# Project Estimating and Scheduling for Engineers

Course No: B03-010
Credit: 3 PDH

Boris Shvartsberg, Ph.D., P.E., P.M.P.

## Introduction

One of the most important tasks of modern engineering personnel is to support, with their technical expertise, various projects they are assigned to. There are many Project Management processes and tasks that engineers are involved in, for example:

- Preparation of Project Scope
- Technical Support of Permitting Process
- Preparation of Estimates
- Participation in Project Scheduling Process
- Procurement of Equipment and Materials
- Participation in Project Meetings
- Submission of Project Updates
- Participation in Project Closeout (lessons learned)

While all these tasks are important for managing projects effectively, estimating and scheduling are critical because they create a project budget and schedule, and the success of any project primarily depends on the Project Manager having enough money and time to accomplish all the tasks included in the Project Scope.

The active role that modern engineers play in preparing project estimates and schedules makes their education in this area extremely important. While Engineers should not be Project Management experts, they need to know basic principles, processes, and tools in order to become a valuable member of a project team and contribute towards the success of a project. This e-book is designed to arm engineers with that kind of basic knowledge in Project Estimating and Scheduling.

## Definition of Estimating. Main Inputs into Estimates

Estimating is one of the key activities of Time and Cost Management. The term 'Estimate' may be defined as an expected, forecasted, likely result of any project component. There are two main types of estimates: cost estimate which serves as a basis for Project Budget, and time estimate which is a basis for Project Schedule.

There are two main inputs into these estimates which should be clearly distinguished:

- Effort – A number of man-hours, man-days, etc. required to complete a task
- Duration – The number of working or calendar days over which the task will be done

Effort depends on the nature of the task, its level of complexity, etc. Duration depends on number of resources assigned to fulfill the task. For example, let's assume that our task is to install a 500

feet long chain link fence and the effort required to do it is 100 man-hours. How long will it take to complete the task depends on number of construction workers assigned to perform it:

- If 5 workers are assigned, it will take 20 hours
- If 4 workers are assigned, it will take 25 hours, etc.

Both of these numbers represent a productive time spent on performing the task.

To calculate an actual duration of this work we need to take into consideration a non-productive time as well: time off work, weekends, holidays, etc.

For example, let's calculate the duration of performing the task based on the following assumptions:

- 5 workers start work at 8:00 A.M. Thursday
- They are working 8 hours a day, there is no work on weekends

How long does it take to finish the task in this case?

Solution:

- Each worker will work 20 hours, or 2.5 days
- If work starts at 8:00 A.M. Thursday, it will be completed at 12:00 P.M. Monday

If we wanted work to be completed by the end of the day Friday, painters would need to work 10-hour days instead of 8.


## Main Estimating Techniques

There are two main estimating techniques:

1. A top-down estimating, which is based on previous experience of performing a similar task, or working on a similar project (prototype).

For example, we want to estimate how much we may expect to pay for a carpet replacement in our apartment. A top-down estimate in this case may be based on the following logic: 5 years ago, I paid for a carpet replacement in the same apartment $4,000. That's what I expect to pay this time.

To be more precise, we may want to adjust this number for a cost escalation during a 5-year period, using the following equation:

$$A_n = A_0 \times (1 + c/100)^n = A_0 \times TF \tag{1}$$

where: $A_0$  - cost of comparable work performed n years ago
        c -   cost escalation per year in percent
        $A_n$ - estimated cost of work that we plan to perform
        TF – Time Factor, which takes into account cost escalation during time
            period between prototype's completion date and today

Let's assume that for our example cost escalation per year c = 5%. Knowing already that $A_0$ = \$4,000 and n = 5, we may find $A_n$ from the equation (1) as follows:

$$A_n = \$4,000 \times (1 + 5/100)^5 = \$4,000 \times 1.276 = \$5,105 \qquad (2)$$

where TF = 1.276. It should be noted that TF is usually higher than 1.0, because costs in general increase over time.

Rounding this number up (to increase a safety margin), we may get $A_n$ = \$5,150 or even $A_n$ = \$5,200 if we want to be more conservative with our estimate.

Let's consider a few more possible scenarios with a top-down estimate for our example:

- 5 years ago, we replaced carpet in the whole apartment with a total area of 1000 sq. ft.  This time, we want to replace carpet in a living room only, which has an area of 400 sq. ft. For simplification purposes, let's make an assumption that the estimated cost from the equation (2) will change in a direct proportion to a reduction in a square footage of carpet to be replaced. Based on that, a new estimated cost $A_{n1}$ may be found as:

$$A_{n1} = A_n \times (400/1000) = \$5,105 \times 0.4 = \$2,042 \qquad (3)$$

  After rounding up, this value becomes \$2,050 or \$2,100 depending on how conservative we want to be with our estimate.
  Let's call this factor which takes into account a scope difference between a prototype and our Project a Scope Factor (SF). In our example, SF = 0.4.
  It should be noted that SF may be any number.

