ALONG THE SUPPLY CHAIN

A Couple of High-Profile Sports Stadium Projects

Cowboys Stadium, home to the National Football League's Dallas Cowboys and the world's largest domed stadium, opened in June 2009 after a three-year mammoth construction project. The stadium site footprint was over 150 acres and the retractable roof covered 660,000 square feet. The project had over 250 subcontractors; as well as suppliers in 10 states and 12 countries, some as far away as China and Australia.

Originally budgeted at $650 million, the project cost eventually climbed by $450 million to $1.1 billion. This budget increase was due in large part to "scope creep," changes that resulted in 1500 modifications to the project's original scope and a 60% increase in the project workload. The original design went through 300 revisions with 5500 clarifications made to the stadium drawings. However, despite the scope creep and the resulting "fluid" budget, one thing that could not change was the project deadline. The Cowboys were scheduled to open their home exhibition season in August 2009 with their regular season opener a month later in September, and before that a country music concert and soccer match were scheduled. During the final three-month push to complete the stadium on time, 100 subcontractors and almost 2200 employees were working on-site. Each employee was working an average of 60 hours per week, and the project management team exceeded that. The team was able to maintain its schedule by adhering to project management practices and maintaining a strict control process.

Across the Atlantic in England, another high-profile stadium, the Olympic Stadium for the 2012 London Olympics, was completed in mid-2011 after a four-year consecution project. Although not quite as large as Cowboys Stadium, seating 80,000 on a 40-acre site, and without as many technological innovations, it still posed its own unique challenges for the project team. First of all, the project management process was more complicated than in the private sector, involving many more public and governmental stakeholders. However, like Cowboys Stadium the project team had an absolute deadline, the lighting of the Olympic torch, in July 2012. Before stadium construction could begin, significant soil remediation of the site had to take place. The East London site was riddled with waste, including a mountain of discarded appliances, and oil-tainted soil. An on-site "soil hospital" with 60 scientists and technicians analyzed soil each day; in the end much of the soil was reused, but 800,000 tons were removed. The site was also surrounded by several rivers that created an island of land limiting the area it could consume. One 1.4-mile stretch of the river was dredged (enabling commercial use for the first time in 35 years) to provide access for barges to the construction zone. These site-preparation activities allowed actual construction to start in May 2008, which included a number of "sustainable" features. About 34% of the stadium was constructed from recycled steel, and the roof included 52 tons of scrap metal from keys, knives, and guns confiscated by the London Metropolitan Police. The project was completed on time in May 2011 at a cost of 537 million pounds. In fact, all of the major Olympic venues were completed almost a year ahead of the games at about £2 billion less than the £9.3 billion budgeted.

Both of these stadium projects had critical completion dates; can you think of other construction projects you are familiar with or that may have been in the news that have similar critical due dates that cannot be changed?

Sources: Based on Donovan Burba, "To the End Zone," *PM Network* 25 (9); (January 2011), pp. 36–43; Jenn Danko, "Serious Conditioning," *PM Network* 24 (5); (May 2010), pp. 60–64.

estimate for activity 2 (laying the foundation) is two months. Since only this one value is given, we must assume that the activity time does not vary (or varies very little) from two months. It is rare that activity time estimates can be made with certainty. Project activities are likely to be unique with little historical evidence that can be used as a basis to predict activity times. Recall that one of the primary differences between CPM and PERT is that PERT uses probabilistic activity times.

PROBABILISTIC TIME ESTIMATES

Beta distribution: a probability distribution traditionally used in CPM/PERT.

In the PERT-type approach to estimating activity times, three time estimates for each activity are determined, which enables us to estimate the mean and variance of a **beta distribution** of the activity times.

The latest start time for activity 6 is

$$\begin{aligned} LS &= LF - t \\ &= 8 - 1 \\ &= 7 \text{ months} \end{aligned}$$

For activity 4, the latest finish time (LF) is eight months, and the latest start time (LS) is five months; for activity 5, the latest finish time (LF) is seven months, and the latest start time (LS) is six months.

Now consider activity 3, which has two activities, 4 and 5, following it. The latest finish time is computed as

$$\begin{aligned} LF &= \min \text{ (LS following activities)} \\ &= \min (5, 6) \\ &= 5 \text{ months} \end{aligned}$$

The latest start time is

$$\begin{aligned} LS &= LF - t \\ &= 5 - 1 \\ &= 4 \text{ months} \end{aligned}$$

All the remaining latest start and latest finish times are computed similarly. Figure 9.12 includes the earliest and latest start times and earliest and latest finish times for all activities.

