**E90 Engineering Design**

Notes on the **Critical Path Method** for project planning and management.

CPM models any project by a network of blocks or circles called NODES that are connected by lines called ARROWS. These represent ACTIVITIES (processes) and EVENTS (states); one has the option of putting Activities on Arrows or Activities on Nodes - the latter method is simpler, quite similar to the use of Block Diagrams for computer programs, and will be presented here. The chief difference between Block Diagrams and CPM Networks is the inclusion of time and duration information in CPM.

The object of CPM modeling is to enable project managers to readily visualize the time and precedence relations among all significant project activities, to discover which sequence(s) of activities are Critical to timely project completion, and to investigate the effects of Crashing (accelerating completion) or Slipping (delaying) activities within the project.

Regarding E90, CPM can enable you to determine in advance

1) whether your proposed project can be completed on or before a deadline, or needs to be modified in order to achieve timely completion;
2) which activities absolutely must be begun and completed on schedule to permit timely project completion;
3) the latest possible start and latest completion dates for each project activity; and
4) the effect of potential delays in material or equipment availability on final project completion.

A very important additional benefit is a week-by-week indication of total project effort ("manpower loading") that you can use to adjust the scope and/or schedule of your project in advance, so that you will then be able to accomplish it and meet all relevant deadlines without sacrificing either your physical or mental health.

As a relevant (and mildly recursive) example of CPM use, consider the "project" of creating a CPM network for your E90 Project and producing a finished CPM Network diagram for your Draft Project Proposal. The main activities involved in this project are:

A Making a list of all significant activities included in your project
B Estimating the time duration and effort needed to complete each activity
C Determining the precedence/dependence of each activity with respect to the others
D Becoming familiar with CPM methodology and conventions
E Creating an initial network diagram showing the activity interrelations within the task
F Examining the diagram to discover the Critical Path, determine overall time feasibility and effort schedule
G Adjusting project scope by adding/modifying/deleting tasks until Spring '00 deadlines can be met within realistic time, effort, material/equipment availability and/or other resource constraints
H Redrawing and preparing the CPM diagram and notes in final format for inclusion in Draft Proposal
(I) Printing the CPM Network diagram and supporting documentation for insertion into Draft Proposal

The list above is mostly in precedence order; that is typical for simple projects, but such clear definition can seldom be achieved in one pass for more complex projects. Frequently, one must work backward from the final product specification to determine the prior activities required, and in such cases one must be very careful not to omit any significant activity - one that will require anyone's effort in a timely manner.

Here, then is the formal Activities List resulting from completion of Activity A:

**Project: Creating a CPM Network diagram for a Draft E90 Proposal**

| Activity | Action |
|---|---|
| A | Make a list of all significant activities included in project |
| B | Estimate time duration and effort needed to complete each activity |
| C | Determine precedence/dependence of each activity |
| D | Become familiar with CPM methodology and conventions |
| E | Draw initial network diagram showing activity interrelations |
| F | Examine diagram to discover Critical Path, determine overall time feasibility and effort schedule |
| G | Adjust project scope and add/modify/delete tasks until deadlines can be met within time, effort and resource constraints |
| H | Redraw and prepare CPM diagram and notes in final format for inclusion in Draft Proposal |
| (I) | Print CPM Network diagram and supporting documentation for insertion into Draft Proposal |

Activity (I) is optional, required only if the CPM Network and accompanying notes is created and saved as a separate word processing document.

Now we add initial Duration and Effort estimates; duration estimates are in days and effort estimates in hours, reflecting the preference of the typical student worker (you) to fit each activity into an existing daily routine rather than do the entire project at once, or even in big chunks. This distinction between Duration and Effort is NOT part of standard CPM texts, but is highly relevant whenever there is part-time activity involved in a project. Minimum increments of duration and effort are here 1 day and 1 hour respectively; others could have been used.