- 5 years ago, we replaced carpet in the apartment with a total area of 1000 sq. ft. in Dallas, TX for \$4,000, but now we want to do the same work for a 400 sq. ft. living room in apartment located in New York, NY. Let's assume that the cost for carpet replacement in New York is 30% higher than the cost of the same type of work performed in Dallas.

  Based on this assumption, a new estimated cost $A_{n2}$ for a carpet replacement in New York may be found as follows:

$$A_{n2} = A_{n1} \times (1 + 30/100) = \$2,042 \times 1.3 = \$2,655 \qquad (4)$$

  After rounding up, this value may become \$2,700, \$2,800 or even higher depending on how conservative we want to be.

Let's call this factor adjusting a cost of prototype for a geographical location of our Project LF (Location Factor). In our example, LF = 1.3.

It should be noted that LF may be both more and less than 1.0.

These examples show how a top-down estimate's accuracy may be increased by adjustment of a prototype project's cost for differences in scope, time, and location between a project that we are estimating and a prototype. All made above adjustments may be summarized into the following relationship between a total estimated cost of the Project $A_N$ and a cost of a prototype $A_0$:

$$A_N = A_0 \text{ x TF x SF x LF} \hspace{2cm} (5)$$

For our example, equation (5) may be written as follows:

$$A_N = \$4,000 \text{ x } 1.276 \text{ x } 0.4 \text{ x } 1.3 = \$2,655$$

Professional estimators are using all kinds of adjustment factors available in estimating manuals to maximize the accuracy level of their top-down estimates, but they almost never are as accurate as the estimates obtained by using the second type of estimating technique that we consider, which is a bottom-up estimating.

2.  A bottom-up estimating is based on:

   • splitting the task, project etc. into smaller components
   • estimating each component
   • adding them up to obtain the total estimate

Let's prepare a bottom-up estimate for the same example with a carpet replacement in a 400 sq. ft. living room of apartment located in New York, if the following information is available:

   • Price of carpet: $2.58 per sq. ft.
   • Price of carpet pad: $0.8 per sq. ft.
   • Effort to replace carpet: 2 workers working an 8-hour day
   • Workers hourly labor rate: $110
   • Cost of materials (glue, staples etc.): $100

Assume a 30% carpet and carpet pad loss for cutting standard rolls to accommodate room's configuration.

Based on this information, let's estimate each component of carpet replacement work:

   2.1. Total price of carpet: $2.58 x 400 x (1 + 30/100) = $1,342
   2.2. Total price of carpet pad: $0.8 x 400 x (1 + 30/100) = $416
   2.3. Cost of materials: $100
   2.4. Labor cost: 2 x 8 x $110 = $1,760

Estimated total cost: $1,342 + $416 + $100 + $1,760 = $3,618

As we can see, the bottom-up estimate in this example is significantly higher than a previously obtained for exactly the same work top-down estimate of $2,655, which may be important for us to plan our personal budget properly.

## Comparison between Top-down and Bottom-up Estimates

1. Top-down estimates:

   - Are based on historical data
   - Are using experience and intuition of a single contributor
   - Are less accurate
   - May be prepared in a relatively short time
   - Are prepared on initial stages of the project
   - May be made more accurate by choosing a more comparable prototype

2. Bottom-up estimates:

   - Are based on splitting the project into components and estimating them separately
   - Are using specific data for unit costs, durations, etc.
   - May require involvement of numerous contributors
   - Are more accurate than top-down estimates
   - May take a relatively long time to prepare
   - Are prepared on advanced stages of the project
   - May be made more accurate by continuous updating of estimating database

## Types of Cost Estimates Based on the Levels of Accuracy

1. Order of magnitude or study:

   - Technique: top-down
   - Accuracy: - 50 to + 50%
   - Project phase: feasibility studies, concept
   - Application: comparison of several options, financial forecast

2. Budget or conceptual:

   - Technique: bottom-up
   - Accuracy: - 30 to + 30%
   - Project phase: preliminary design and engineering
   - Application: justification for project budget

3. Detailed or definitive:

- Technique: bottom-up
- Accuracy: - 10 to + 10%
- Project phase: detail design and engineering
- Application: forecast for budget at completion

The following examples illustrate what each level of accuracy means:

- Order of magnitude estimate of $500,000 means that actual cost is expected to be no lower than $250,000 and no higher than $750,000
- Budget estimate of $500,000 means that actual cost is expected to be no lower than $350,000 and no higher than $650,000
- Detailed estimate of $500,000 means that actual cost is expected to be no lower than $450,000 and no higher than $550,000

It is important to mention that deviation from the estimated numbers for each type of estimate may be negative as well. So, estimated number may be hypothetically higher than a real cost, not necessarily lower. And despite popular belief that spending less money than a budgeted amount is always good, it is not necessarily true, because extra funds could be directed somewhere else to provide a better return on investment or they would not be acquired to begin with. Let's illustrate this thought with a simple example.

