

Introduction to Engineering Planning

Engineering Planning

Civil Engineering Department
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Advice for the course…

'I hear and I forget.
I see and I remember.
I do and I understand.'

Chinese proverb
(Chinese Confucian philosopher Xunzi)

2

Advice for the course…

'I hear and I forget.
I see and I remember.
I do and I understand.'
it the right way
Chinese proverb **
(Chinese Confucian philosopher Xunzi)

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What is Engineering Planning?

- *Engineering planning* is a fundamental and challenging activity in the design, management, and execution of engineering projects.

Engineering planning is the process of modeling the future of engineering projects by determining "*what*" is going to be done, "*how*," "*where*," and by "*whom*".

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Why is Planning Important in Civil Engineering Projects?

- **TIME**: Civil engineering projects typically take many months to a number of years to complete design and construction
- **COST**: Civil engineering projects require intensive capital investments
- Complexity, quality, safety, sustainability, etc.

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Need for Planning: Mega-Projects

- According to Flyvbjerg et al. (2003), of mega-projects go over budget.
- Why?
  - *Underestimation of construction costs*
  - *Overestimation of future benefits*

➔ Planning Failures!

Source: Flyvbjerg, B., Skamrisholm, M.K., and Buhl, S.L. (2003). "How common and how large are cost overruns in transport infrastructure projects?" *Transport Reviews*, Taylor & Francis Online, 23(1), 71-88.

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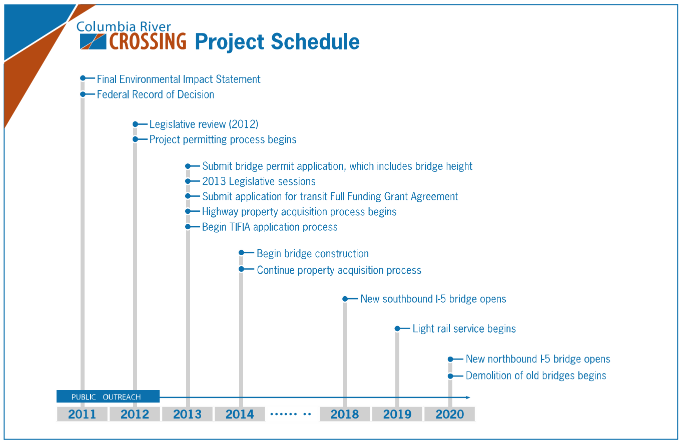
Case 1: Columbia River Crossing

- Many years of preparation



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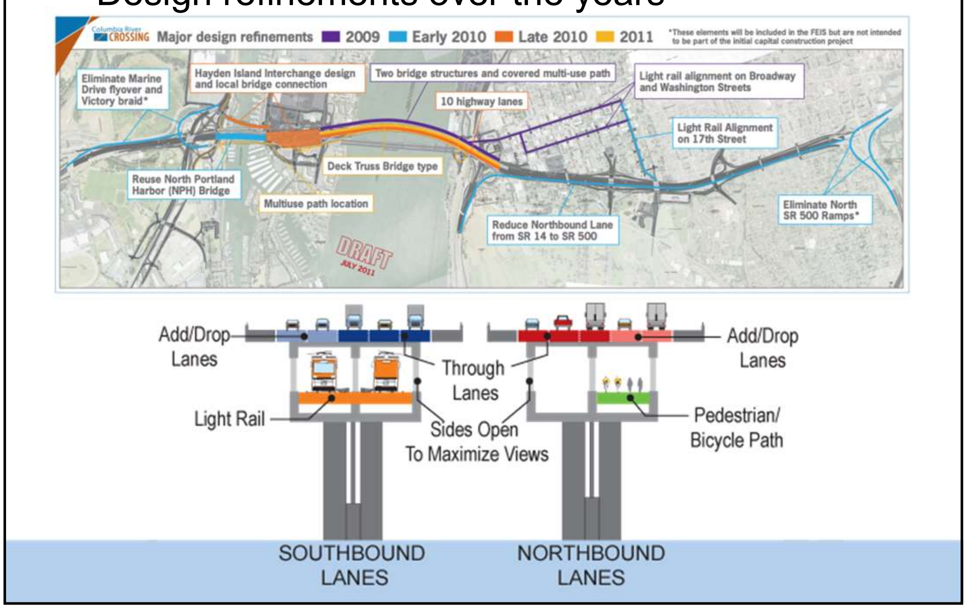
Case 1: Columbia River Crossing

- Design refinements over the years



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Case 2: TVA's Nuclear Generation Expansion

- Tennessee Valley Authority (TVA) nuclear generation expansion project.
- Scheduled for completion in 2012 at a cost of $2.5 billion.
- It required an additional $1.5–2 billion and 3 more years to complete.
- According to the TVA, the principal causes of the overruns were:
  - "deficiencies in project set-up," and
  - "ineffective management oversight."

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Case 3: Boston's Big Dig

- 3.5-mile long tunnel through downtown Boston
- Initial plan:
  - Completed in 1998 at an estimated cost of $2.8 billion
- As-built:
  - Completed in 2007 at a cost of over $14.6 billion

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Case 4: Oregon Highway Projects

Some of the current large ODOT projects will cost more than twice ODOT's projected cost.

- The seven-mile long rebuild of US-20 between Corvallis and Newport was estimated to cost $130 million, but still incomplete and $397 million projected.
- In May 2013, ODOT took over the project from the GC and destroyed newly-built bridge structures.

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Engineering Planning

- Developing the plan is a critical task in project management for delivering what a customer wants:
  - on <u>budget</u>, on <u>time</u>, with the desired <u>quality</u>, and <u>safely</u>.
- ***Inadequate planning can break the project!***

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Nature of Engineering Projects

- How does it all start?
  - An idea or need
- Private and public sectors
  - Funding source
  - Stakeholders
  - Motivation
  - Impacts

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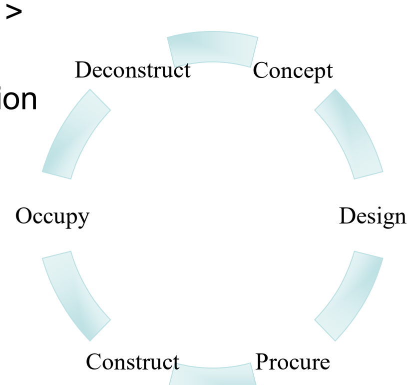
The Facility Lifecycle

- Lifecycle phases of a project:
  - Initiation > design > procurement > construction > operation > end of life
  - Planning, execution, operation



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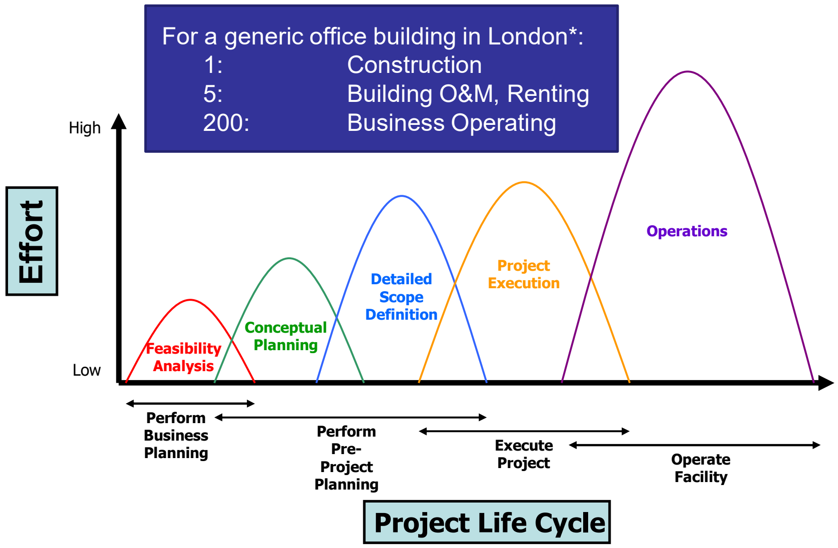
Facility Lifecycle Effort



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Facility Development

- Broken into customary pieces, each of which forms a “project”:
  - Program managers produce facility programs
  - Designers produce plans and specifications
  - Constructors produce the physical facility
  - Commissioning agents produce a working facility

…and each of these projects has many sub-projects.

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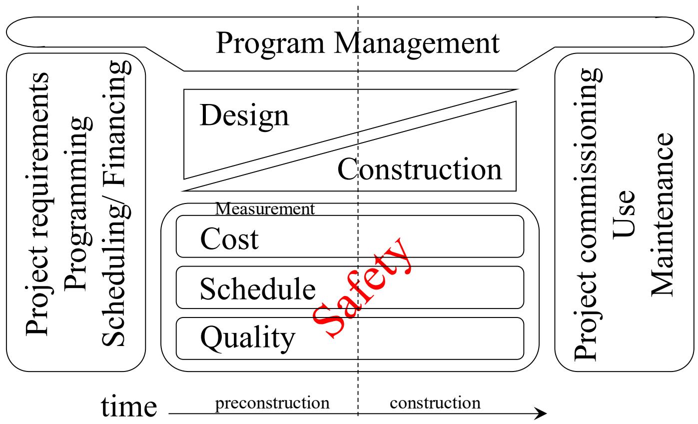
Facility Development



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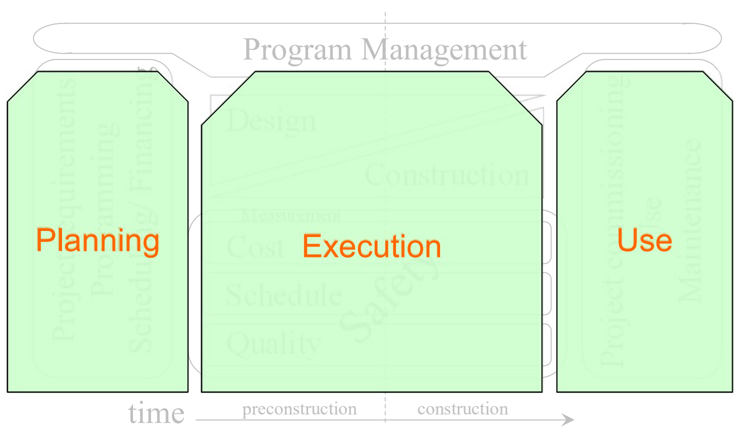
The Development Process