**Project: Creating a CPM Network diagram for a Draft E90 Proposal**

| Activity | Duration | Effort | Action |
|---|---|---|---|
| A | 1d | 1h | List significant activities |
| B | 2d | 2h | Estimate activity duration and effort |
| C | 1d | 2h | Determine activity precedence |
| D | 2d | 2h | Learn CPM fundamentals |
| E | 2d | 3h | Draw initial network diagram |
| F | 2d | 4h | Examine diagram for Critical Path, feasibility, effort schedule |
| G | 0-4d | 0-8h | Adjust project scope, tasks |
| H | 3d | 4h | Prepare final CPM diagram and notes |
| (I) | 1d | 1h | Print CPM Network and supporting docs |

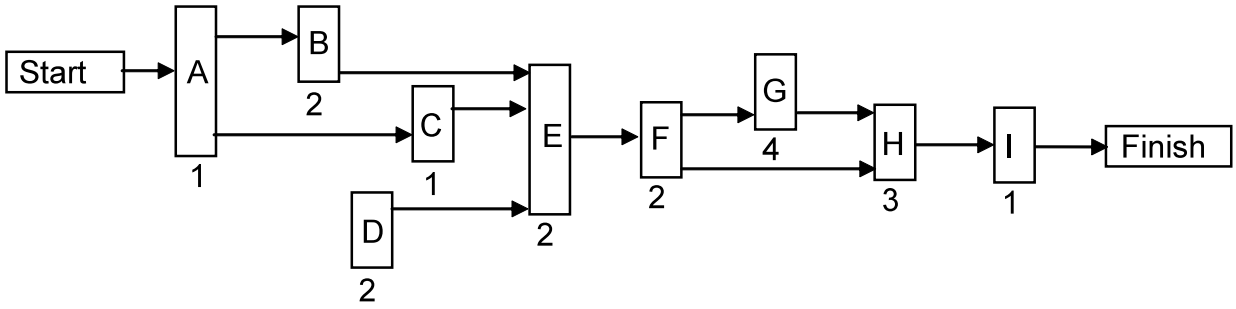
Next we add precedence information for each activity. At this stage of a larger project, it might become apparent that some activities should be subdivided on account of the subactivities being more or less independent and/or subject to different precedents.

**Project: Creating a CPM Network diagram for a Draft E90 Proposal**

| Activity | Needs | Feeds | Duration | Effort | Action |
|---|---|---|---|---|---|
| A | - | B | 1d | 1h | List significant activities |
| B | A | E | 2d | 2h | Estimate activity duration and effort |
| C | A | E | 1d | 2h | Determine activity precedence |
| D | - | E | 2d | 2h | Learn CPM fundamentals |
| E | B,C,D | F | 2d | 3h | Draw initial network diagram |
| F | E | G | 2d | 4h | Examine diagram for Critical Path, feasibility, effort schedule |
| G | F | H | 0-4d | 0-8h | Adjust project scope, tasks |
| H | G | I | 3d | 4h | Prepare final CPM diagram and notes |
| (I) | H | - | 1d | 1h | Print CPM Network and supporting documents |

Note that Activity G may not be required if Activity F indicates no need for adjustments.

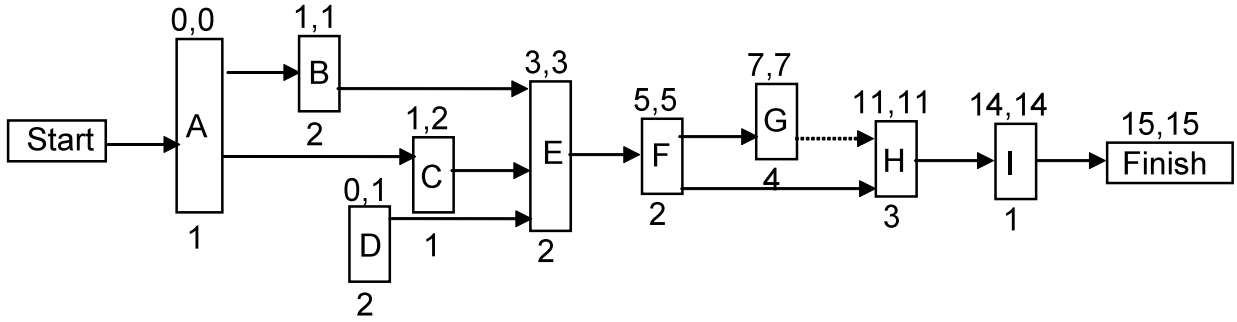
Now we're ready to draw the initial CPM Network (Activities on Nodes). First, lay out the sequence of activities with arrows indicating precedence. Note the smaller arrow connecting F to G, indicating the optional character of G, and the parallel branch indicating that if G is not required, F must still conclude before H can begin. Precedence arrows can emanate from or arrive at the left (Start) or right (Finish) edge of an activity Node, depending upon whether the preceding activity need only be Started or must be Finished before the dependant activity can Start or Finish