You need to remodel your kitchen. Estimating the work you plan to do at $25,000, you took a home equity loan for that amount at 5% for 1 year. When work was done 6 months later, you've found out that actual cost of it was $15,000, which seems nice until you factor in an interest (roughly $250) you've paid on extra $10,000 ($25,000 - $15,000), which you would not need to borrow if original estimate was more accurate.

For a multi-year construction project, depending on its budget, this extra interest paid because of an inaccurate estimate may amount to hundreds of thousands or even millions of dollars wasted. So, a Project Manager finishing the project significantly under the budget may be reprimanded rather than praised.

## Impact of Estimating Errors and Steps to Increase Quality of Estimates

The overall impact of estimating errors may be defined as follows:

- Project delays and cost overruns
- Unrecoverable revenue losses
- Project failures
- Loss of client trust
- Scope and quality reduction
- Legal repercussions
- Increase in operation and maintenance costs

- Repercussions against personnel

The following steps may be taken to increase quality of estimates:

- Create extensive historical database
- Learn from a previous project experience
- Expand personal knowledge
- Use reliable data as an input to estimating
- Include all necessary project components in bottom-up estimates
- Achieve cooperation from other contributors into estimating process
- Use estimating software

## Definition of Scheduling, Views of Project Schedules

Another key activity of Time Management besides estimating is Project Scheduling, which is the development of planned dates for performing project activities and meeting milestones[1]. Milestone, in its turn, is a significant point or event in the project.

These are the following views of Project Schedules:

- List or table of start and finish dates for all activities.
- List of milestones
- Milestone chart
- Gantt chart
- Network diagram

All these formats of the schedule provide different level of detail and serve specific purposes, with the list of milestones being the least detailed and mostly used for reporting and network diagram providing the most amount of information and being used for an actual management of the Project. To familiarize ourselves with different views of the Project schedule let's consider a simple example of procurement of power transformer. The list of activities for such project may be presented as follows:

| Activity | Start Date | Finish Date |
|---|---|---|
| 1. Obtain funds | 11/3/08 | 12/30/08 |
| 2. Prepare Specification | 1/2/09 | 1/29/09 |
| 3. Prepare RFP package | 2/2/09 | 2/16/09 |
| 4. Send RFP to vendors | 2/17/09 | 2/19/09 |
| 5. Evaluate bids | 3/16/09 | 3/31/09 |
| 6. Place an order | 4/1/09 | 4/6/09 |

---

[1] URL: science.energy.gov./~/media/opa/powerpoint/Final_Module_3.ppt

If we are interested just in major milestones, the above-mentioned list may be compressed into the following:

| Activity | Date |
|---|---|
| 1. Obtain funds | 12/30/08 |
| 2. Send RFP to vendors | 2/19/09 |
| 3. Place an order | 4/6/09 |

A Gantt chart for our example, which shows durations of activities as horizontal bars, is shown in Fig. 1. The black line in the middle of the bar shows a completion of the task. The corresponding milestone chart is shown in Fig. 1 as well.
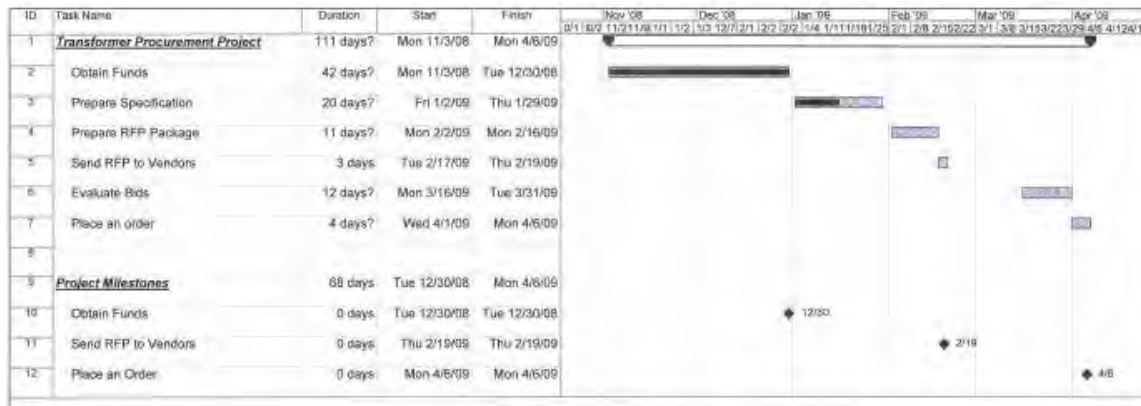


Fig. 1. Gantt and Milestone Charts for Transformer Procurement

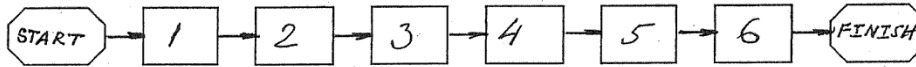And finally, Fig. 2 shows a Network Diagram for the same transformer procurement project:



Fig. 2. Network Diagram

Where:

1 - Obtain funds;          2 - Prepare Specification;
3 - Prepare RFP package;    4 - Send RFP to vendors;
5 - Evaluate bids;          6 - Place an order

## Network Diagrams. Activity Boxes

Main concepts of a network diagram may be formulated as follows:

- Network diagram is always drawn left to right to reflect sequence of work between start and finish of the Project.
- Diagram consists of boxes, representing activities, and arrows showing logical relationships between them

Typical network diagram activity box is shown in Fig. 3.

