**Project Schedule Management, PMBOK 6th Edition**

Michael D. Harper, Ph.D.

*“Project schedule management involves defining and controlling the timely completion of the project.”*

|  |  |  |
| --- | --- | --- |
|  | **Project Time Management** | **Process Groups** |
|  | **Major Processes** | Initiating | Planning | Executing | Monitoring &Controlling | Closing |
|  | Plan Schedule Management |  | 1 |  |  |  |
| **🡪** | Define Activities |  | 2 |  |  |  |
| **🡪** | Sequence Activities |  | 3 |  |  |  |
| **🡪** | Estimate Activity Durations |  | 4 |  |  |  |
| **🡪** | Develop Schedule |  | 5 |  |  |  |
| **🡪** | Control Schedule |  |  |  | 6 |  |

|  |  |
| --- | --- |
| **Define Activities** | Activity List |

|  |  |
| --- | --- |
| **Sequence Activities** | Network 🡪 AOA, AON |

|  |  |
| --- | --- |
| **Estimate Activity Durations** | Time 🡪 Gantt Chart |

|  |  |
| --- | --- |
| **Develop Schedule** | CPM, PERT |

|  |  |
| --- | --- |
| **Control Schedule** | Monitoring, Crashing, Fast Tracking, Resource Allocation |

**Define Activities.**

Determine all the activities of the project. In general,

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **WBS** | **🡪** | **Decomposition** | **🡪** | **Activity List** |

Decomposition in more complex projects creates activities from work packages.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **WBS** | **🡪** | **Work Packages** | **🡪** | **Activities** |

A Work Package can represent a collection of activities that represent a deliverable, a defined amount of work, pre-determined amount of time, pre-allocated resources, or other groupings sufficient for management control of reporting, scheduling, or directing work.

|  |
| --- |
| **Goal: Define activities in enough detail to be scheduled and managed.**  |
| **Caution-1: Too detailed introduces unnecessary control (micro-management).****Caution-2: Not enough detail creates inadequate direction (internal scope creep).** |
| **Definition initially depends on project, project manager, and project team.** |

Example:

|  |
| --- |
| WBS for Responding to RFP 1.0 Evaluation 1.1 Organize RFP requirements 1.2 Identify internal constraints and capabilities 2.0 Development 2.1 Introduction (Background, justification, and approach) 2.2 SOW (Statement of Work) 2.3 Satisfy regulation compliance 3.0 Closeout 3.1 Prepare document 3.2 Obtain approvals |
| **Activity List**

|  |  |
| --- | --- |
| **Activity** | **Description of Activities** |
| 1 | 1.1 Organize RFP requirements |
| 2 | 1.2 Identify internal constraints and capabilities |
| 3 | 2.1 Introduction (Background, justification, and approach) |
| 4 | 2.2 SOW (Statement of Work) |
| 5 | 2.3 Satisfy regulation compliance |
| 6 | 3.1 Prepare document |
| 7 | 3.2 Obtain approvals |

. |

Defining Activities can be based on project needs:

* Work resources. (Allocation of M/S resources and scheduling.)
* Work time. (Coordinating labor within scheduling.)
* Work deliverables. (Coordination of responsibilities or reporting.)

**Sequence Activities.**

Activity List 🡪 Dependency Relationships 🡪 Project Network

[Dependencies: Mandatory, Discretionary, External]

[Arrow Diagramming Method (ADM) or Activity-on-Arrow (AOA)]

[Precedence Diagramming Method (PDM) or Activity-on-Node (AON)]

|  |
| --- |
| Let A=Activity, PA=Predecessor Activity. |
| **A** | **Description** | **PA** |
| 1 | 1.1 Organize RFP requirements | --- |
| 2 | 1.2 Identify internal constraints and capabilities | --- |
| 3 | 2.1 Introduction (Background, justification, and approach) | 1 |
| 4 | 2.2 SOW (Statement of Work) | 2 |
| 5 | 2.3 Satisfy regulation compliance | 2 |
| 6 | 3.1 Prepare document | 3,4 |
| 7 | 3.2 Obtain approvals | 3,4,5 |