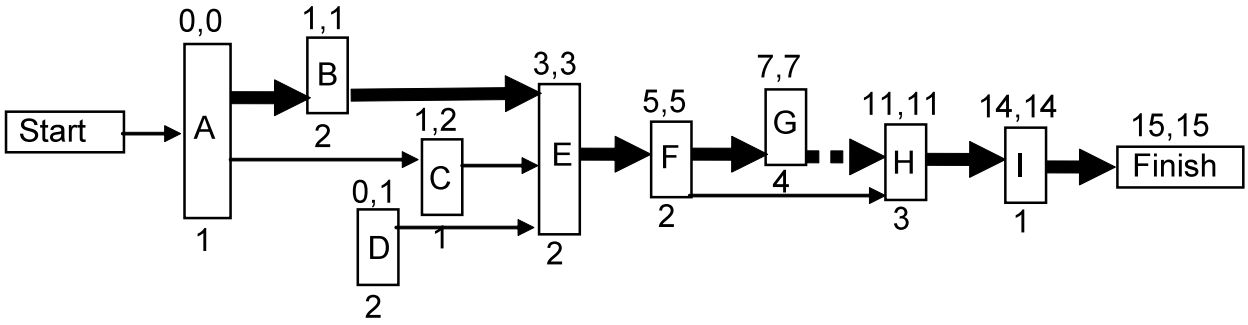

We now determine the Earliest Start Time (ES) for each activity by making a "forward pass" through the diagram from Start to Finish, beginning with ES=0 for the first activity in any branch and adding the Duration of each activity to determine ES for each subsequent activity. When multiple branches converge at a node, the latest of the possible ESs prevails.

We also determine the Latest Start Time (LS) for each activity by making a "backward pass" from Finish to Start, subtracting the duration of each activity from LS of the subsequent one to determine LS for that activity. When multiple branches emanate from a node, the earliest of the possible LSs prevails.

Below we add the Earliest and Latest Start Time information to each activity by writing its **ES,LS** above the node. In this particular diagram, the smaller arrowhead on the dashed arrow from G to H indicates that H may not require G.



Now we're ready to find the Critical Path for this network. Any arrow connecting nodes that each have equal ES and LS values is part of the Critical Path. Nodes having unequal ES and LS values have "Slack" or "Float" time associated with that activity equal to the difference between ES and LS. There is no slack anywhere on a Critical Path - any delay or "slip" in an activity on the Critical Path results in equal slip at the Finish. Thick arrows below denote the Critical Path:




Now that we have found the Critical Path, we can note several things about this project:

1) Total duration is 15 days Start to Finish. If the project deadline were less than 15 days distant from today, this project could not be completed on time unless one or more activity durations along the Critical Path were reduced. Such reductions are possible, because activity duration, as distinct from effort, is somewhat discretionary.

2) Activity G is on the Critical Path, even though it might not be required, because one cannot decide whether to eliminate it until Activity F is complete; thus sufficient time must be built into the project schedule. If G turns out not to be necessary, the project can be completed as many as four days sooner, or some vacation days may be enjoyed.

3) Activities C and D each have one day slack; one can start these activities anywhere between their ES and LS without compromising timely project completion.