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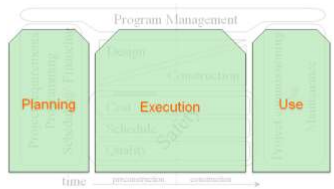
The Development Process



- Planning:
  - Documenting the goals and the process for the execution
- Execution:
  - Acquiring and managing the resources and measuring against the goals
- Use:
  - Passing the result of the execution on to the next party in the chain for their value-added activity

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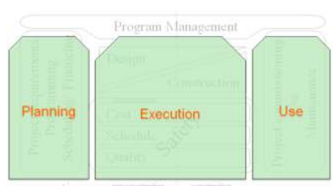
The Development Process



- The project process works at any level:
  - At the level of the larger client project
  - For the design process and the construction process
  - In fact, for anything definable as a “project”

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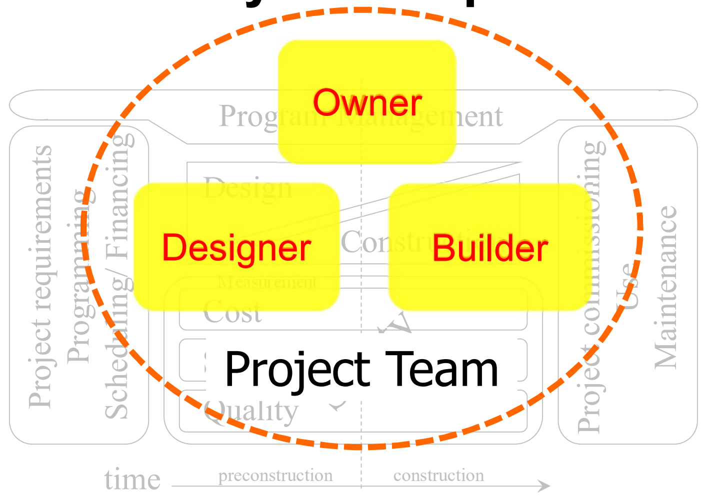
Facility Development



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What is project management?

- Planning the project execution
  - Modeling the execution process—scope development, costs, and schedule
  - Controlling and communicating the implementation of the plan
- Executing the plan
  - Developing the scope, measuring cost and time
  - Management of time, equipment, tasks, materials, people, money
- Transferring the product to the client for its use
  - A designer produces plans and specifications
  - A builder produces a constructed facility

Applies at every stage of a project.
Other goals may be measured as well.

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Planning and Scheduling

- There is a significant difference between "*planning*" and "*scheduling*"
  - Often used interchangeably — which is a misuse
- Scheduling is one component of planning
- *Planning* can be thought of as:
  - Determining "*what*" is going to be done, "*how*," "*where*," and by "*whom*"
- *Scheduling* consists of:
  - Integrating the plan with a calendar or specific time frame
  - Determining "*when*" something will be done

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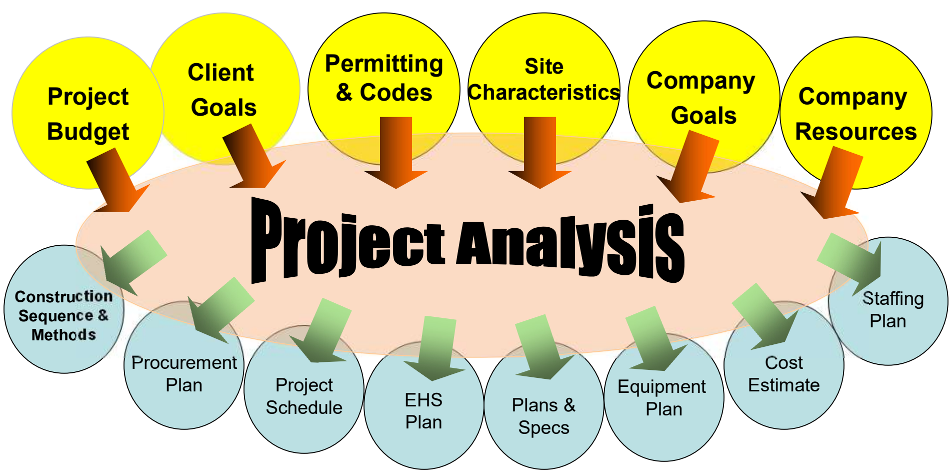
Engineering Planning



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Engineering Planning

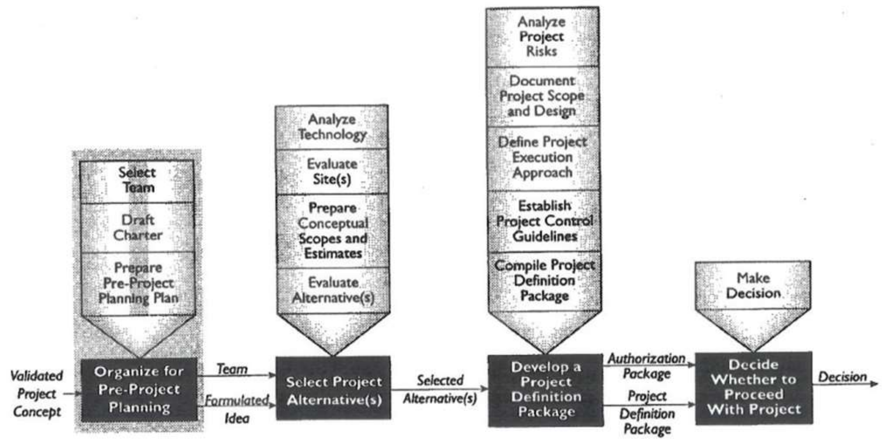

Figure 1.5 *Pre-Project Planning*

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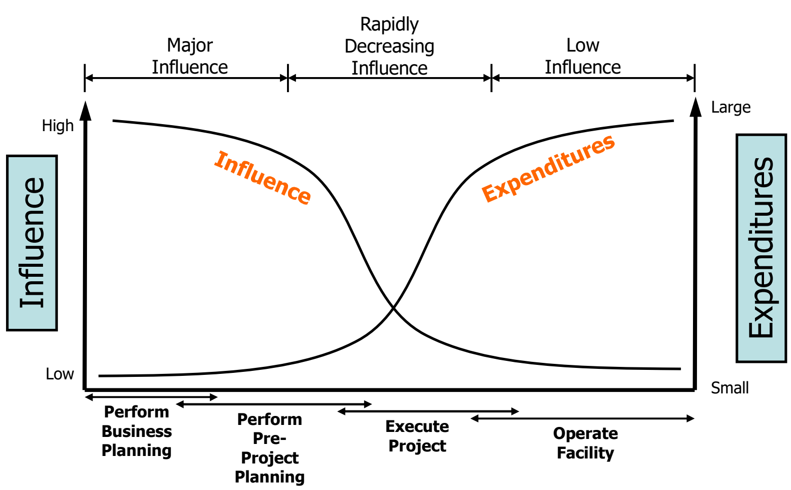
Dynamics of Influence and Expenditures: Importance of Early Planning



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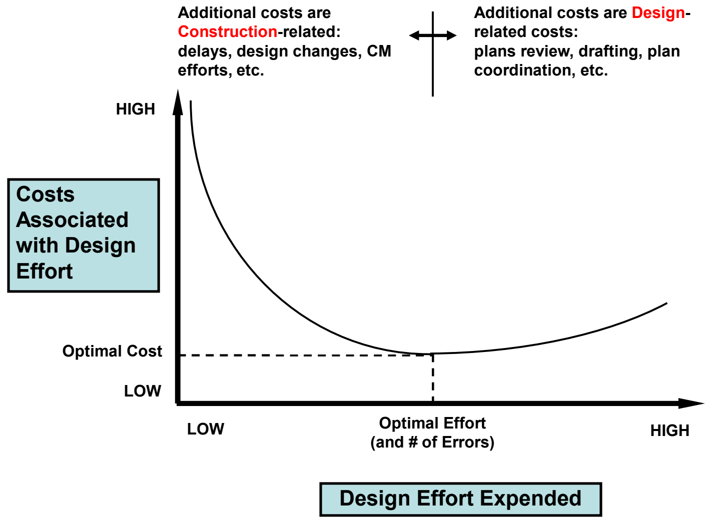
Design Effort vs. Cost



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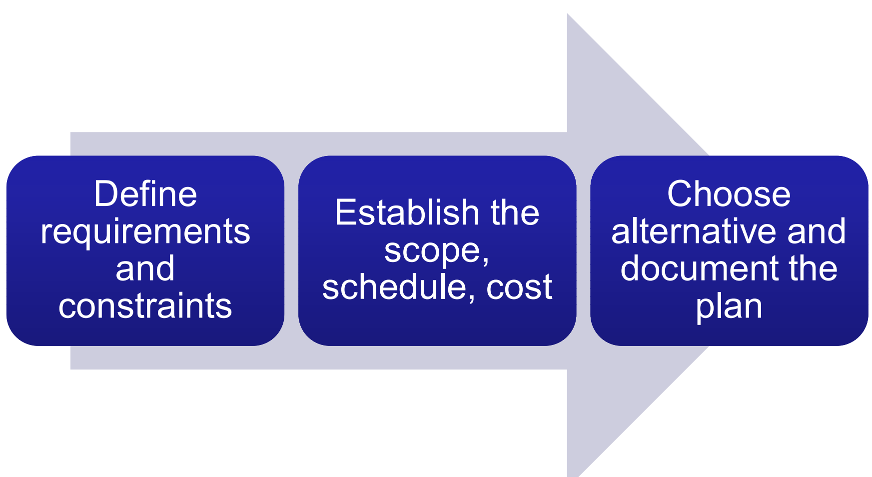
Steps of Engineering Planning



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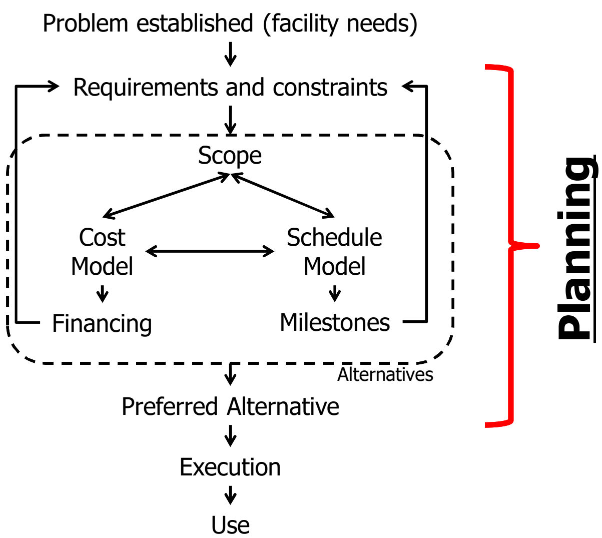
Engineering Planning in a Nutshell



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Planning – Step 1

Define requirements and constraints

1) Identify the problem
   - Scope of project must be clearly defined!