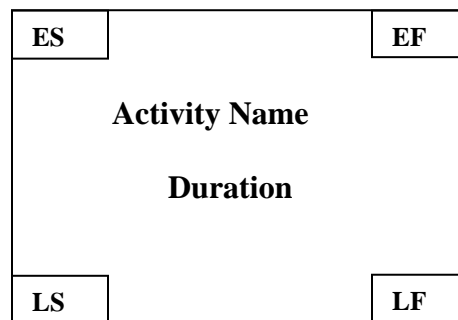| ES | | EF |
|---|---|---|
| | **Activity Name** | |
| | **Duration** | |
| LS | | LF |

Fig. 3. Typical Network Diagram Activity Box,

Where:

ES – Early Start - Earliest an activity can start
LS – Late Start - Latest an activity can start without delaying project completion
EF - Earliest an activity can finish, based on early start
LF - Latest an activity can finish without delaying project completion

It should be noted that the main characteristic of each activity is its duration, which is an estimated value. One of the most popular techniques for estimating activity's duration is PERT[2] which is using three time estimates: Optimistic (O), Pessimistic (P) and Most Likely (M) to derive the duration of activity DUR as follows:

$$DUR = (O + 4M + P) / 6 \qquad\qquad (6)$$

Let's make an assumption that for duration of activity "Obtain Funds" (box 1 in a network diagram shown in Fig.2), the following time estimates are available: O = 20 days, M = 45 days, P = 100 days.
Based on equation (6), the duration DUR (1) of activity "Obtain Funds" may be found as:

---

[2] URL: science.energy.gov./~/media/opa/powerpoint/Final_Module_3.ppt

DUR (1) = (20 + 4 x 45 + 100) / 6 = 50 days.

This duration for a box 1 may be used when creating a network diagram shown in Fig. 2. Another option, is to use instead of a 50 day duration (obtained by using PERT) the most likely duration of this activity, which is 45 days but it makes the whole schedule less conservative.

As an example, let's fill in the 1st box of a network diagram built for transformer procurement process, which is "Obtain Funds," assuming that duration of this activity DUR(1) = 50 days. From the list of activities above, we know that "Obtain Funds" one can start as early as 11/3/08 and finish as late as 12/30/08. Based on that, ES = 11/3/08 and LF=12/30/08. EF and LS may be found using the following equations:

EF = ES + DUR(1) = 11/3/08 + 50 days = 12/23/08

LS = LF – DUR(1) = 12/30/08 – 50 days = 11/10/08

Summarizing all the information for activity "Obtain Funds," its network diagram activity box may be shown as follows (see Fig. 4):

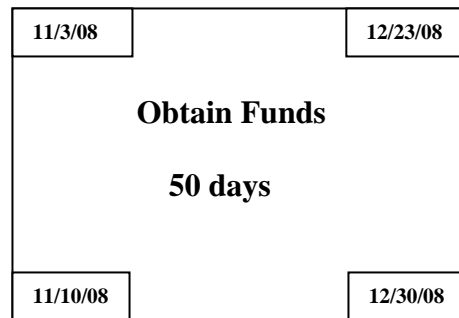| 11/3/08 | | 12/23/08 |
|---------|--|----------|
| | **Obtain Funds** | |
| | **50 days** | |
| 11/10/08 | | 12/30/08 |

Fig.4. Network Diagram Activity Box "Obtain Funds".

The difference between the early and late starts as well as between the early and late finishes is called "float" or "slack," which tells us how much activities may be delayed without delaying the project finish date.

So, a float for each activity may be found as follows:

$$Float = LS - ES = LF - EF \tag{7}$$

For activity "Obtain Funds" (see Fig. 4), Float = 7 days.

If activity has no float (it equals zero), it means that this activity in the network diagram is located on the critical path[3]. So, the critical path connects activities not allowing any slip without negatively impacting the duration of the project. A method of managing the project by identifying a critical path in a project's network diagram is called Critical Path Method (CPM)[3].

Let's learn how to create network diagrams and what to use them for.