|  |
| --- |
| **AOA (Activity On Arrow)** |
| **A** | **PA** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | -- |  |  |  |  | 1 |  |  |  |  | 3 |  |  |  |  |  | 6 |  |  |  |  |
| 2 | -- |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | 2 |  |  |  |  | 2 |  |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |
| 5 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 | 3,4 |  |  |  |  |  |  |  |  |  | 5 |  |  |  |  |  | 7 |  |  |  |  |
| 7 | 3,4,5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

|  |
| --- |
| **AON (Activity On Node** |
| **A** | **PA** |  |  |  |  |  |  |  |
| 1 | -- |  | 1 |  | 3 |  | 6 |  |
| 2 | -- |  |  |  |  |  |  |  |
| 3 | 1 |  | 2 |  | 4 |  | 7 |  |
| 4 | 2 |  |  |  |  |  |  |  |
| 5 | 2 |  |  |  | 5 |  |  |  |
| 6 | 3,4 |  |  |  |  |  |  |  |
| 7 | 3,4,5 |  |  |  |  |  |  |  |

**Paths through the network:**

|  |  |
| --- | --- |
|  | Paths: |
| 1 | 1-3-6 |
| 2 | 1-3-7 |
| 3 | 2-4-6 |
| 4 | 2-4-7 |
| 5 | 2-5-7 |

**Predecessor-Successor Dependency Relationships**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |
|  | Type of |  | Predecessor Activity |  | SuccessorActivity |  |
|  | Relationship |  | Start | Finish |  | Start | Finish |  |
|  | (FS) |  |  |  |  |  |  |  |
|  | PA FinishTo SA Start | 🡪 | PredecessorActivity |  | SuccessorActivity |  |
|  |  | Start | Finish |  | Start | Finish |  |
|  | (FF) |  |  |  |  |  |  |  |
|  | PA FinishToSA Finish | 🡪 | PredecessorActivity |  |  |  |  |
|  |  | Start | Finish |  |  |  |  |
|  |  |  |  |  | SuccessorActivity |  |
|  |  |  |  |  | Start | Finish |  |
|  | (SS) |  |  |  |  |  |  |  |
|  | PA StartToSA Start | 🡪 | PredecessorActivity |  |  |  |  |
|  |  | Start | Finish |  |  |  |  |
|  |  |  |  |  | SuccessorActivity |  |
|  |  |  |  |  | Start | Finish |  |
|  | (SF) |  |  |  |  |  |  |  |
|  | PA StartToSA Finish | 🡪 | PredecessorActivity |  |  |  |  |
|  |  | Start | Finish |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  | SuccessorActivity |  |
|  |  |  |  |  | Start | Finish |  |
|  |  |  |  |  |  |  |  |  |

**Predecessor-Successor Lead, Lag Relationships**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |
|  | PA FinishTo SA StartWithLead Time | 🡪 | PredecessorActivity |  |  |  |  |
|  |  | Start | Finish |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  | SuccessorActivity |  |  |  |
|  |  |  | Start | Finish |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  | PA FinishToSA Start With Lag Time | 🡪 | PredecessorActivity |  |  |  |  |
|  |  | Start | Finish |  |  |  |  |
|  |  |  |  |  | SuccessorActivity |  |
|  |  |  |  |  | Start | Finish |  |
|  |  |  |  |  |  |  |  |  |

**Estimate Activity Durations.** “Obtain the amount of work needed for each activity.”

 Activity List 🡪 Estimation 🡪 Activity Duration List

|  |  |  |  |
| --- | --- | --- | --- |
| **A** | **Description** | **PA** | **T** |
| 1 | 1.1 Organize RFP requirements | --- | 5 weeks |
| 2 | 1.2 Identify internal constraints and capabilities | --- | 2 weeks |
| 3 | 2.1 Introduction (Background, justification, and approach) | 1 | 2 weeks |
| 4 | 2.2 SOW (Statement of Work) | 2 | 3 weeks |
| 5 | 2.3 Satisfy regulation compliance | 2 | 3 weeks |
| 6 | 3.1 Prepare document | 3,4 | 3 weeks |
| 7 | 3.2 Obtain approvals | 3,4,5 | 1 weeks |