2) Define the goal(s) and objective(s)
   - Should be measurable and specific

3) Gather relevant data
   - "Without data, you're just another person with an opinion."
   - Should be directly related to the goals and objectives, and be realistic
   - Identify the project constraints

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Planning – Step 2

Establish the scope, schedule, and cost

4) Identify alternative solutions
   - Evaluate time and cost
   - Include “do nothing” alternative
   - Only alternatives may be “yes” or “no”

5) Determine selection criteria
   - Often financial in nature, but not always
   - Should be related to priority goals and objectives

6) Analyze alternative solutions
   - In terms of selection criteria
   - Use models, predictions, and the data from Step 3

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Planning – Step 3

Choose alternative and document the plan

7) Establish preferred alternative
   - Choose the best alternative based on selection criteria
   - Should most effectively meet goals and objectives

8) Develop and document plan
   - Communicate the plan to all parties

9) Monitor and evaluate results of execution phase
   - Evaluate results against measurables; often schedule and financial in nature
   - Collect data and compare with goals, previous data, models, and analysis
   - Act based on data and evaluations—revise plan if required

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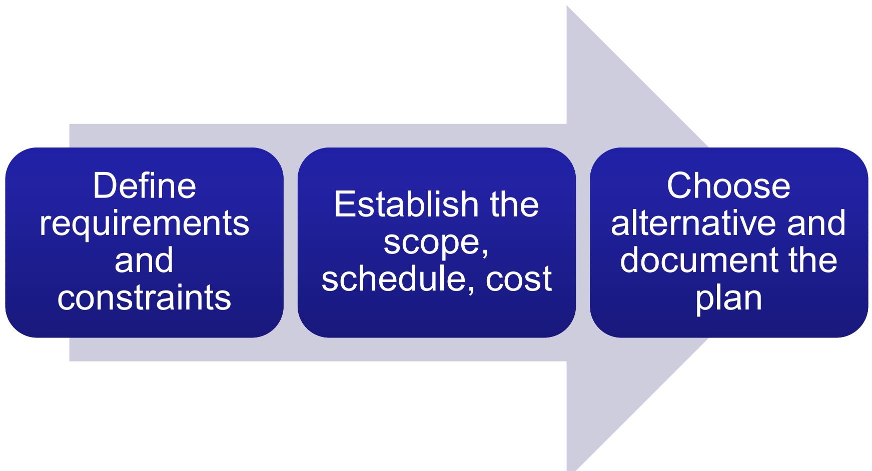
Class Discussion: Choose a project

Create a plan for the project



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Work Breakdown Structure (WBS)

- A **logical hierarchy describing the work elements of a project** used for a number of related management control activities.

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Work Breakdown Structure (WBS)

- The WBS will continue to expand as the project develops, often beginning with dozens of items and eventually reaching hundreds or thousand of items.

A high level for a building WBS may be:

1. Earthwork
2. Foundations
3. Structure
4. Enclosure
5. Rough MEP
6. Partitions
7. Interior Finishes
8. Paving and Landscape

A high level for a transit WBS may be:

1. Guideway
2. Stations
3. Support Facilities
4. Sitework
5. Systems
6. Right of Way
7. Vehicles
8. Professional Services

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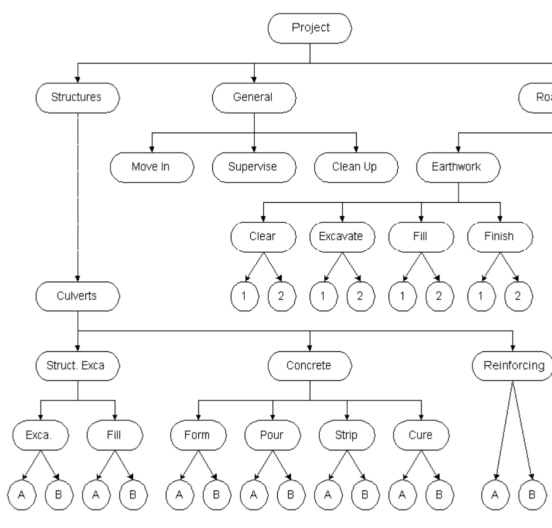
Work Breakdown Structure (WBS)



Illustrative WBS for a Roadway Project (source: pmbook.ce.cmu.edu)

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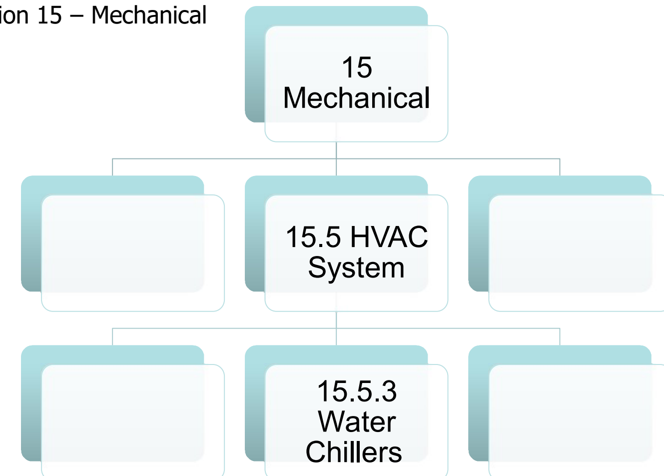
Three Levels of WBS for buildings based on CSI Master Format

For example: Section 15 – Mechanical

Top Level

Second Level

Third Level



CSI: The Construction Specifications Institute

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Work Breakdown Structure Summary

- Important for comparison among alternatives
- Start with large work systems then divide into smaller systems or items
- Identify all tasks required for a project, but keep the detail appropriate for the phase
- Keep estimating and scheduling in mind
- *Not a schedule—don't try to sequence yet*

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Scheduling

- Planning can be thought of as determining "*what*" is going to be done, "*how*," "*where*," and by "*whom*"
- Then, scheduling is to determine "*when*" specific tasks are to be performed

Scheduling consists of determining the time needed for each of the planned tasks and the overall length of the project schedule

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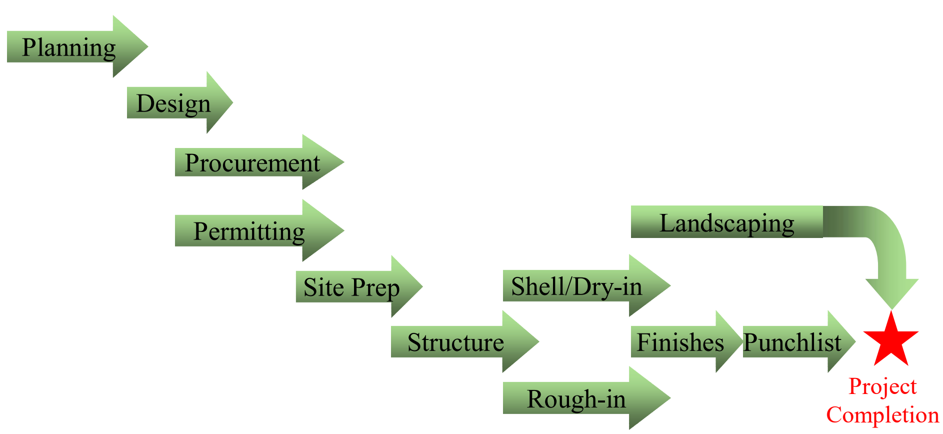
Project Schedule



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Types of Project Schedules

- Bar Chart (Gantt Chart)
- Critical Path Method (CPM):
  - Network scheduling method
- "Alternative" Scheduling Techniques

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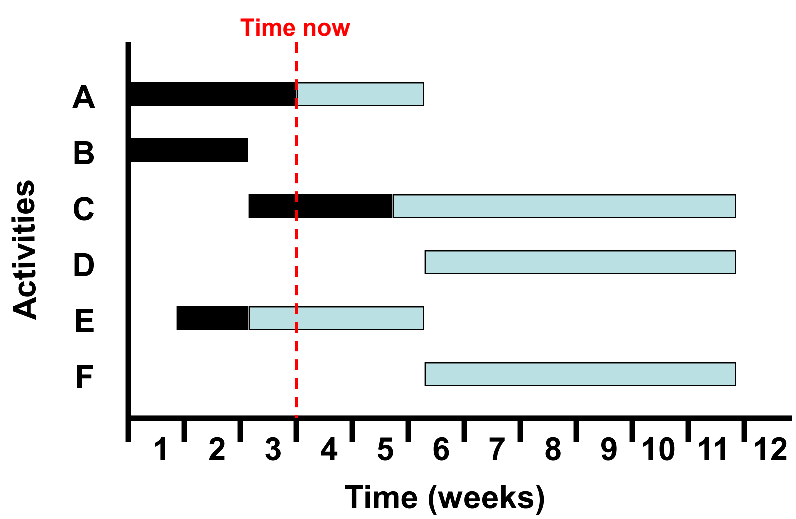
Bar Chart (Gantt Chart)