## Dependencies

As we stated before, there are logical relationships (or dependencies) between separate activities in a network diagram. The following 4 types of scheduling dependencies may be identified[3]:

- Finish to Start – you should finish activity A before you can start activity C (the most popular type of scheduling dependency). This dependency type is shown in Fig.5.
  Example: House foundations should be installed before erecting the walls.
- Start to Start – you can start activity C as soon as we started activity A.
  Example: As soon as we began buying paint for the house, we can start painting walls
- Finish to Finish – you cannot finish activity C until you finished activity A.
  Example: You need to complete last chapter before the whole book may be finished.
- Start to Finish – you cannot finish activity A unless activity C started.
  Example: Replacement guard should start his shift before a previous guard may be released
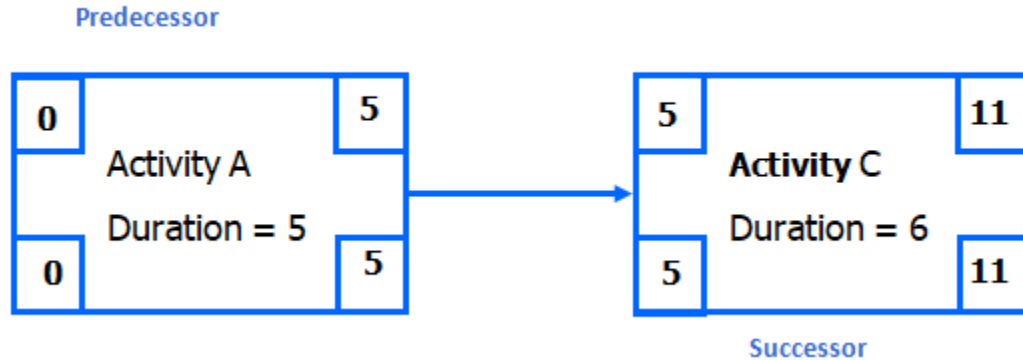
Fig. 5. Example of "Finish to Start" dependency between Activity Boxes

All these dependencies may be shown in the network diagram by connecting activities with corresponding arrows.

## Building a Network Diagram

In order to build the network diagram, the following two processes are used[3]:

---

[3] URL: science.energy.gov./~/media/opa/powerpoint/Final_Module_3.ppt

- The Forward Pass through the project network determines the early start (ES) and the early finish (EF) of each activity. It is performed in the following sequence:

    - The Forward Pass begins at a project start with ES of a first task $A_1 = 0$
    - After that, it calculates $EF(A_1) = ES(A_1) + DUR(A_1) = ES(A_2)$ etc.: $EF(A_n) = ES(A_n) + DUR(A_n)$, where $ES(A_n) = EF(A_{n-1})$
    - With two and more predecessors, successor's ES is a maximum out of predecessors' EFs

- The Backward Pass determines the late start (LS) and the late finish (LF) of each activity. It is performed in the following sequence:

    - The Backward Pass begins at a project finish with $LF(A_n)$ of last task $= EF(A_n)$
    - After that, it calculates $LS(A_n) = LF(A_n) - DUR(A_n) = LF(A_{n-1})$ etc.: $LS(A_1) = LF(A_1) - DUR(A_1)$, where $LF(A_1) = LS(A_2)$
    - With two and more successors, predecessor's LF is a minimum out of successors' LSs

To better understand both Forward and Backward Passes, let's start with using them for the simplest network diagram shown in Fig. 5, which consists of only 2 activities: A and C.

Forward pass starts with assigning 1st activity A a $ES(A) = 0$. After that, $EF(A)$ may be found as $EF(A) = ES(A) + DUR(A) = 0 + 5 = 5$. $ES(C) = EF(A) = 5$. And finally, $EF(C) = ES(C) + DUR(C) = 5 + 6 = 11$.

Backward pass starts with $LF(C) = EF(C) = 11$. After that, $LS(C)$ may be found as: $LS(C) = LF(C) - DUR(C) = 11 - 6 = 5$. $LF(A) = LS(C) = 5$, and finally, $LS(A) = LF(A) - DUR(A) = 5 - 5 = 0$.

All determined values for both activities are shown in Fig. 5. It may be noted that both activities A and C have a zero float, because:
$ES(A) = LS(A) = 0$; $LF(A) = EF(A) = 5$. $ES(C) = LS(C) = 5$. $LF(C) = EF(C) = 11$.

So, by definition, if both activities are a part of a network diagram, they will be located on a critical path.

Now let's expand our understanding of CPM by creating a network diagram for a case study described below.

## Case Study

**Renovation of a 2-story Family Home**

John Doe, the owner of a 2-story family home, hired the ABC Construction Company to repaint ceilings and walls and replace wallpaper and carpeting in all the rooms on the 1st and 2nd floors of

the house. Besides that, John wants to have wall and floor tiles replaced in the 2$^{nd}$ floor bathroom. All the work should start on 8/16/18 and be completed no later than 8/31/18 (before the start of a schoolyear for John's kids).

ABC Construction Company agreed to do the work in the timeframe requested by John for the price of $ 30,000 and assigned Peter Smith to manage this renovation project. Peter started his work with identifying all activities that the renovation project involves and estimating durations for them. Results of Peter's analysis are shown in a Table 1.