**Estimation Approaches**

|  |
| --- |
| **Expert Judgment**. Soliciting expert opinion. |
| **Analogous Estimation**. Application from other projects. |
| **Parametric Modeling**. Estimation from formulas, templates, or processes. |
| **Three-point Estimation**. From Program Evaluation and Review Technique (PERT)Duration = (Optimistic Time + 4\*(Most Likely Time) + Pessimistic Time)/6 |

|  |
| --- |
| **AOA (Activity On Arrow)** |
| **A** | **PA** | **T** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | -- | 5 |  |  |  |  | 1 |  |  |  |  | 3 |  |  |  |  |  | 6 |  |  |  |  |
| 2 | -- | 2 |  |  |  |  | 5 |  |  |  |  | 2 |  |  |  |  |  | 3 |  |  |  |  |
| 3 | 1 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | 2 | 3 |  |  |  |  | 2 |  |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |
| 5 | 2 | 3 |  |  |  |  | 2 |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |
| 6 | 3,4 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 7 | 3,4,5 | 1 |  |  |  |  |  |  |  |  |  | 5 |  |  |  |  |  | 7 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  | 1 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

|  |
| --- |
| **AON (Activity On Node** |
| **A** | **PA** | **T** |  |  |  |  |  |  |  |
| 1 | -- | 5 |  | 1=5 |  | 3=2 |  | 6=3 |  |
| 2 | -- | 2 |  |  |  |  |  |  |  |
| 3 | 1 | 2 |  | 2=2 |  | 4=3 |  | 7=1 |  |
| 4 | 2 | 3 |  |  |  |  |  |  |  |
| 5 | 2 | 3 |  |  |  | 5=3 |  |  |  |
| 6 | 3,4 | 3 |  |  |  |  |  |  |  |
| 7 | 3,4,5 | 1 |  |  |  |  |  |  |  |

**Develop Schedule.** “Determine the time parameters of each activity.”

 Project Network 🡪 Analysis (Gantt, CPM, PERT) 🡪 Project Schedule

**Gantt Chart**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **A** | **PA** | **T** |  |  |  |  |  |  |  |  |  |  |  |
| 1 | -- | 5 |  | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |  |  |
| 2 | -- | 2 |  | 🡪 | 🡪 |  |  |  |  |  |  |  |  |
| 3 | 1 | 2 |  |  |  |  |  |  | 🡪 | 🡪 |  |  |  |
| 4 | 2 | 3 |  |  |  | 🡪 | 🡪 | 🡪 |  |  |  |  |  |
| 5 | 2 | 3 |  |  |  | 🡪 | 🡪 | 🡪 |  |  |  |  |  |
| 6 | 3,4 | 3 |  |  |  |  |  |  |  |  | 🡪 | 🡪 | 🡪 |
| 7 | 3,4,5 | 1 |  |  |  |  |  |  |  |  | 🡪 |  |  |

|  |
| --- |
| **All times are interpreted as “the end of a time period”.** |

|  |
| --- |
| **Gantt Chart** |
| ES=Early StartEF=Early FinishTOC=Time of Completion | All times are interpreted as‘the end of a time period’ |

|  |
| --- |
| **Critical Path Method**. (CPM) |
| ES=Early StartEF=Early FinishLS=Late StartLF=Late FinishSlack= LF–EF=LS–ES | Slack=Total Slack=Total FloatA Critical Activity is an activity with zero slack. All critical activities define the Critical Path, CP |

|  |
| --- |
| **Program Evaluation and Review Technique (PERT)** |
| t1=Optimistic Timet2=Most Likely Timet3=Pessimistic Time | E[Duration]=(t1+4t2+t3)/6 V[Duration]=[(t3–t1)/6]2TOC=Time of CompletionTOC~N( =E(TOC), 2=V(TOC) ) | P[TOC<T]=  |