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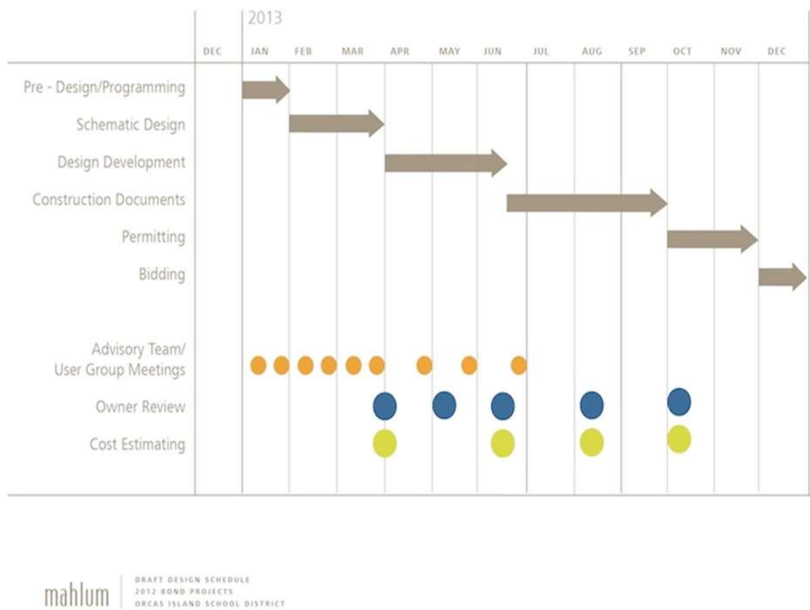

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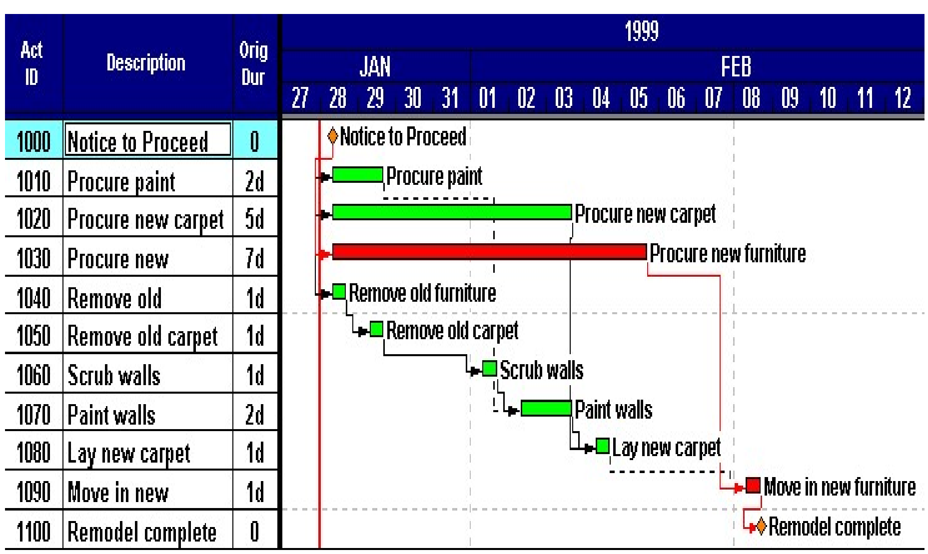
Bar Chart – Example



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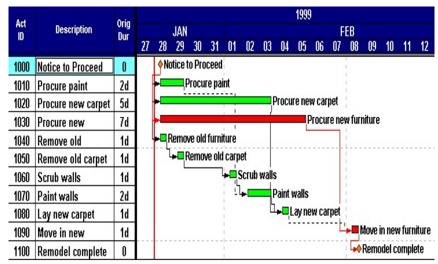
Bar Chart (Gantt Chart)

- Advantages:
  - Graphical representation
  - Easy to read and quickly grasped
  - No extensive training needed
  - Simple way to schedule small projects
  - Summary display of more detailed projects
  - Good for upper management, subs, workers



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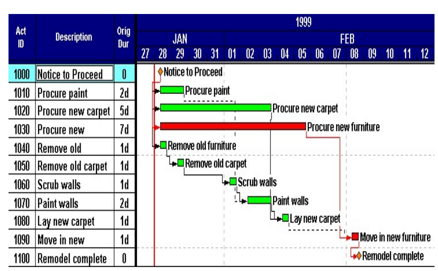
Bar Chart (Gantt Chart)

- Disadvantages:
  - Activity dependencies not clearly shown
  - Hard to relate individual activity delays to overall project completion
  - Difficult to maintain for large, complex projects



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Critical Path Method (CPM)

- Developed in the late 1950's.
- Uses assigned activity durations and constraints to calculate schedule characteristics.
- Types:
  - Arrow diagram method (ADM)
  - Precedence diagram method (PDM)
- Can incorporate statistical calculations (PERT).

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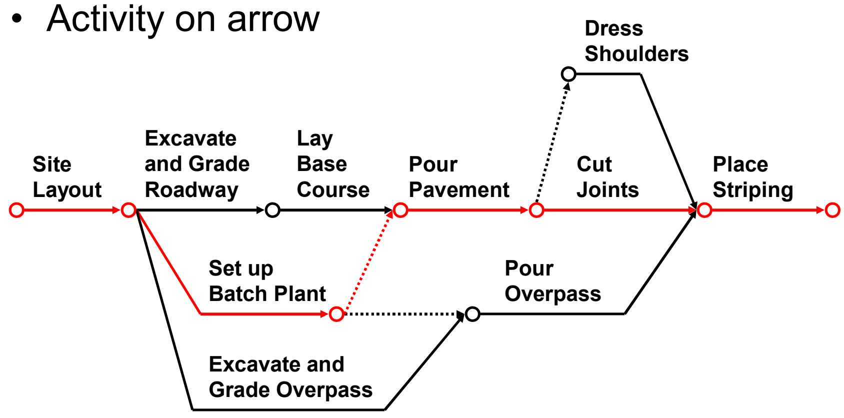
CPM – Arrow Diagram Method (ADM)

- Activity on arrow



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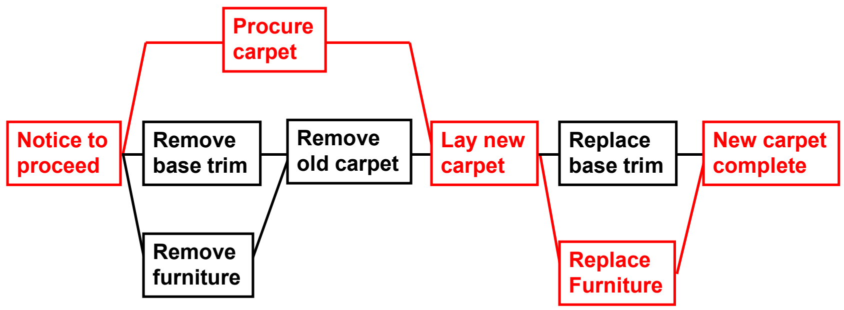
CPM – Precedence Diagram Method (PDM)

- Activity on node



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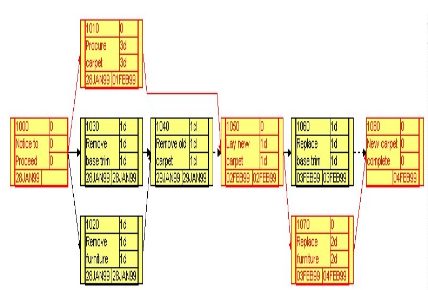
Critical Path Method (CPM)

- Advantages:
  - Identifies critical activities
  - Determines critical path and shortest completion time
  - Shows "flexibility" in timing (float) of non-critical activities
  - Good for any size project



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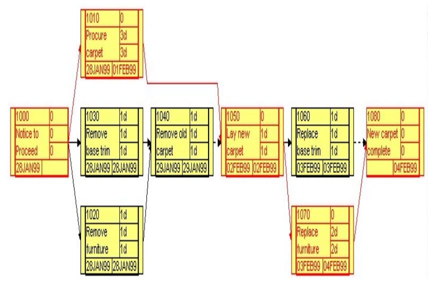
Critical Path Method (CPM)

- Disadvantages:
  - Complex schedules more difficult to grasp
  - Not supported by all computer scheduling programs
  - Printed schedules difficult to work with



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"Alternative" Scheduling Techniques

- Short-interval schedule
- Matrix schedule
- Line of balance (linear) schedule
- "S" curve schedule
- "Horse blanket" schedule

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Short Interval Schedule

Date														
Activity	Respon.	M	Tu	W	Th	F	S	S	M	Tu	W	Th	F	Comments
Main Bldg.														
Struct. Steel	STI													
West wing		Stair		Deck	Deck	Insp.								
East wing				Deliver Steel					Columns		Beams		Deck	
Conc. Deck	R-mix								Pour					Order 3 days early
Fireproofing	ISC	1st floor		2nd floor								3rd floor		
Sprinkler	Jackson			piping								piping		Verify by phone

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Matrix Schedule

Interior Design Projects	Interior Finishes	FF&E Package	Programming	Schematic Design	Specifications	Color Boards	Construction Documents	Shop Drawing Review	Construction Administration	Walk-thru, Punch List, Project Close out
Van H. Gilbert Architect, PC										
V. Sue Cleveland High School	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
Mesa Middle School	◆	◆	◆	◆	◆	◆	◆	◆	◆	
UNM Science & Math Learning Center	◆	◆		◆	◆	◆	◆	◆	◆	◆
UNM Centennial Engineering Building		◆				◆		◆	◆	◆
Mack Energy Corporate Office			◆	◆	◆		◆			
Jackson Middle School Gym (Renovation)			◆	◆	◆	◆	◆	◆	◆	
Garcia Honda/Infiniti/Kia/Subaru	◆									◆
CNM Westside Phase II	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
NM Military Institute	◆	◆						◆	◆	◆
NM State University – O'Donnell Hall (Renovation)	◆	◆	◆	◆	◆		◆	◆	◆	◆
Mountain States (Tenant Retrofit)	◆	◆	◆				◆		◆	◆
UNM Popejoy Hall (Renovation)	◆		◆	◆	◆		◆	◆	◆	◆
City of Albuquerque Water Treatment Plant Administration Building		◆				◆		◆	◆	◆
WHA Architecture & Planning										
IO Piazza (High-Rise Condominium Building)	◆		◆	◆	◆	◆	◆	◆	◆	◆
Joule (Mid-Rise Condominium Building)	◆		◆	◆	◆	◆	◆	◆	◆	◆
Bromptons at Cherrydale (Planned Community)	◆					◆		◆	◆	◆
Bromptons at Rosslyn & Courthouse (Townhomes)	◆				◆	◆		◆		◆
Bromptons at Lyon Park (Commercial Building)	◆		◆	◆	◆		◆	◆	◆	◆
Bergman Residence (Private Residence)	◆		◆	◆	◆					
Group Azure, LLC										
1020 Bridle Way (Private Residence)	◆	◆	◆	◆	◆		◆	◆	◆	◆
512 Van Ness (Corporate Apartments)	◆	◆								
Duvall Designs										
P. G. Journal Office Building (Renovation)	◆					◆				
Summerville Assisted Living Facility		◆								
Alexandria Hospital Nursery (Renovation)	◆					◆				
Vienna Family Dentistry (Renovation)	◆					◆				