ACTIVITY SLACK

The project network in Figure 9.12, with all activity start and finish times, highlights the critical path (1–2–4–7) we determined earlier by inspection. Notice that for the activities on the critical path, the earliest start times and latest start times are equal. This means that these activities on the critical path must start exactly on time and cannot be delayed at all. If the start of any activity on the critical path is delayed, then the overall project time will be increased. We now have an alternative way to determine the critical path besides simply inspecting the network. The activities on the critical path can be determined by seeing for which activities ES = LS or EF = LF. In Figure 9.12 the activities 1, 2, 4, and 7 all have earliest start times and latest start times that are equal (and EF = LF); thus, they are on the critical path.

For activities not on the critical path for which the earliest and latest start times (or earliest and latest finish times) are not equal, *slack* time exists. We introduced slack with our discussion

A primary use of CPM/PERT is to plan and manage construction projects of all types, such as this Virginia Department of Transportation bridge construction project near Springfield, Virginia, where I-95 and I-395 converge.

CHARLES DHARAPAK/AP Images

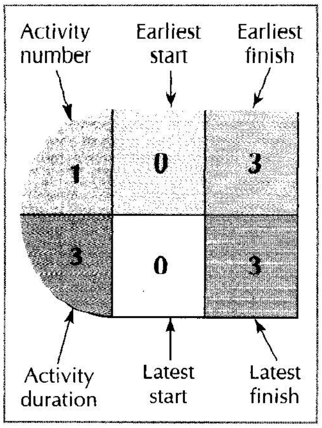


Figure 9.10

Node Configuration

Forward pass: starts at the beginning of a CPM/PERT network to determine the earliest activity times.

Earliest finish time (EF): is the earliest start time plus the activity time.

the scheduling process, we will alter our node structure a little. Figure 9.10 shows the structure for node 1, the first activity in our example network for designing the house and obtaining financing.

To determine the earliest start time for every activity, we make a **forward pass** through the network. That is, we start at the first node and move forward through the network. The earliest start time for an activity is the maximum time in which all preceding activities have been completed—the time when the activity start node is realized.

The **earliest finish time (EF)** for an activity is simply the earliest start time plus the activity time estimate. For example, if the earliest start time for activity 1 is at time 0, then the earliest finish time is three months. In general, the earliest start and finish times for an activity are computed according to the following mathematical relationship.

$$\text{ES} = \text{maximum (EF) of immediate predecessors}$$
$$\text{EF} = \text{ES} + t$$

The earliest start and earliest finish times for all the activities in our project network are shown in Figure 9.11.

The earliest start time for the first activity in the network (for which there are no predecessor activities) is always 0, or, ES = 0. This enables us to compute the earliest finish time for activity 1 as

$$\begin{aligned}\text{EF} &= \text{ES} + t\\ &= 0 + 3\\ &= 3 \text{ months}\end{aligned}$$

The earliest start for activity 2 is

$$\begin{aligned}\text{ES} &= \text{max (EF immediate predecessors)}\\ &= 3 \text{ months}\end{aligned}$$

and the corresponding earliest finish time is

$$\begin{aligned}\text{EF} &= \text{ES} + t\\ &= 3 + 2\\ &= 5 \text{ months}\end{aligned}$$

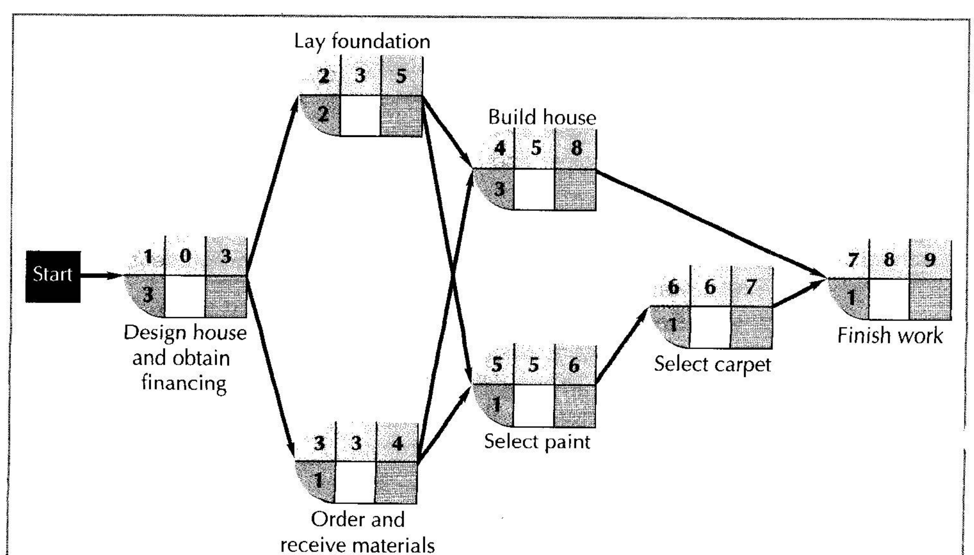
For activity 3 the earliest start time (ES) is three months, and the earliest finish time (EF) is four months.