Table 1 **–** Major Project Activities

| Activity Designation | Activity Description | Estimated Duration, Days |
|---|---|---|
| A | Wall and Ceiling Painting on the 1$^{st}$ Floor | 6 |
| B | Wall and Ceiling Painting on the 2$^{nd}$ Floor | 3 |
| C | Wallpaper Replacement on the 1$^{st}$ Floor | 5 |
| D | Wallpaper Replacement on the 2$^{nd}$ Floor | 5 |
| E | Carpet Replacement on the 2$^{nd}$ Floor | 4 |
| F | Tiles Replacement in the 2$^{nd}$ Floor Bathroom | 4 |
| G | Carpet Replacement on the 1$^{st}$ Floor | 3 |
| H | Cleanup and Customer Acceptance | 2 |

The next step for a Project Manager was identification of dependencies between all the activities in the Table 1. Results of this analysis are shown below.

## Dependencies

There is a "finish-to-start" relationship between the following activities:

- "A" and "C"
- "B" and "D"
- "B" and "F"
- "D" and "E"
- "C" and "G"
- "D" and "E"
- "F" and "E"
- "G" and "H"
- "E" and "H"

Based on information about dependencies, Peter Smith built a network diagram shown In Fig. 6.  After that, using activity durations from Table 1, he performed both Forward and Backward Passes  to define for each activity ES, LS, EF and LF and fill in this data into activity boxes (see Fig. 6).
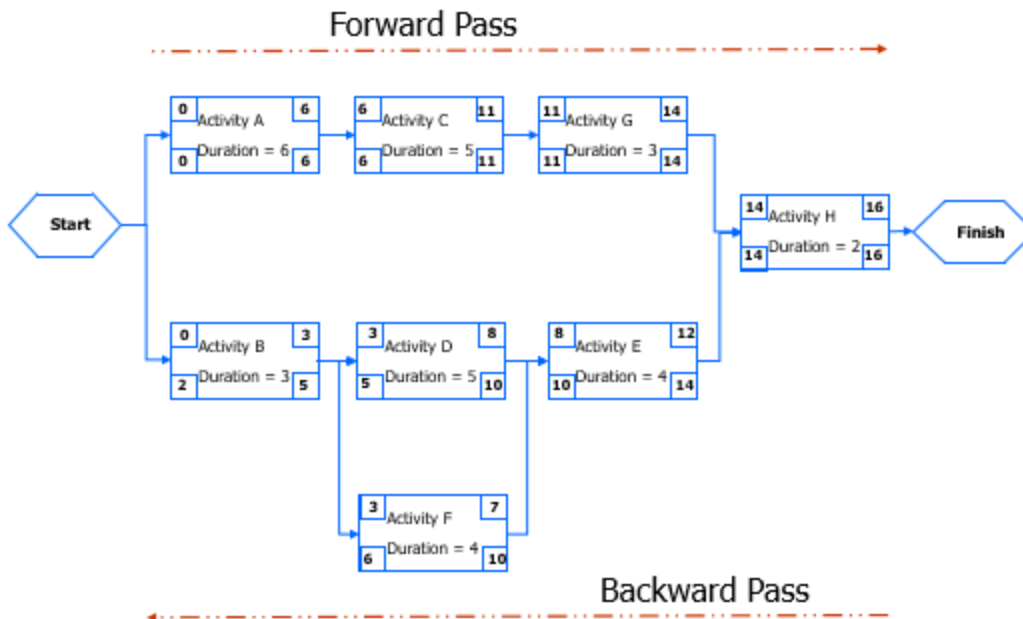
Fig. 6. Network Diagram for a Case Study

Let's see how it was done.

1. Forward Pass.

   1.1. $ES(A) = 0$, $EF(A) = ES(A) + DUR (A) = 0 + 6 = 6$
   1.2. $ES(C) = EF(A) = 6$. $EF(C) = ES(C) + DUR(C) = 6 + 5 = 11$
   1.3. $ES(G) = EF(C) = 11$. $EF(G) = ES(G) + DUR(G) = 11 + 3 = 14$

   As we see so far, a Forward Pass for activities A, C and G was performed exactly in the same way it was previously done for activities A and C shown in Fig. 5.

