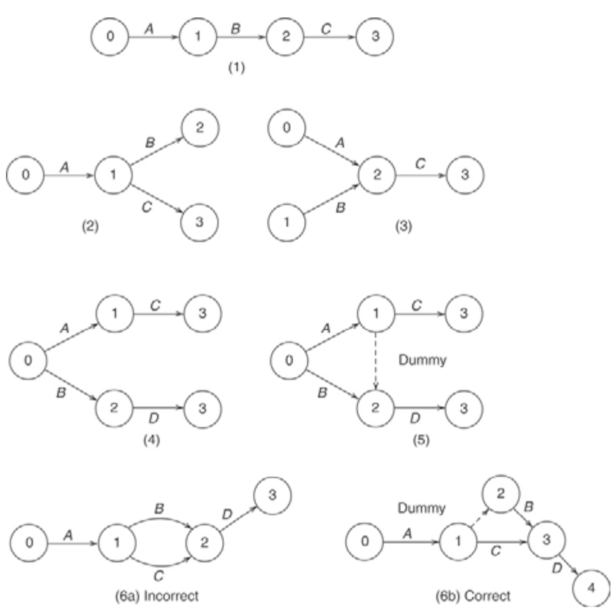
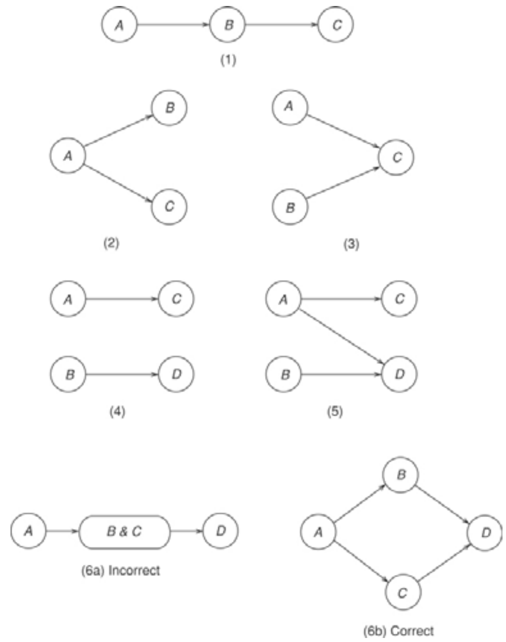


Figure 7.13 (p. 111)
Elements of a precedence network. (After Antill and Woodhead, 1982).



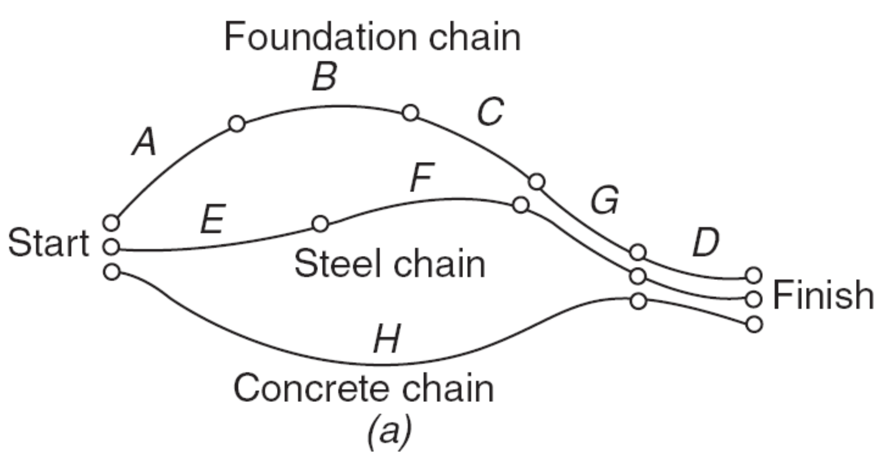


Figure 7.14a (p. 112)
Preliminary network diagram.
(a) Initial sketch, arrow notation (Continued on next three slides.).