**Critical Path Method (CPM)**

|  |
| --- |
| **AOA (Activity On Arrow)** |
| **A** | **PA** | **T** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | -- | 5 |  |  |  |  | 1 |  |  |  |  | 3 |  |  |  |  |  | 6 |  |  |  |  |
| 2 | -- | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 | 1 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | 2 | 3 |  |  |  |  | 2 |  |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |
| 5 | 2 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 | 3,4 | 3 |  |  |  |  |  |  |  |  |  | 5 |  |  |  |  |  | 4 |  |  |  |  |
| 7 | 3,4,5 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**CPM Algorithm**

|  |
| --- |
| **-----Steps-----** |
| Determine ES | Determine LF |
| Step 1. For no PA, ES=0Step 2. For all activities, EF=ES+TStep 3. For one PA, ES=EF of PA.Step 4. For more than one PA, ES=Max(EF of all PA). | Step 1. For no SA, LF=TOCStep 2. For all activities, LS= LF–T.Step 3. For one SA, LF=LS of SA.Step 4. For more than one SA, LF=Min(LS of all SA). |
| Slack=LF–EF=LS–ES |

Start with activities with no predecessors.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **A** | **Determination of ES** | **PA** | **ES** | **T** | **EF=ES+T** | **A** |
| 1 | ES=0 for no Predecessor | -- | 0 | 5 | 5 | 1 |
| 2 | ES=0 for no Predecessor | -- | 0 | 2 | 2 | 2 |
| 3 | ES=EF of Predecessor | 1 | 5 | 2 | 7 | 3 |
| 4 | ES=EF of Predecessor | 2 | 2 | 3 | 5 | 4 |
| 5 | ES=EF of Predecessor | 2 | 2 | 3 | 5 | 5 |
| 6 | ES=Max(EF of Predecessors) | 3,4 | 7 | 3 | 10 | 6 |
| 7 | ES=Max(EF of Predecessors) | 3,4,5 | 7 | 1 | 8 | 7 |
|  | TOC=Max(EF). Time of Completion (TOC) |  |  |  | 10 |  |

Invert predecessors to determine successors. SA=Successor Activity.

Start with activities with no successors.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **A** | **PA** | **Determination of LF** | **SA** | **LF** | **T** | **LS=LF**–**T** | **A** |  | **Slack****(LF**–**EF)** |
| 1 | -- | LF=LS of Successor | 3 | 5 | 5 | 0 | 1 |  | 0 = 5 – 5 |
| 2 | -- | LF=Min(LS of Successors) | 4,5 | 4 | 2 | 2 | 2 |  | 2 = 4 – 2 |
| 3 | 1 | LF=Min(LS of Successors) | 6,7 | 7 | 2 | 5 | 3 |  | 0 = 7 – 7 |
| 4 | 2 | LF=Min(LS of Successors) | 6,7 | 7 | 3 | 4 | 4 |  | 2 = 7 – 5 |
| 5 | 2 | LF=LS of Successor | 7 | 9 | 3 | 6 | 5 |  | 4 = 9 – 5 |
| 6 | 3,4 | LF=TOC for no Successors | -- | 10 | 3 | 7 | 6 |  | 0 = 10 – 10 |
| 7 | 3,4,5 | LF=TOC for no Successors | -- | 10 | 1 | 9 | 7 |  | 2 = 10 – 8 |

A Critical Activity has zero slack. All Critical Activities define the Critical Path (CP)

**Critical Path**

**Gantt Chart**

 0 1 2 3 4 5 6 7 8 9 10

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **A** | **PA** | **T** | **Slack** |  |  |  |  |  |  |  |  |  |  |  |
| 1 | -- | 5 | 0 |  | **🡺** | **🡺** | **🡺** | **🡺** | **🡺** |  |  |  |  |  |
| 2 | -- | 2 | 2 |  | **🡪** | **🡪** |  |  |  |  |  |  |  |  |
| 3 | 1 | 2 | 0 |  |  |  |  |  |  | **🡺** | **🡺** |  |  |  |
| 4 | 2 | 3 | 2 |  |  |  | **🡪** | **🡪** | **🡪** |  |  |  |  |  |
| 5 | 2 | 3 | 4 |  |  |  | **🡪** | **🡪** | **🡪** |  |  |  |  |  |
| 6 | 3,4 | 3 | 0 |  |  |  |  |  |  |  |  | **🡺** | **🡺** | **🡺** |
| 7 | 3,4,5 | 1 | 2 |  |  |  |  |  |  |  |  | **🡪** |  |  |