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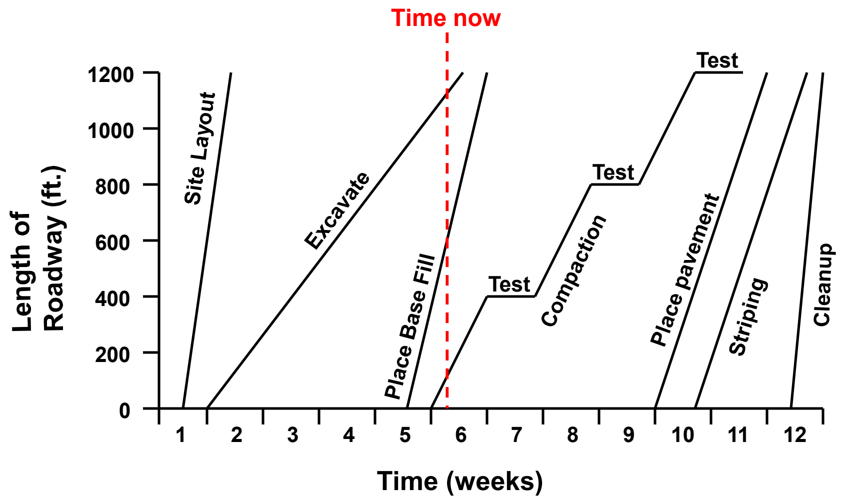
Line of Balance (Linear) Schedule



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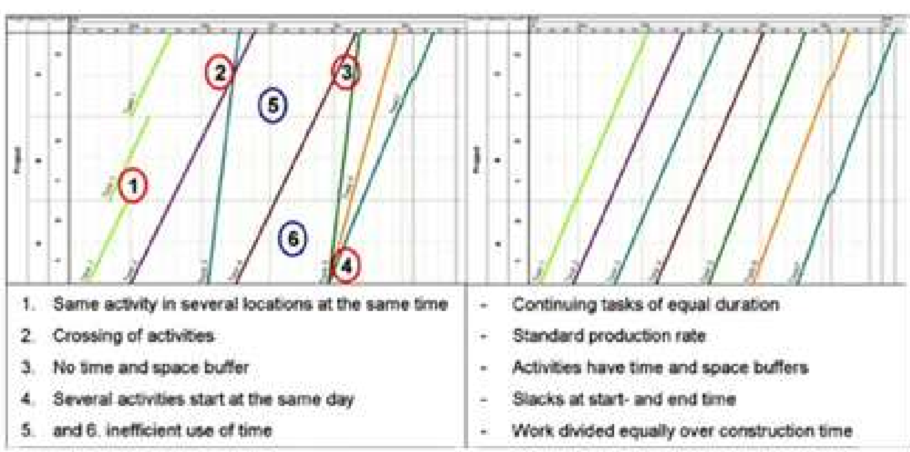
Olofsson, T., Jongeling, R. (2007)



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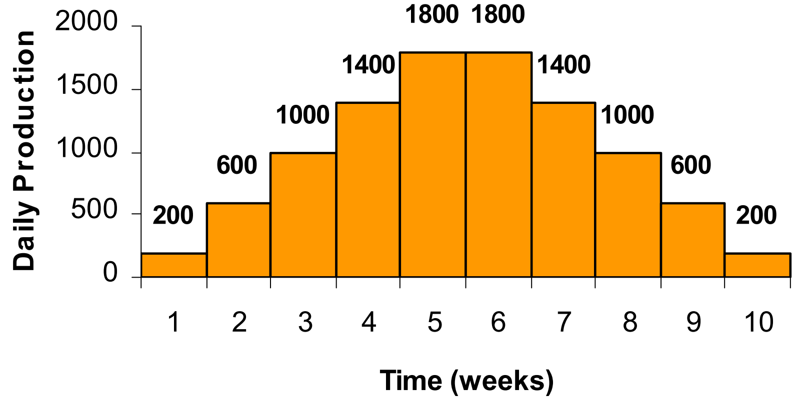
“S” Curve Schedule



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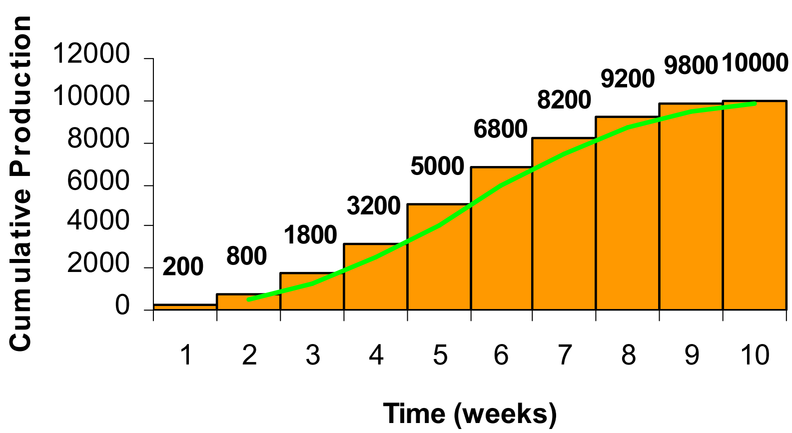
“S” Curve Schedule



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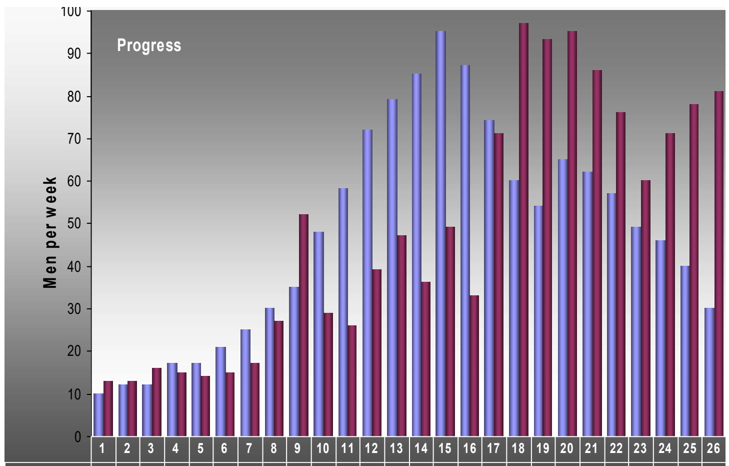
Production curves



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Planed Men	10	12	12	17	17	21	25	30	35	48	58	72	79	85	95	87	74	60	54	65	62	57	49	46	40	30
Earned Men	13	13	16	15	14	15	17	27	52	29	26	39	47	36	49	33	71	97	93	95	86	76	60	71	78	81

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“Alternative” Scheduling Techniques

- Advantages:
  - Graphical communication benefits
  - Enable achieving schedule buy-in
  - Can be utilized with other conventional techniques
  - Better for certain single-element work
- Disadvantages:
  - Not commonly used
  - In some cases, more difficult to apply on large projects

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Developing a Schedule

1. Define the goals, objectives, and desired outcomes
   – Develop a Basis of Schedule document
2. Define activities (start with WBS)
3. Logically order the activities
4. Assign durations
5. Include any outside constraints
6. Establish activity start/finish times
7. Assign resources and costs to activities
8. Review schedule with stakeholders

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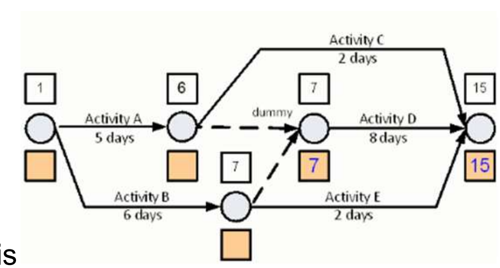
Activities

- Scheduling is based on a series of tasks that are called "**activities**."



  – Estimated duration (and sometimes cost) is associated with each activity
  – Activity completion time is related to amount of resources committed to activity, and the effect of surrounding activities
  – Degree of activity detail depends on schedule purpose and level of specificity of data

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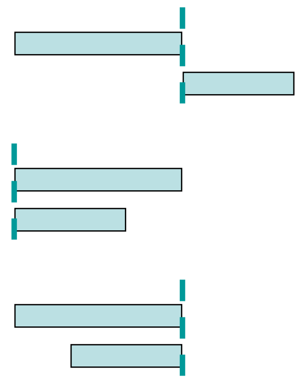
Activities

- Activity relationships:

Finish-to-Start: **A:**
(Start-to-Finish similar) **B:**

Start-to-Start: **A:**
B:

Finish-to-Finish: **A:**
B:



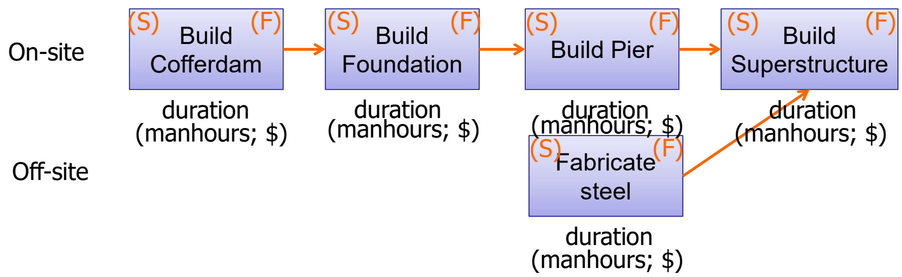
Activities

- To determine optimal schedules:
  - Identify all of the project's activities
  - Determine the precedent relationships among activities