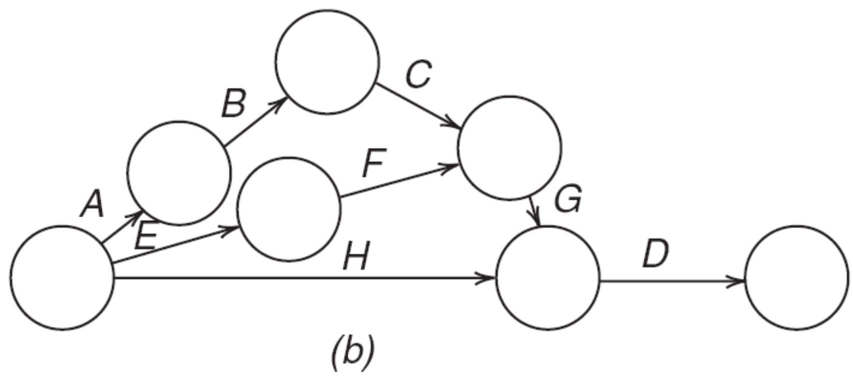


Figure 7.14b (cont.)
Preliminary network diagram.
(b) First draft – arrow notation.

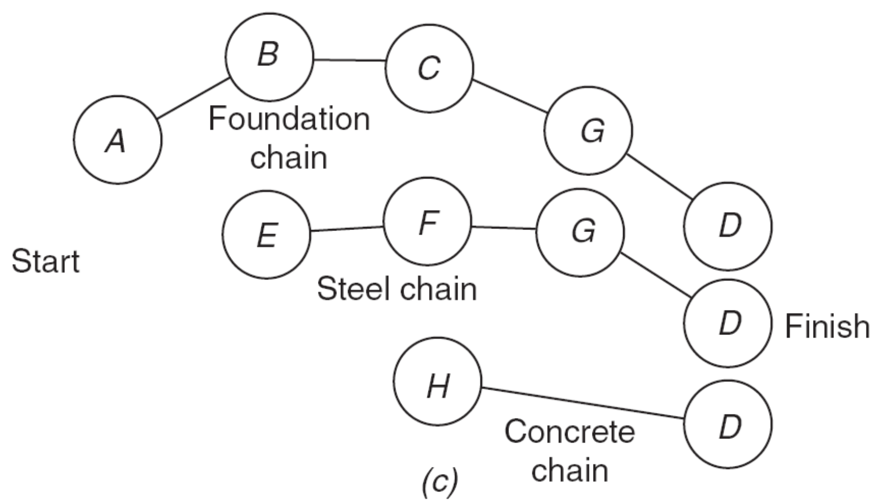


Figure 7.14c (cont.)
Preliminary network diagram.
(c) Initial sketch – precedence notation.

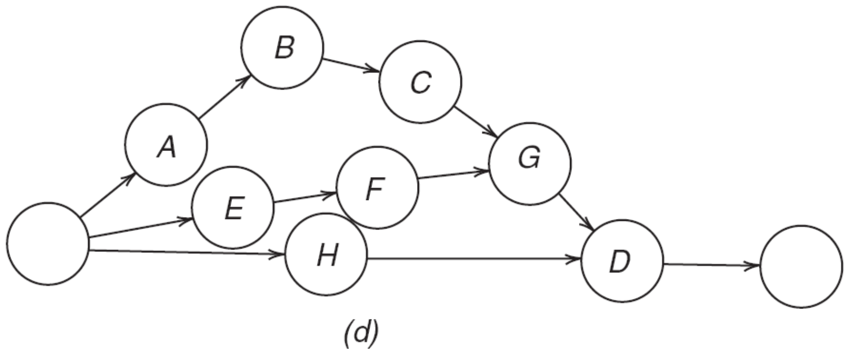


Figure 7.14d (cont.)
Preliminary network diagram.
d) First draft – precedence notation. (After Antill and Woodhead, 1982).

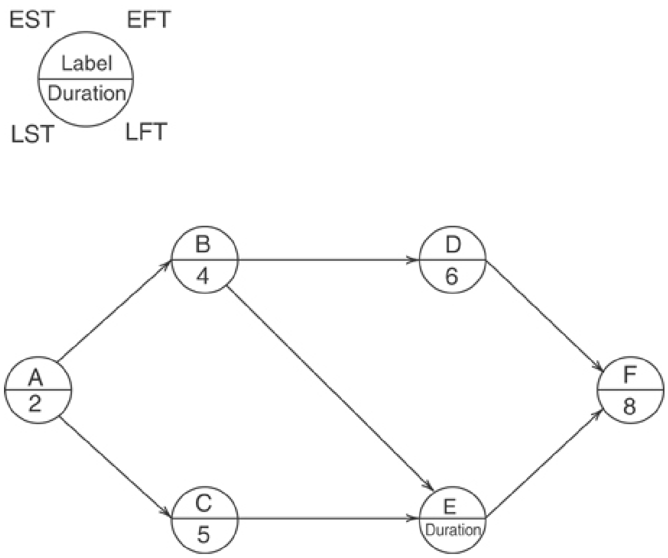


Figure 7.15 (p. 113)
Precedence Notation Scheduling Network.