|  |
| --- |
| **AOA (Activity On Arrow)** |
| **A** | **PA** | **T** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | -- | 5 |  |  |  |  | 1 |  |  |  |  | 3 |  |  |  |  |  | 6 |  |  |  |  |
| 2 | -- | 2 |  |  |  |  | 5 |  |  |  |  | 2 |  |  |  |  |  | 3 |  |  |  |  |
| 3 | 1 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | 2 | 3 |  |  |  |  | 2 |  |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |
| 5 | 2 | 3 |  |  |  |  | 2 |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |
| 6 | 3,4 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 7 | 3,4,5 | 1 |  |  |  |  |  |  |  |  |  | 5 |  |  |  |  |  | 7 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  | 1 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

|  |
| --- |
| **AON (Activity On Node** |
| **A** | **PA** | **T** |  |  |  |  |  |  |  |
| 1 | -- | 5 |  | 1=5 |  | 3=2 |  | 6=3 |  |
| 2 | -- | 2 |  |  |  |  |  |  |  |
| 3 | 1 | 2 |  | 2=2 |  | 4=3 |  | 7=1 |  |
| 4 | 2 | 3 |  |  |  |  |  |  |  |
| 5 | 2 | 3 |  |  |  | 5=3 |  |  |  |
| 6 | 3,4 | 3 |  |  |  |  |  |  |  |
| 7 | 3,4,5 | 1 |  |  |  |  |  |  |  |

**Network, Durations, and Paths through the Network**

|  |
| --- |
| **AOA (Activity On Arrow)** |
| **A** | **PA** | **T** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | -- | 5 |  |  |  |  | 1 |  |  |  |  | 3 |  |  |  |  |  | 6 |  |  |  |  |
| 2 | -- | 2 |  |  |  |  | 5 |  |  |  |  | 2 |  |  |  |  |  | 3 |  |  |  |  |
| 3 | 1 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | 2 | 3 |  |  |  |  | 2 |  |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |
| 5 | 2 | 3 |  |  |  |  | 2 |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |
| 6 | 3,4 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 7 | 3,4,5 | 1 |  |  |  |  |  |  |  |  |  | 5 |  |  |  |  |  | 7 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  | 1 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

|  |
| --- |
| **AON (Activity On Node** |
| **A** | **PA** | **T** |  |  |  |  |  |  |  |
| 1 | -- | 5 |  | 1=5 |  | 3=2 |  | 6=3 |  |
| 2 | -- | 2 |  |  |  |  |  |  |  |
| 3 | 1 | 2 |  | 2=2 |  | 4=3 |  | 7=1 |  |
| 4 | 2 | 3 |  |  |  |  |  |  |  |
| 5 | 2 | 3 |  |  |  | 5=3 |  |  |  |
| 6 | 3,4 | 3 |  |  |  |  |  |  |  |
| 7 | 3,4,5 | 1 |  |  |  |  |  |  |  |

**Paths through the network:**

|  |  |  |
| --- | --- | --- |
|  | Paths: | Time of Completion(TOC) |
| **1** | **1-3-6** | **5+2+3=10 🡨Max TOC = Critical Path** |
| 2 | 1-3-7 | 5+2+1=8 |
| 3 | 2-4-6 | 2+3+3=8 |
| 4 | 2-4-7 | 2+3+1=6 |
| 5 | 2-5-7 | 2+3+1=6 |