   1.4. $ES(B) = 0$. $EF(B) = ES(B) + DUR(B) = 0 + 3 = 3$
   1.5. $ES(D) = EF(B) = 3$. $EF(D) = ES(D) + DUR(D) = 3 + 5 = 8$
   1.6. $ES(F) = EF(B) = 3$. $EF(F) = ES(F) + DUR(F) = 3 + 4 = 7$

   Here we need to note that both activities D and F are successors of activity B. That's why for both of them, Early Start ES equals an Early Finish EF of their common predecessor activity B, i.e. $ES(D) = ES(F) = EF(B) = 3$

   1.7. $EF(D) > EF(F)$ $(8 > 7) \rightarrow ES(E) = EF(D) = 8$

   Here we need to note that activity E has two predecessor activities F and D. By the logic of dependencies between F, D and E, **both** F and D should finish before E can start. If we compare early finishes of activities D and F, we'll see, that F will finish after 7 days from

the start of the project, while D will finish after 8 days (see Fig. 6). So, if we need both D and F to finish before E can start, the earliest it may happen is after 8 days. That's why ES(E) = EF(D) = 8

1.8. EF(E) = ES(E) + DUR(E) = 8 + 4 = 12
1.9. EF(G) > EF(E) (14>12) → ES(H) = EF(G) = 14

Here again we have activity H with two predecessors E and G, and like it was explained before for activity E, the ES(H) is the maximum out of EF(G) and EF(E)

1.10. EF(H) = ES(H) + DUR(H) = 14 + 2 = 16.

So, Project will finish on 8/31/18 or 16 days after the start as requested. And now let's perform the Backward Pass to finish a network diagram.

2. Backward Pass.

2.1. LF(H) = EF(H) = 16. LS(H) = LF(H) – DUR(H) = 16 – 2 =14

We start with LF(H) equal EF(H) because project's completion date is rigid – no later than 8/31/18 or 16 days after the start of the project

2.2. LF(G) = LF(E) = LS(H) = 14
2.3. LS(G) = LF(G) – DUR(G) = 14 – 3 = 11
2.4. LS(E) = LF(E) – DUR(E) = 14 – 4 = 10
2.5. LF(C) = LS(G) = 11. LS(C) = LF(C) – DUR(C) = 11 – 5 = 6
2.6. LF(A) = LS(C) = 6. LS(A) = LF(A) – DUR(A) = 6 – 6 = 0
2.7. LF(D) = LF(F) = LS(E) = 10
2.8. LS(D) = LF(D) – DUR(D) = 10 – 5 = 5
2.9. LS(F) = LF(F) – DUR(F) = 10 – 4 = 6
2.10. LS(D) < LS(F) (5<6) → LF(B) = LS(D) = 5

Here we have a situation with one predecessor B and two successors D and F. It means that for **both** D and F to start, B should finish. If we compare late starts of activities D and F, we'll see that D should start **no later** than 5 days after the start of the project, while F can start as late as 6 days (see Fig. 6). To satisfy both conditions, activity B should finish at the earliest of activities D and F start dates. That's why

 LF(B) = LS(D) = 5

2.11. LS(B) = LF(B) – DUR(B) = 5 – 3 = 2.

The results of calculations of ES, EF, LF, LS for all the activities are shown in Fig. 6.

Now, to define a critical path for this network diagram, let's calculate a float for each activity and draw a path through activities with zero float. The results of this process are shown in Fig .7.
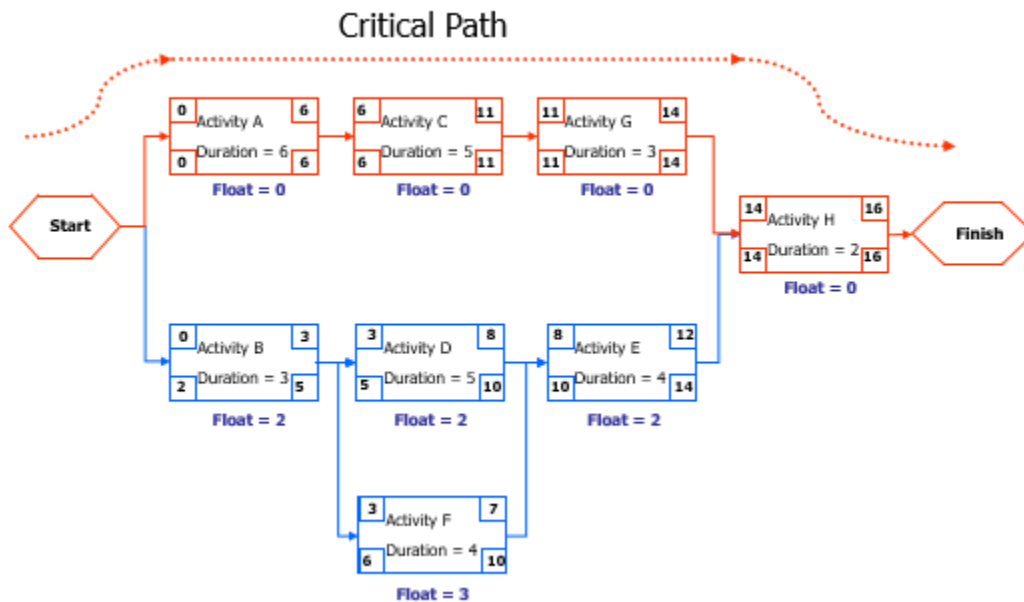
Fig. 7. Determination of a Critical Path for a Case Study

# Benefits from Network Diagrams

So, in the case study considered above, a Project Manager created a network diagram and identified a critical path. What can he do with all this information? First of all, the network diagram shown in Fig. 7 presents a workable schedule that supports a requested delivery date of the Project. Very often, when all activities with their specific durations and dependencies are connected in a diagram for the very first time, a finish date is off: you may have a project delayed beyond a requested finish date or maybe you are planning to finish it earlier than needed. While delay is unacceptable, having a project completed too early is not desirable because most likely it happened as a result of spending extra money on activities: using more workers than needed, bringing some more productive (and usually more expensive) equipment, etc.