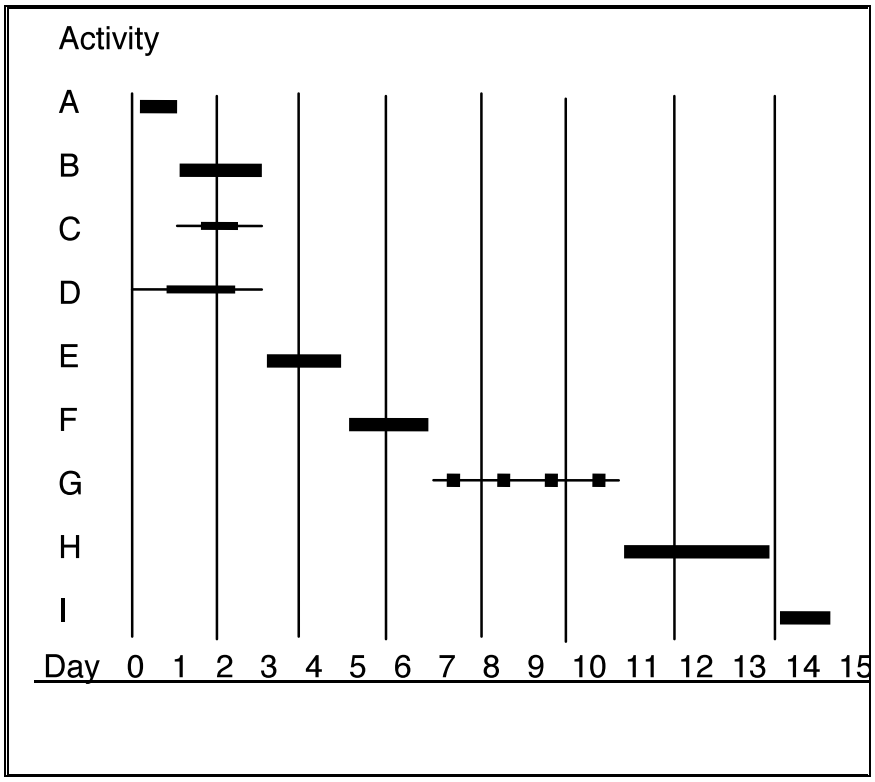
But we're not done yet. Because critical path analysis assumes that time is the critical resource, and because this particular project (preparation of a CPM Network diagram for an E90 proposal) will most probably be the work of one person, it would be prudent to examine an effort schedule as well.

**Day by Day Activities Summary**

| Day | Act's. In Progress | Act. Effort Hrs | Day's Total Effort | Total Hrs to Date |
|---|---|---|---|---|
| 0 | A, (D) | 1, (0-2) | 1 - 3 | 1 - 3 |
| 1 | B, (D), (C) | 1, (0-2), (0-2) | 1 - 5 | 2 - 5 |
| 2 | B, (D), (C) | 1, (0-2), (0-2) | 1 - 5 | 7 |
| 3 | E | 1.5 | 1.5 | |
| 4 | E | 1.5 | 1.5 | 10 |
| 5 | F | 2 | 2 | |
| 6 | F | 2 | 2 | 14 |
| 7 | G | 0-2 | 0 - 2 | |
| 8 | G | 0-2 | 0 - 2 | |
| 9 | G | 0-2 | 0 - 2 | |
| 10 | G | 0-2 | 0 - 2 | 14 - 22 |
| 11 | H | .75 | .75 | |
| 12 | H | .75 | .75 | |
| 13 | H | .75 | .75 | 17 - 25 |
| 14 | I | 1 | 1 | 18 - 26 |
| 15 | Done | | | |

This list makes it quite apparent that the Duration of most activities could be reduced at the cost of increased daily Effort. However, that might well conflict with one's other responsibilities and priorities that day – a situation that is dangerous to overlook if you are planning an E90 project on a weekly (rather than daily) basis and some weeks are known in advance to include important professional (job seeking), social, familial or institutional obligations.

Another very useful project planning tool is a chart showing activities versus time - known in business as a GANTT chart or a Milestone Chart. Here is the one for our project corresponding to the Activities Summary list:




Thin lines here indicate optional activity placement (e.g. C requires 1 day between Days 1 and 3). Thick lines indicate activities that are on the Critical Path.

A Hardcopy of such a chart readily permits easy comparison of Planned (printed as shown) versus Actual (written in using contrasting color(s)) project activity. Significant deadlines or other milestones can be added using markers along the timeline or at the End of appropriate activities.

The Specification, Purchase ordering, Delivery and/or Construction and Availability of important items of equipment, instrumentation or supplies can be included in projects as appropriate Activities. Such things are frequently on a project's Critical Path but are not sufficiently acknowledged by appearance in the CPM Network; naively excluding them is a serious and often risking omission.

For the "project" of creating a CPM analysis for an E90 Senior Engineering Design Project, this handout has presented each of the necessary steps in turn. Your CPM analysis for your own E90 project should therefore include:

1) an Activities List written in sufficient detail to enable the reader to understand the scope and output of each activity;

2) a Table of Activities showing Needs/Feeds, Duration and Effort for each Activity;

3) a CPM Network diagram showing ES/LS, Precedence and Duration for each Activity, and clearly indicating the Critical Path;

4) a GANTT or Milestone Chart showing Activities versus Time, and indicating appropriate Deadlines and/or Milestones; and

5) a Bill of Materials and/or Equipment List describing all critical physical resources whose timely availability is mentioned and indicated within the project plan.

* * * THE END * * *