Now consider activity 4, which has two predecessor activities. The earliest start time is

$$\begin{aligned}\text{ES} &= \text{max (EF immediate predecessors)}\\ &= \text{max } (5, 4)\\ &= 5 \text{ months}\end{aligned}$$

Figure 9.11

Earliest Activity Start and Finish Times



9-13. The Farmer's American Bank of Leesburg is planning to install a new computerized accounts system. Bank management has determined the activities required to complete the project, the precedence relationships of the activities, and activity time estimates as follows:

Activity	Description	Activity Predecessor	Time Estimates (Weeks) a	m	b
a	Position recruiting	—	5	8	17
b	System development	—	3	12	15
c	System training	a	4	7	10
d	Equipment training	a	5	8	23
e	Manual system test	b, c	1	1	1
f	Preliminary system changeover	b, c	1	4	13
g	Computer-personnel interface	d, e	3	6	9
h	Equipment modification	d, e	1	2.5	7
i	Equipment testing	h	1	1	1
j	System debugging and installation	f, g	2	2	2
k	Equipment changeover	g, i	5	8	11

Determine the earliest and latest activity times, the expected completion time and standard deviation, and the probability that the project will be completed in 40 weeks or less.

9-14. The following probabilistic activity time estimates are for the network in Problem 9-6:

Activity	Time Estimates (months) a	m	b
1	4	8	12
2	6	10	15
3	2	10	14
4	1	4	13
5	3	6	9
6	3	6	18
7	2	8	12
8	9	15	22
9	5	12	21
10	7	20	25
11	5	6	12
12	3	8	20

Determine the following:
a. Expected activity times
b. Earliest start and finish times
c. Latest start and finish times
d. Activity slack
e. Critical path
f. Expected project duration and standard deviation

9-15. The following probabilistic activity time estimates are for the CPM/PERT network in Problem 9-9:

Activity	Time Estimates (days) a	m	b	Activity	Time Estimates (days) a	m	b
1	1	2	6	7	1	1.5	2
2	1	3	5	8	1	3	5
3	3	5	10	9	1	1	5
4	3	6	14	10	2	4	9
5	2	4	9	11	1	2	3
6	2	3	7	12	1	1	1

Determine the following:
a. Expected activity times
b. Earliest start and finish times
c. Latest start and finish times
d. Activity slack
e. Critical path
f. Expected project duration and standard deviation

9-16. For the CPM/PERT network in Problem 9-14, determine the probability that the network duration will exceed 50 months.

9-17. The Stone River Textile Mill was inspected by OSHA and found to be in violation of a number of safety regulations. The OSHA inspectors ordered the mill to alter some existing machinery to make it safer (e.g., add safety guards); purchase some new machinery to replace older, dangerous machinery; and relocate some machinery to make safer passages and unobstructed entrances and exits. OSHA gave the mill only 35 weeks to make the changes; if the changes were not made by then, the mill would be fined $300,000. The mill determined the activities in a PERT network that would have to be completed and then estimated the indicated activity times, as shown in the table below. Construct the PERT network for this project and determine the following:

Activity	Description	Activity Predecessor	Time Estimates (Weeks) a	m	b
a	Order new machinery	—	1	2	3
b	Plan new physical layout	—	2	5	8
c	Determine safety changes in existing machinery	—	1	3	5
d	Receive equipment	a	4	10	25
e	Hire new employees	a	3	7	12
f	Make plant alterations	b	10	15	25
g	Make changes in existing machinery	c	5	9	14
h	Train new employees	d, e	2	3	7
i	Install new machinery	d, e, f	1	4	6
j	Relocate old machinery	d, e, f, g	2	5	10
k	Conduct employee safety orientation	h, i, j	2	2	2

a. Expected activity times
b. Earliest and latest activity times and activity slack
c. Critical path
d. Expected project duration and variance
e. The probability that the mill will be fined $300,000

9-18. In the Third Battle of Bull Run, for which a CPM/PERT network was developed in Problem 9-15, General Beauregard would have won if his preparations had been completed in 15 days. What would the probability of General Beauregard's winning the battle have been?