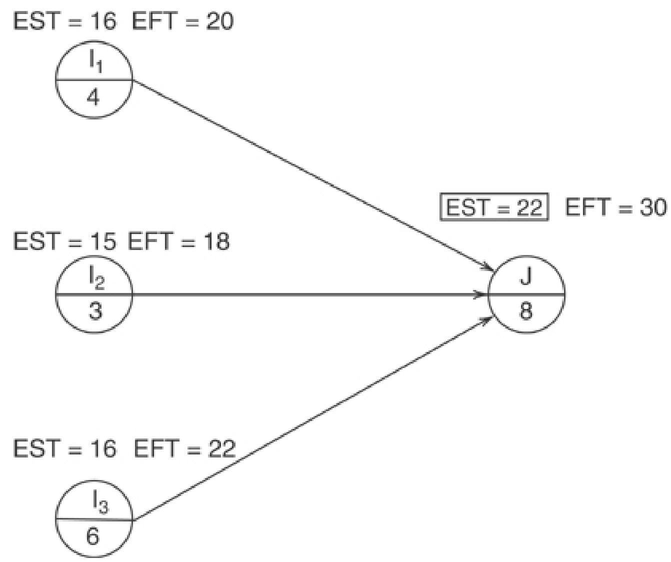


Figure 7.16 (p. 114)
Calculation of EST(J).

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

Table on Page 114

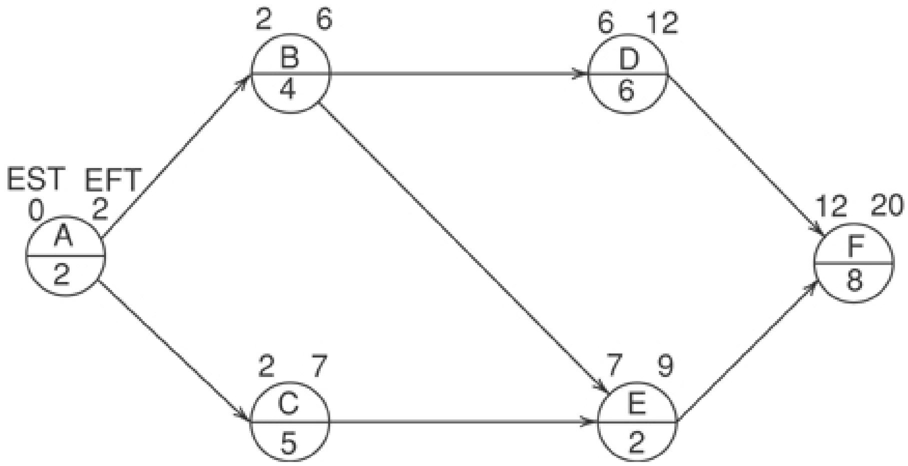


Figure 7.17 (p. 115)
Calculation of the EST/EFT Values.

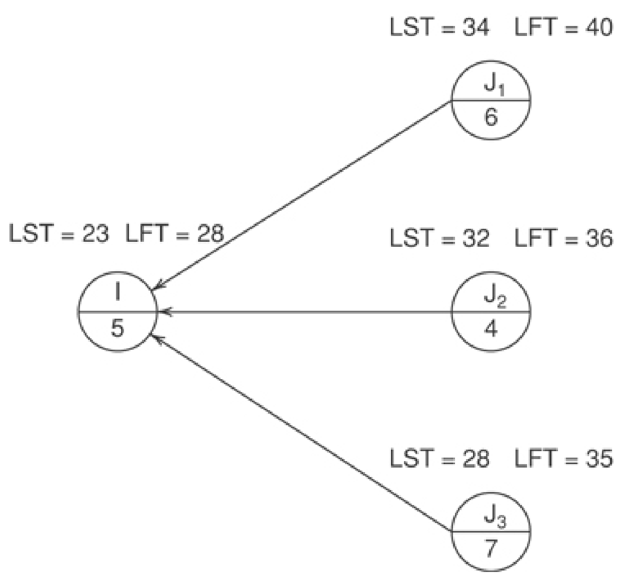


Figure 7.18 (p. 115)
Calculation of LFT(I).