A network diagram allows a Project Manager to optimize the schedule: shortening some activities or extending them to avoid wasting extra funds depending on what he wants to achieve.

Another benefit that a Project Manager can get from a network diagram is having a critical path identified. As we stated before, it goes through activities with a zero float, which cannot slip without delaying the project. For example, activity A "Wall and Ceiling Painting on the 1st Floor" cannot be delayed at all without impacting the project delivery date while activity B "Wall and Ceiling Painting on the 2nd Floor" has a float equal 2 (see Fig. 7) which means that a 2-day slip for activity "B" is permissible from a project being on time stand point. So, knowing the activities on the critical path, a Project Manager can give them more attention to ensure that they will not slip.

Unfortunately, projects rarely go as planned, and despite the best efforts of a Project Manager, some of the critical path activities may indeed slip during the course of the project or some non-critical activities may use more slack than the original network diagram allowed them to do.

If that kind of slippage occurs, then the Project Manager may use a network diagram to find an optimal way to bring a project back on track (to correct a schedule).

## Schedule Correction Techniques

There are two main schedule correction (optimization) techniques:

- Schedule Crashing:
    - Adding resources: Workers, Equipment, etc.
    - Working overtime
    - Using better technology

- Schedule Fast Tracking:
    - Changing schedule logic (for example, performing activities in parallel instead of sequentially, overriding dependencies etc.)

We can use our home renovation case study to get a better understanding of both schedule correction techniques. Let's assume that activity A "Wall and Ceiling Painting on the 1st Floor" took 7 days to finish instead of planned 6 days. Because it is a critical path activity, this 1 day slip may result in the project delay unless the Project Manager uses one of schedule correction techniques to bring a project back on track. Obviously, the remaining critical path activities C, G and H should be expedited to compensate for a slip of activity A. The following may be done:

- Schedule Crashing:
    - Add manpower to work on wallpaper and/or carpet replacement on The 1st floor.
      One of the options is to move some wallpaper and carpet installers from the 2nd floor, where activities have float to the 1st floor
    - Work overtime on wallpaper and/or carpet replacement
    - Use some better materials (for example, a fast-drying glue) to expedite wallpaper installation

- Schedule Fast Tracking:
    - Start carpet replacement before wallpaper replacement is completed on the whole 1st floor
      For example, if there are several rooms on the 1st floor, move carpet installers into the rooms where wallpaper is already replaced. So, you will have both wallpaper and carpet replacement crews working simultaneously on the 1st floor which will require additional coordination but allow you to expedite the work.

The use of each of these techniques will allow you to eliminate or reduce schedule slippage and bring the Project back on track. On the negative side, possible results from application of both techniques are:

- Higher cost
- Increased risk

There is another measure to compensate a possible slippage in the schedule – to add a buffer to it. For example, in our case study Peter Smith could build the initial network diagram with a 8/30/18 project delivery date instead of requested 8/31/18. As a result, having a 1 day buffer could compensate for possible schedule slippage risks.

As you could see from this house renovation case study, a network diagram is a very valuable schedule management tool. But the project that we considered was very small. For a medium size project (for example, a construction of multi-story building) a network diagram may consist of tens, even hundreds activity boxes. For something like a new power plant, a number of activity boxes may reach thousands.

As you could see working with the case study above, even a creation of a very small network diagram (we had 8 activities) was a rather cumbersome process. That's why project schedulers are using different software packages (Microsoft Project, for example) to build network diagrams for the projects of all sizes. However, the overall process is similar to the one that we discussed above for a house renovation case study.

## Conclusion

This course presented an overview of modern practices in effective Project Estimating and Scheduling to enable you to:

- Understand the importance of estimating and scheduling for overall success of the project
- Define the estimating and list the main inputs into estimates
- Compare two main estimating techniques: top-down and bottom-up estimating
- Define types of cost estimates based on the levels of their accuracy and learn when to use each of them
- Understand the impact of estimating errors and list the steps to increase quality of estimates
- Define the scheduling and list different views of project schedule
- Learn main concepts of network diagrams and main components of activity boxes
- Define a critical path and float
- List logical dependencies between activities in a network diagram
- Learn how to build a network diagram using Forward and Backward Passes
- Understand benefits from network diagrams
- Learn schedule correction techniques