**Example: Building a House**

|  |  |
| --- | --- |
| A=ActivityPA=Predecessor ActivityT=Duration | ES=Early StartEF=Early Finish |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Activity** | **PA** | **T** |  | **Paths** |
| A. Excavation | --- | 5 |  | A-B-H-M-N=5+2+9+7+8=31 |
| B. Pour foundation | A | 2 |  | A-B-D-G-M-N=5+2+12+5+7+8=39 |
| C. Outside plumbing | A | 6 |  | A-B-D-G-J-K-L=5+2+12+5+2+3+9=38 |
| D. Framing | B | 12 |  | A-B-D-F-K-L=5+2+12+9+3+9=40 |
| E. Inside plumbing | D | 10 |  | A-B-D-E-I-K-L=5+2+12+10+1+3+9=42 |
| F. Wiring | D | 9 |  | A-C-I-K-L=5+6+1+3+9=24 |
| G. Roofing | D | 5 |  |  |
| H. Brickwork | B | 9 |  |  |
| I. Plumbing inspection | C,E | 1 |  |  |
| J. Shingling | G | 2 |  |  |
| K. Cover walls | F,I,J | 3 |  |  |
| L. Interior finishing | K | 9 |  |  |
| M. Exterior finishing | H,G | 7 |  |  |
| N. Landscaping | M | 8 |  |  |

**AON (with Critical Path)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **A** |  |  | **B** |  |  |  |  |  | H |  |  |  |  |  | M |  |  | N |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | **D** |  |  | G |  |  | J |  |  | **K** |  |  | **L** |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | F |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | **E** |  |  | **I** |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | C |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Example: Building a House**

|  |  |
| --- | --- |
| A=ActivityPA=Predecessor ActivityT=Duration | ES=Early StartEF=Early Finish |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Activity** | **PA** | **T** |  | **Paths** |
| A. Excavation | --- | 5 |  | A-B-H-M-N=5+2+9+7+8=31 |
| B. Pour foundation | A | 2 |  | A-B-D-G-M-N=5+2+12+5+7+8=39 |
| C. Outside plumbing | A | 6 |  | A-B-D-G-J-K-L=5+2+12+5+2+3+9=38 |
| D. Framing | B | 12 |  | A-B-D-F-K-L=5+2+12+9+3+9=40 |
| E. Inside plumbing | D | 10 |  | A-B-D-E-I-K-L=5+2+12+10+1+3+9=42 |
| F. Wiring | D | 9 |  | A-C-I-K-L=5+6+1+3+9=24 |
| G. Roofing | D | 5 |  |  |
| H. Brickwork | B | 9 |  |  |
| I. Plumbing inspection | C,E | 1 |  |  |
| J. Shingling | G | 2 |  |  |
| K. Cover walls | F,I,J | 3 |  |  |
| L. Interior finishing | K | 9 |  |  |
| M. Exterior finishing | H,G | 7 |  |  |
| N. Landscaping | M | 8 |  |  |

**Gantt Chart (with Critical Path)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |  |  |  |  |
| A | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| B |  |  |  |  |  | 🡪 | 🡪 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| C |  |  |  |  |  | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |  |  |  |  |  |  |  |  |  |
| D |  |  |  |  |  |  |  | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |  |
| H |  |  |  |  |  |  |  | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |  |  |  |  |
|  | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 |
| E | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| F | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| I |  |  |  |  |  |  |  |  |  |  | 🡪 |  |  |  |  |  |  |  |  |  |  |  |  |
| J |  |  |  |  |  | 🡪 | 🡪 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| K |  |  |  |  |  |  |  |  |  |  |  | 🡪 | 🡪 | 🡪 |  |  |  |  |  |  |  |  |  |
| L |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |
| M |  |  |  |  |  | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |  |  |  |  |  |  |  |  |
| N |  |  |  |  |  |  |  |  |  |  |  |  | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 | 🡪 |  |  |  |