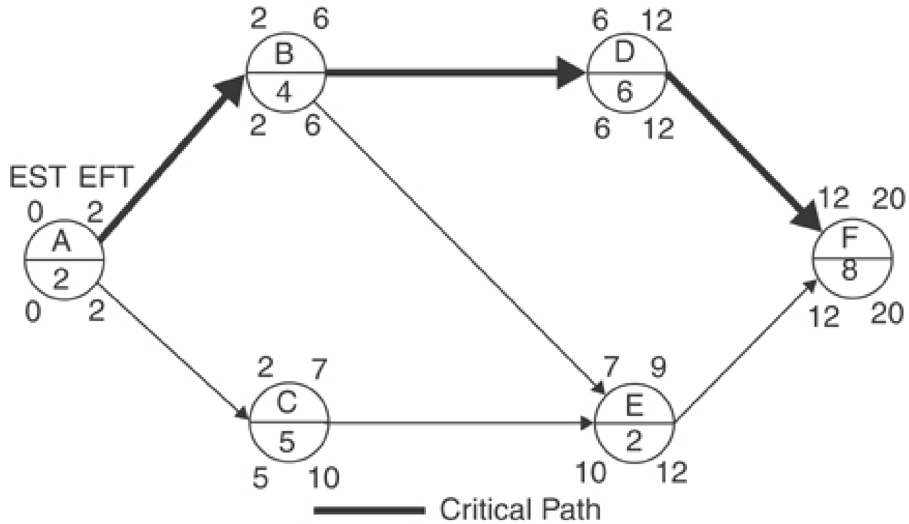


Figure 7.19 (p. 116)
EST, EFT, and LST, LFT values for small precedence notation network.

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

Table on Page 116

Table 7.1 Four Types of Activity Float

Total Float

$TF(I) = LFT(I) - [EST(I) + DUR(I)]$
$= LFT(I) - EFT(I)$

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

Free Float

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

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

Interfering Float

$IF(I) = TF(I) - FF(I)$

Independent Float

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

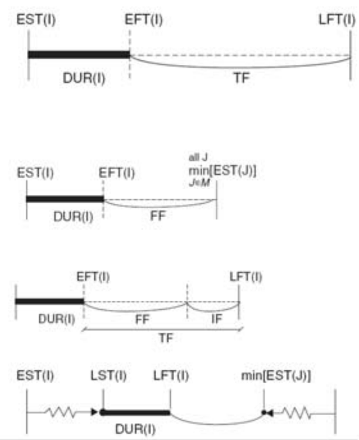


Table 7.1 (p. 118)

Four Types of Activity Float

Table 7.2 (p. 119)

Durations of Activities for the Small Gas Station

Table 7.2 Durations of Activities for the Small Gas Station

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

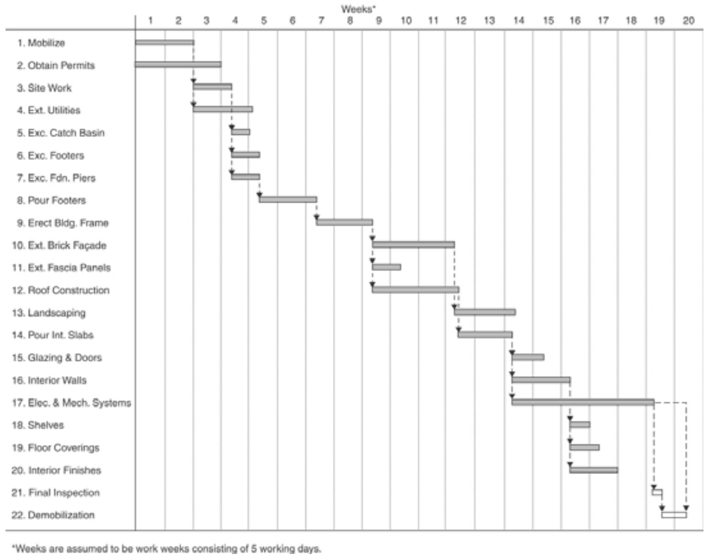


Figure 7.20 (p. 120)
Expanded Bar-Net Schedule for the Small Gas Station.