- Based on this information we can develop managerial tools for project control

- Activities are related to the WBS

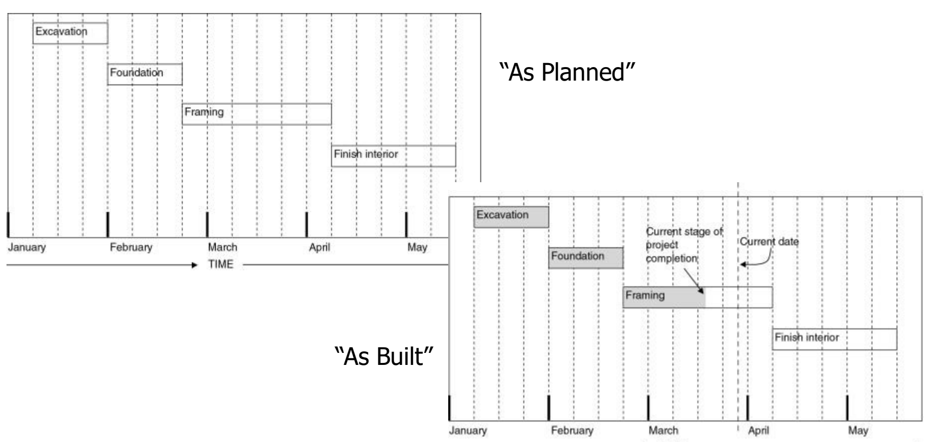
Example: Columbia River Crossing



66

Scheduling as Project Control

- Scheduling is also an important control function



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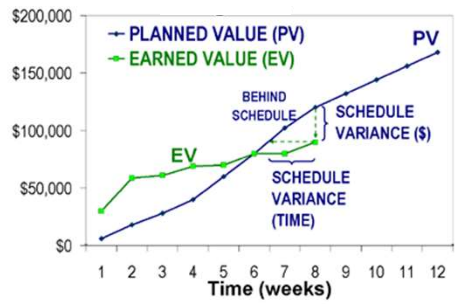
Scheduling as Project Control

- Investigating the results of possible delays in an activity's completion time
- Progress control (e.g., earned value management)
- Smoothing out resource allocations over the duration of the project



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Critical Path Method (CPM)

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Critical Path Method (CPM)

- Critical Path:
  - Chain of activities that controls overall project completion
  - Longest path in the network
- Reducing project duration can only be accomplished through reduction of length of critical path.
  - Re-arranging critical activities
  - Reducing critical activity durations

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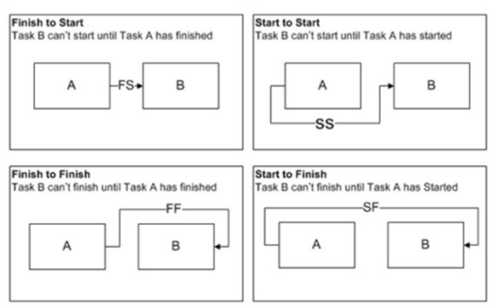
Relationships and Lag



- Relationships:
  - Finish-to-Start (FS)
  - Finish-to-Finish (FF)
  - Start-to-Start (SS)
  - Start-to-Finish (SF)
- Lag:
  - Sometimes denoted on diagrams
  - FS/2 = finish-to-start relationship with a 2-day lag
  - Think of a lag as a separate activity called “Wait”

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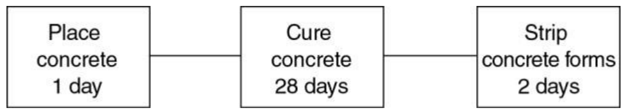
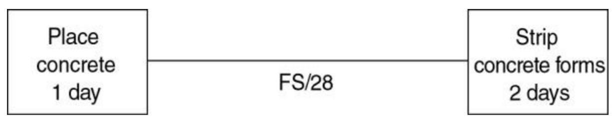
Lag Example



Typical Sequence of Finish-to-Start Relationships

Can be represented as:



Finish-to-Start Relationship with a 28-Day Delay

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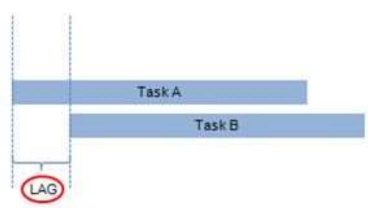
Lag and Lead

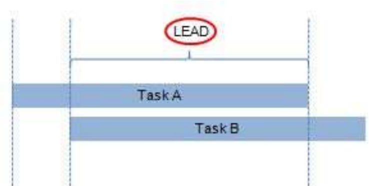
- Lag: delay of a successor

SS between Task A and Task B
With a lag



- Lead: acceleration of a successor

FS between Task A and Task B
With a lead



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Critical Path Method (CPM)

- Activity times:
  - Early Start (ES): The earliest time an activity can begin based on completion of all previous activities.
  - Early Finish (EF): The earliest time an activity can finish based on network logic. EF = ES + duration
  - Late Start (LS): The latest time an activity can start without delaying project completion. LS = LF – duration
  - Late Finish (LF): The latest time an activity can finish without delaying project completion.

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Critical Path Method (CPM)

- Activity times:
  - Early Event Time (EET): The earliest time an event can occur based on network logic. Equals the latest EF of those activities that immediately precede the event.
  - Late Event Time (LET): The latest time an event can occur based on network logic. Equals the earliest of the late start times of those activities that immediately follow the event.

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Critical Path Method (CPM)

- Total Float (TF):
  - Amount of time an activity can be delayed without delaying overall project completion.
  - Critical path is the series of activities with the least TF.
  - TF = LF – EF = LS – ES
- Free Float (FF):
  - Amount of time an activity can be delayed without delaying the start of another activity.
  - FF = (early event time of activity's ending event) – EF

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Critical Path Method (CPM)

- Independent Float:
  - Float that is "owned" exclusively by only one activity
  - Not available for use by any other activity
  - Can have independent float only if it has FF
  - $(\text{Independent Float})_{ij} = ES_{jk} - LF_{hi} - \text{Duration}_{ij}$
- Interfering Float:
  - The float an activity might have that is subject to use by (shared with) other activities
  - $(\text{Interfering Float})_{ij} = TF_{ij} - FF_{ij} = LF_{ij} - ES_{jk}$

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Critical Path Method (CPM)

- Forward pass:
  - Determines ES and EF times
- Backward pass:
  - Determines LS and LF times
- Total float and free float values determined from start and finish times
- For all activities: FF ≤ TF

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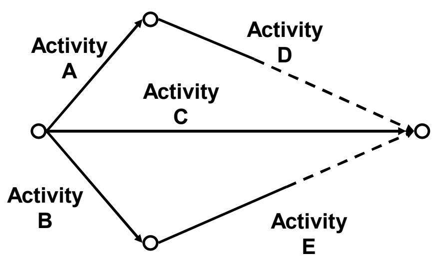
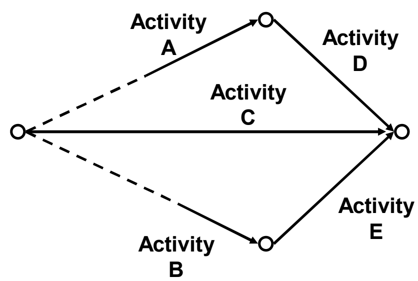
Critical Path Method (CPM)

- Early Start Schedule:



- Late Start Schedule:



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Critical Path Method (CPM)

- Advantages:
  - Identifies critical activities
  - Determines critical path and shortest completion time
  - Shows “flexibility” in timing (float) of non-critical activities
  - Good for any size project

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Critical Path Method (CPM)

- Disadvantages:
  - Complex schedules more difficult to grasp
  - Not supported by all computer scheduling programs
  - Printed schedules difficult to work with

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Arrow Diagrams

82

CPM – Arrow Diagram Method (ADM)

- Arrows = activities
  - Consume time and resources
  - Performance of the work
  - "i" node at beginning; "j" node at end
- Nodes = events
  - No associated duration or resources
  - Milestones

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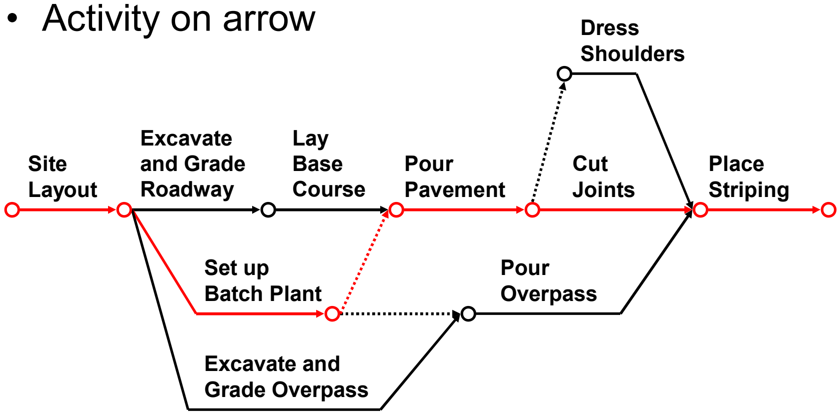
CPM – Arrow Diagram Method (ADM)

- Activity on arrow



84

CPM – Arrow Diagram Method (ADM)

- Logic relationships:
  - All activities that precede an activity in the network must be complete before the activity can commence.
- Dummy activities:
  - No associated duration or resources
  - To permit proper logic
  - To provide unique node numbering for each activity

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Precedence Diagrams

86

CPM - Precedence Diagram Method (PDM)

- Nodes = activities
  - Consume time and resources
  - Performance of the work
- Lines (arrows) = activity links
  - Show network logic
  - Can include time (lag or lead time)