**PERT: Program Evaluation and Review Technique**

|  |
| --- |
| **AON (Activity On Node** |
| **A** | **PA** | **T** |  |  |  |  |  |  |  |
| 1 | -- | 5 |  | 1 |  | 3 |  | 6 |  |
| 2 | -- | 2 |  |  |  |  |  |  |  |
| 3 | 1 | 2 |  | 2 |  | 4 |  | 7 |  |
| 4 | 2 | 3 |  |  |  |  |  |  |  |
| 5 | 2 | 3 |  |  |  | 5 |  |  |  |
| 6 | 3,4 | 3 |  |  |  |  |  |  |  |
| 7 | 3,4,5 | 1 |  |  |  |  |  |  |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **A** | **t1=Optimistic** | **t2=Most Likely** | **t3=Pessimistic** | **E[Duration]****=(t1+4t2+t3)/6** | **V[Duration]****=[(t3–t1)/6]2** |
| 1 | 4.1 | 5 | 7.1 | 5.2 | 0.25 |
| 2 | 1.4 | 2 | 3.2 | 2.1 | 0.09 |
| 3 | 0.8 | 2 | 6.8 | 2.6 | 1.00 |
| 4 | 2.1 | 3 | 4.5 | 3.1 | 0.16 |
| 5 | 0.6 | 3 | 4.2 | 2.8 | 0.36 |
| 6 | 1.2 | 3 | 7.2 | 3.4 | 1.00 |
| 7 | 1 | 1 | 1 | 1 | 0 |

For example, for activity ‘1’: E[D] = ( 4.1 + 4(5) + 7.1 )/6 = 5.2

 V[D] = [ ( 7.1 – 4.1 )/6 ]2  = 0.25

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **┌** | **CPM** | **┐** |  |  |  |
| **A** | **E[D]** | **V[D]** | **Slack** | **Critical Path** | **E[D]** | **V[D]** |
| 1 | 5.2 | 0.25 | 0 | Yes | 5.2 | 0.25 |
| 2 | 2.1 | 0.09 | 2.6 |  |  |  |
| 3 | 2.6 | 1.00 | 0 | Yes | 2.6 | 1.00 |
| 4 | 3.1 | 0.16 | 2.6 |  |  |  |
| 5 | 2.8 | 0.36 | 5.3 |  |  |  |
| 6 | 3.4 | 1.00 | 0 | Yes | 3.4 | 1.00 |
| 7 | 1 | 0 | 2.4 |  |  |  |
|  |  |  |  | Sum | 11.2 | 2.25 |
|  |  |  |  |  | E[TOC] | V[TOC] |

Assume TOC follows a normal distribution with mean 11.2 and variance 2.25 which implies standard deviation is 1.5 (square root of 2.25). Then, for a fixed value of T,

P[TOC < T]=P[Z < ( T – 11.2 )/1.5 ]= .

Let Z=(T–11.2)/1.5 be the standard normal random variate.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **T** | **Z** | **P[TOC<T]= ** |  | In Excel, use function, NORMSDIST(Z). |
| 10 | –0.8 | 0.212 |  | 0.2119=NORMSDIST(–0.8) |
| 11 | –0.133 | 0.447 |  | 0.4470=NORMSDIST(–0.133) |
| 12 | +0.533 | 0.703 |  | 0.7031=NORMSDIST(+0.533) |
| 13 | +1.2 | 0.885 |  | 0.8849=NORMSDIST(+1.2) |
| 14 | +1.867 | 0.969 |  | 0.9690=NORMSDIST(+1.867) |

**Control Schedule.** “Manage the progress and changes in the project schedule.”

 Project Schedule 🡪 Schedule Change Control System 🡪 Schedule Updates

[Monitoring, Crashing, Fast Tracking, Resource Allocation]

|  |
| --- |
| **Monitoring**“Monitoring” can include various elements such as monitoring the probabilities of critical and non-critical activities in PERT, identifying and managing parallel paths in the critical path occurring in CPM and PERT, and including cost, labor, or other resources in addition to time in Gantt, CPM, or PERT.  |
| **Crashing**“Crash” a project is to reduce the time of completion of a project. “Crashing” a project is accomplished by “crashing” one or more activities usually according to a set of criteria or priorities. |
| **Fast Tracking**“Fast tracking” modifies work to reduce the time of an activity. As an example, the work could be changed from a series of tasks within an activity to tasks done in parallel. This can be done by changing such elements as sequencing relationships or activity definitions. |
| **Critical Chain**“Critical chain” approach can be described as combining CPM with resource constraints, duration uncertainties, and buffer management.  |
| **Resource Leveling (Smoothing)**Resource leveling can be defined as the reallocation of slack in activities to manage fluctuations in resource requirements. |