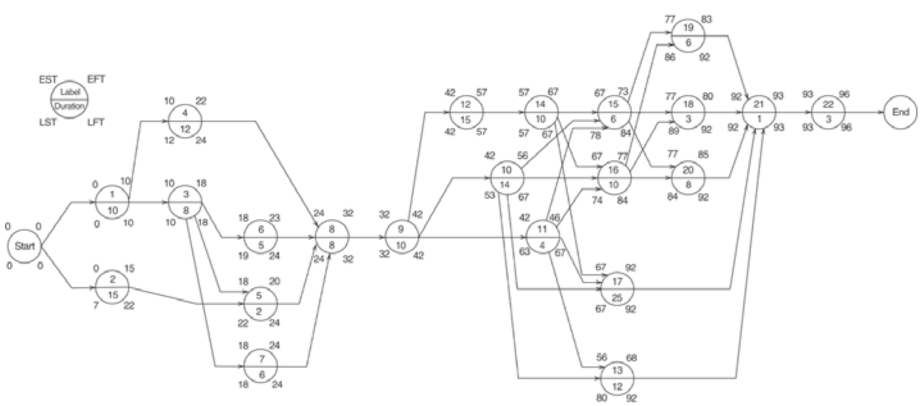


Figure 7.21 (p. 121)
Expanded Network Schedule for the Small Gas Station Project.

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

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

Table 7.3 (p. 122)

Forward-Pass Calculations for the Small Gas Station Project

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

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

Table 7.4 (p. 123)

Backward-Pass Calculations for the Small Gas Station Project

Table 7.5 Float Values for the Small Gas Station Project

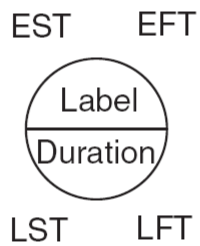
Activity	Total Float	Free Float	Interfering Float
* 1	TF(1) = 10–10 = 0	FF(1) = 10–10 = 0	IF(1) = 0–0 = 0
2	TF(2) = 22–15 = 7	FF(2) = 18–15 = 3	IF(2) = 7– 3 = 4
* 3	TF(3) = 18–18 = 0	FF(3) = 18–18 = 0	IF(3) = 0–0 = 0
4	TF(4) = 24–22 = 2	FF(4) = 24–22 = 2	IF(4) = 2–2 = 0
5	TF(5) = 24–20 = 4	FF(5) = 24–20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

Table 7.5 (p. 124)

Float Values for the Small Gas Station Project

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

Problem 7.1 (p. 125)

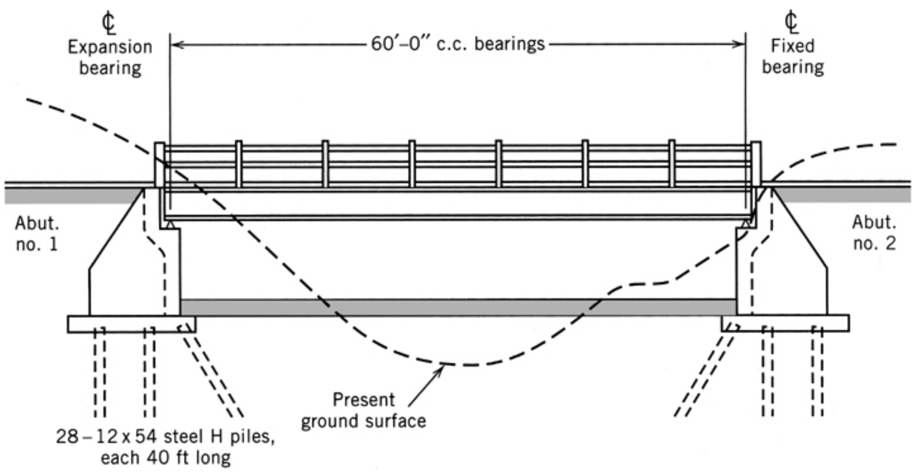


Label	Duration	Must Follow Operations
A	2	—
B	4	*A*
C	7	*A*
D	3	*A*
E	5	*A*
F	7	*B*
G	6	*B*
H	7	*F*
I	5	*G*
J	3	*G*
K	8	*C,G*
L	9	*H,I*
M	4	*F,J,K*
N	7	*D,K*
O	8	*E,K*
P	6	*M,N*
Q	10	*N,O*
R	5	*L,O,P*
S	7	*Q,R*