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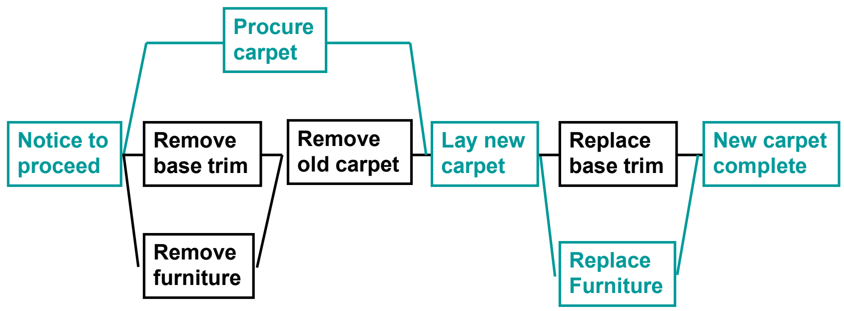
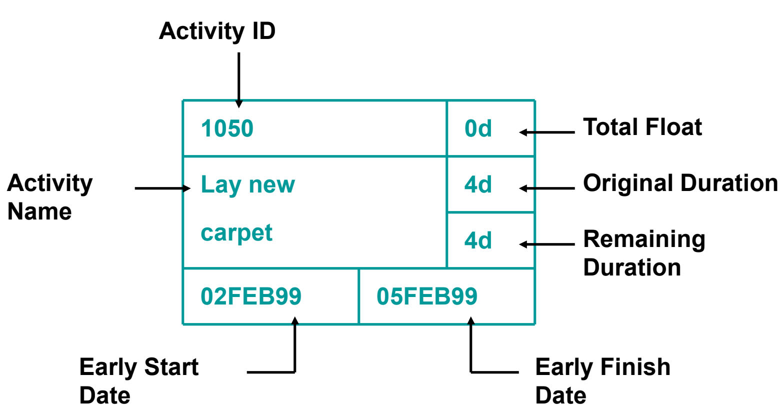
CPM - Precedence Diagram



88

CPM - Precedence Diagram



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CPM - Precedence Diagram

- Advantages over arrow diagrams:
  - Easier to draw (no dummy activities)
  - Easier to add activities
  - Included in many computer scheduling programs

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CPM – Precedence Diagram

- Overall Procedure:
  1. Determine the sequence and durations of activities
  2. Construct the precedence diagram
  3. Starting from the left, compute the Early Start (ES) and Early Finish (EF) times for each activity
  4. Starting from the right, compute the Late Finish (LF) and Late Start (LS) times for each activity
  5. Find the Total Float (TF) and Free Float (FF) for each activity
  6. Identify the Critical Path

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Activity	Description	Immediate Predecessors	Duration (days)
A	Obtain permit	---	3
B	Prefabricate structure	A	3
C	Prepare foundation	A	2
D	Transport structure to site; set on foundation	B	3
E	Install utility services	C	7
F	Obtain furnishings	B,C	3
G	Connect utilities	D,E	6
H	Install landscaping	C	2
I	Clean up	F, G, H	1

Example Project

Activities, duration, and sequencing

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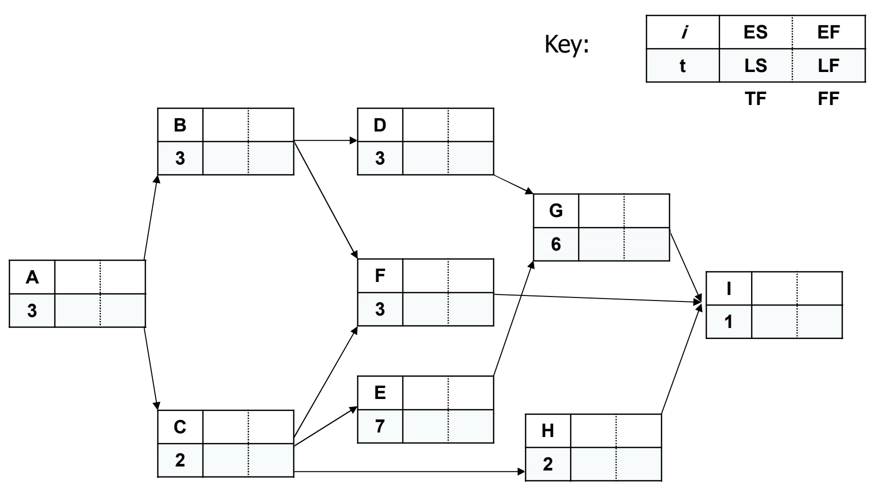

Example Project

Activities, durations, and precedence diagram network

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Early Start and Early Finish Times

Step 3: Make a forward pass through the network as follows:

For each activity, beginning at the Start node, compute:

Early Start time = the maximum of the Early Finish times of all activities immediately preceding the activity.

Early Finish time = (Early Start time) + (Time to complete the activity)

The project completion time is the Early Finish time at the finish node.

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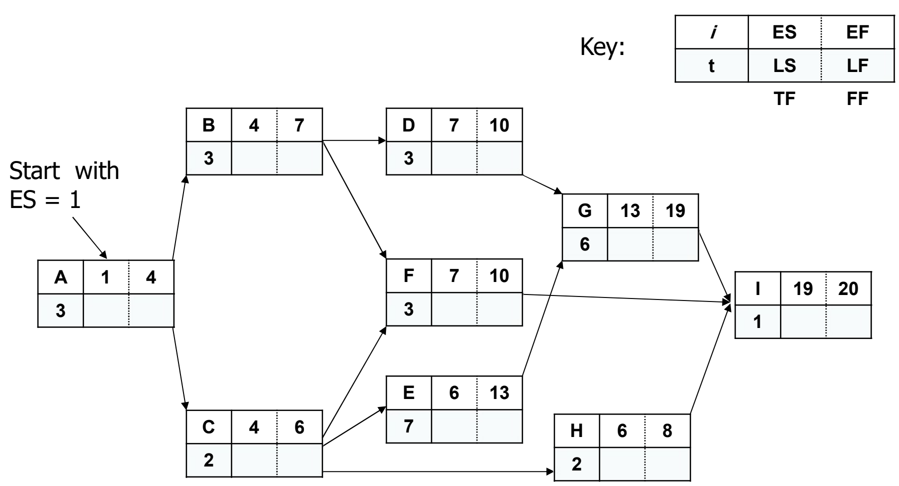

Example Project: Forward pass

Activities, durations, and precedence diagram network

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Late Start and Late Finish Times

Step 4: Make a backward pass through the network as follows:

Late Finish time rule: LF = Earliest LS of the immediate successors of the activity.

Procedure for obtaining late times for all activities:

- For the activity at the finish node, set LF equal to project completion time (EF).
- For each activity whose LF value has just been obtained, calculate LS = LF – (duration of activity)
- For each new activity whose immediate successors now have LS values, obtain its LF by applying the latest finish time rule. Then calculate LS = LF – (duration of activity)
- Repeat steps above until LF and LS have been obtained for all activities.

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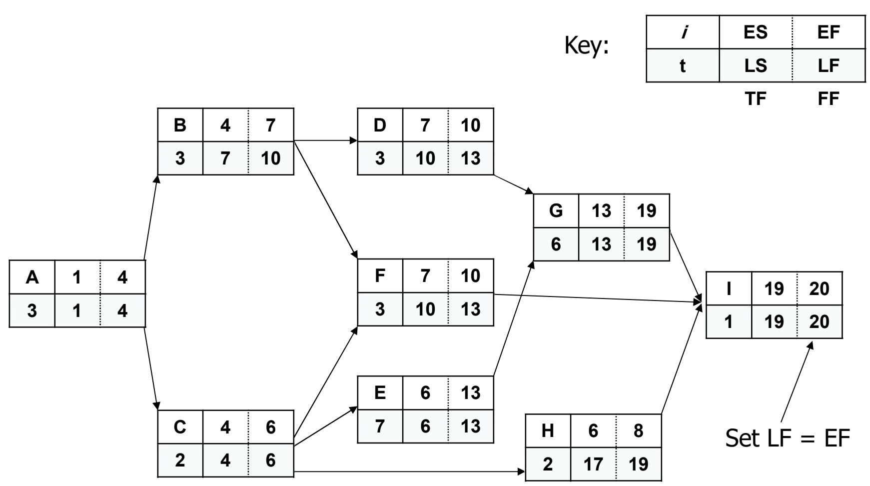

Example Project: Backward pass

Activities, durations, and precedence diagram network

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Determining the Critical Path

Step 5: Calculate the float values for each activity by:

For each link, Link Lag = $ES_j - EF_i$

Total Float (TF) = LS – ES
= LF – EF

Also: $TF_i = \min.(\text{Link lag}_{i\text{-}j} + TF_j)$
$= \min.(ES_j - EF_i + TF_j)$

Free Float (FF) = the smallest link lag value among those link lines that emanate from the activity.

The critical path is along those activities with zero float.

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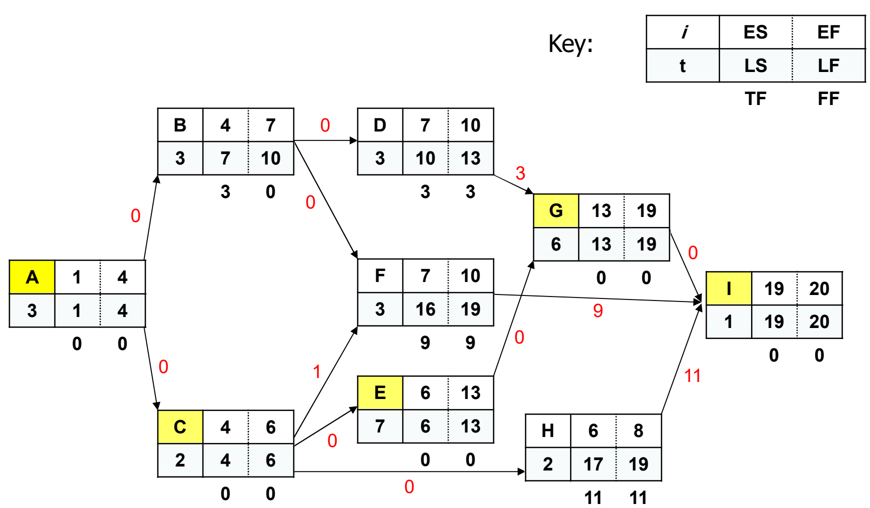

Example Project

Float values and critical path

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Handling Lag and Lead Times

- Lags and leads act like “hidden” activities
  - they introduce time through the logic relationships
- Lags and leads should be used carefully in a schedule, and should ideally be modeled as activities, because they become hidden when the schedule is printed as a bar chart
- The early start for an activity is the latest of the (EF + Lag) of all predecessors
- Leads are similar, but usually are applied in SF or SS relationships