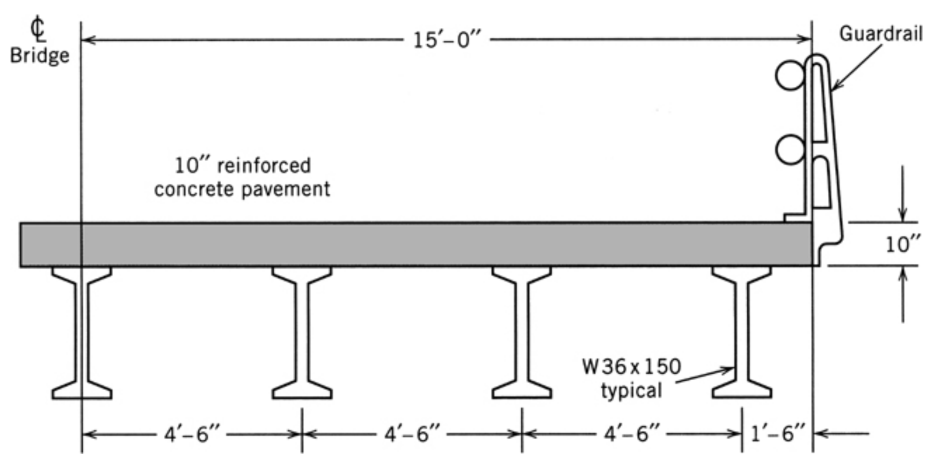
Problem 7.2 (p. 125)

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

Problem 7.3 (p. 125)



Problem 7.4.1 (p. 126)
(Continued on next three slides.)



Problem 7.4.2 (cont.)

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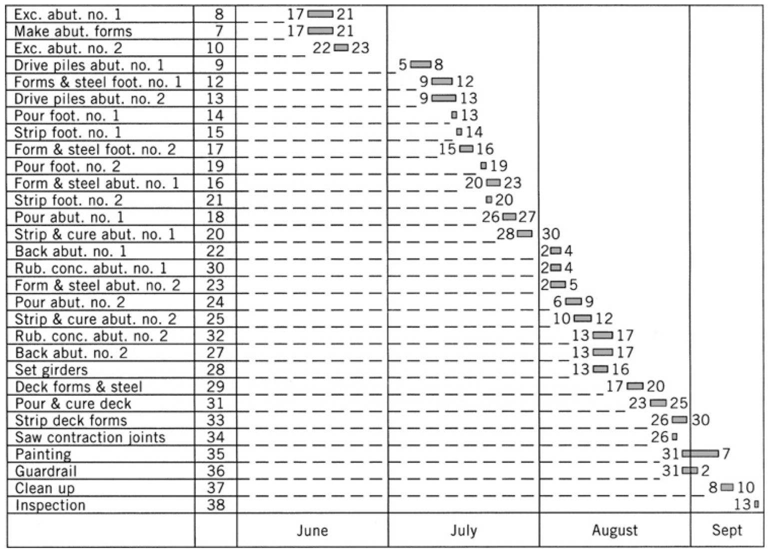
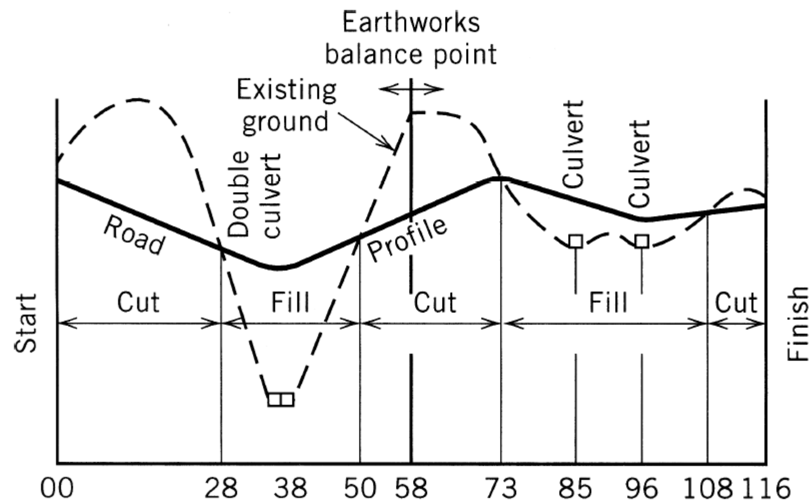


Problem 7.4.3 (cont.)

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

Problem 7.4.4 (cont.)



Problem 7.5a (p. 127)

(Continued on next slide).

Problem 7.5b (cont.)

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