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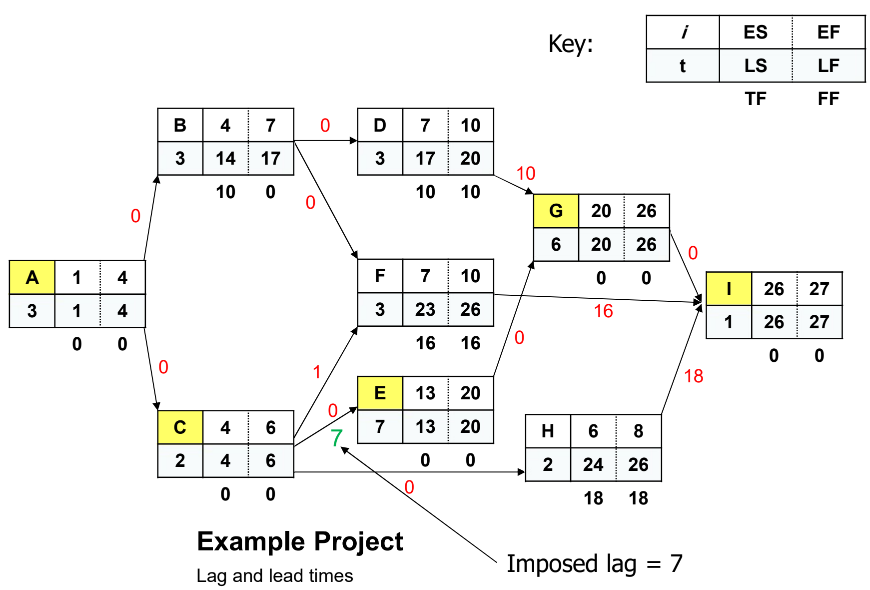

Example Project
Lag and lead times

101

Critical Path Method (CPM)

- Independent Float:
  - Float that is "owned" exclusively by only one activity
  - Not available for use by any other activity
  - Can have independent float only if it has FF
  - (Independent Float)$_{ij}$ = $ES_{jk} - LF_{hi} - Duration_{ij}$
  - **Earliest Successors' Early Start – Earliest Predecessors' Late Finish – Activity's duration**
- Interfering Float:
  - The float an activity might have that is subject to use by (shared with) other activities
  - (Interfering Float)$_{ij}$ = $TF_{ij} - FF_{ij} = LF_{ij} - ES_{jk}$

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Special Activity Relationships

- FS relationships are the most common, and should be used where possible
- However, there are other relationships that may be conceived, including SS and FF relationships; SF relationships are rarely used.
  - Start-to-start (SS): the successor activity cannot start until the predecessor activity has begun.
  - Finish-to-finish (FF): the successor activity cannot finish until the predecessor activity has completed

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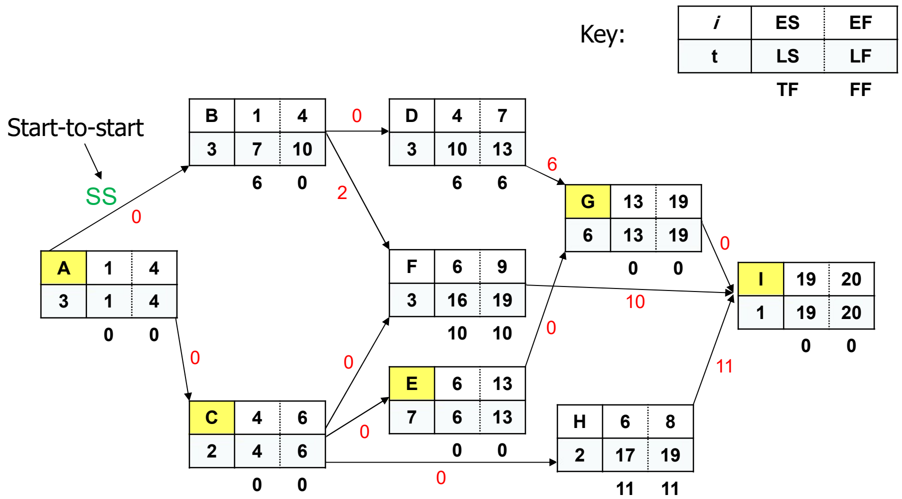

Example Project

Special Activity Relationships

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Determining Activity Durations

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Activity durations

- Activity durations generally fall into two categories:
  - Deterministic durations
    - Single-point durations that predict one outcome
  - Stochastic durations
    - Multi-point durations which recognize that durations are not perfectly predictable
    - These durations are often characterized with three points—the optimistic, likely, and pessimistic durations
- Most duration estimates start out with a deterministic estimate

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Activity durations

- Duration estimates are predictions of the future, based upon:
  - some historical basis and expected future conditions

- The historical basis can be:
  - statistical data-based or judgmental, using personal professional experience
- The future conditions are developed through:
  - an analysis of the project and the environment surrounding the project

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Activity durations

The development of activity durations can occur in three phases:

- Determine unconstrained durations
  - i.e., if the activity were performed alone, with reasonably-available resources and a "normal" environment—how long would it take?
- Determine the constraints and adjust the activity
- Revise the duration based on other project considerations

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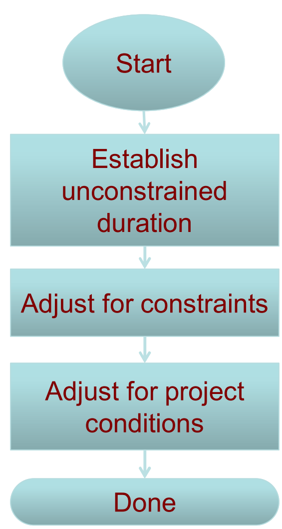
Activity durations



109

Unconstrained durations

- Start with any data that may be provided:
  - Is there a program or design document that has a schedule attached?
  - Does any historical data exist?
  - Are there experts available who can provide duration estimates?
- Gather any and all of these that are available
- Compare among the information discovered and resolve discrepancies until a best-judgment duration is assigned

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Unconstrained durations

- Previous documentation may provide valid durations estimates
  - Look for any Basis of Estimate document that will outline how the previous estimate's durations were developed
  - Judge whether the previous information is reliable
- Previous documents are often only partially useful
  - Previous schedules are often at a higher summary level
  - Previous schedules may include hidden "contingencies" that mask the actual duration values
- **Every project is DIFFERENT!**

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Unconstrained durations based on historical data

- Historical data is often very useful, if available
- Consider the 2-mile-long Alaskan Way Viaduct tunnel

- How would you develop a schedule for this?

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Determine unconstrained durations using historical data

- Suppose you have a 2000-sf wall to paint. Previous projects suggest that the average production rate is 25 sf/hr.

- Given
  – Quantity of painting = 2000 sf (determined in the estimate)
  – Production rate = 25 sf/hr (obtained from historical data)
- Find
  – Painting time = quantity / production rate = (2000 sf) / (25 sf/hr) = 80 hrs

  – If five workers, duration = 80 hrs / 8 hrs /5 workers = 2 days (**use 2 days**)
  – If six workers, duration = 80 hrs / 8 hrs / 6 workers = 1.7 days (**use 2 days**)

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Determine unconstrained durations based on historical data

- Suppose you have a 3000-sf drywall to build. Previous projects indicated that the average production rate is 30 sf/hr. Compare 4-man crew vs. 5-man crew.

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Unconstrained durations

- Often, the best method is to use experts who are familiar with the type of work
  - Project personnel who are familiar with the work are very helpful
  - Outside experts may provide additional information, especially for highly specialized work
- Beware of biases in estimated durations—especially from project-based personnel
  - Studies have demonstrated that most project personnel are optimistically biased

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Determine unconstrained durations based on budget

- Suppose you have 30 cy of dirt to move. Your budget indicates the activity must be done within $3,000 assuming a labor cost of $33.30 per hour.

- Given
  - Quantity of dirt = 30 cy (determined in the estimate)
  - Budget amount = $3,000 (provided in the budget)
  - Hourly cost per worker = $33.30 (including general conditions and overhead)
- Find
  - Cost rate = budgeted cost / quantity = $3000 / 30cy = $100/cy
  - Production rate = cost rate / hourly cost = ($100/cy) / ($33.30/hr) = 3 hrs/cy
  - Excavation time = production rate * quantity = (3 hr/cy) * (30 cy) = 90 hrs

  - If two workers, duration = 90 hrs / 8 hrs / 2 workers = 5.6 days (**use 6 days**)
  - If four workers, duration = 90 hrs / 8 hrs / 4 workers = 2.8 days (**use 3 days**)

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Determine unconstrained durations based on budget

- Suppose you have a 1000-ft long pipe to lay. Your budget indicates the activity must be done within $4,000 assuming a labor cost of $25 per hour. Compare 4-man crew vs. 5-man crew.

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Project durations

- Two major classifications of ***project*** duration estimating are commonly used:
  - *Top-down* estimation
    - Parametric methods are used to compare against historic models
  - *Bottom-up* estimation
    - Breaking the work activity into small, discrete tasks provides the estimating data

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Constraints

- Projects exist in an environment that often places limits on the ability to freely pursue a work activity
  - Examples include:
    - Resource availability
    - Productivity factors
    - Contract constraints
    - Scope of work
    - Means and methods planning
    - Permitting
    - Management skill
    - Material availability
    - Equipment availability
    - Seasonal considerations
    - Work restrictions
    - Locality restrictions
    - Quality of work
    - Subcontractor and vendor considerations
    - Engineering deliverables
    - Fast-tracking

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Constraints

- Constraints should be carefully listed
- Where possible, constraints should be noted on the schedule, as a **Milestone** Activity
- Some constraints may be modeled using different calendars
  - For example, weather or working hours constraints
- Some constraints affect the duration calculation

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Project considerations

- Project planning considerations will play a part in the scheduling process
- For example, the project planner must determine the project flow—
  - Where will the project begin and where will it end?
  - How will resources be brought into the project?
  - What is the interplay between funding and cash flow, based on the proposed schedule?
  - What is the project delivery method, and how does that affect the schedule?
- These considerations may create alternatives that should be evaluated using methods such as **Benefit-Cost analysis**.

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Program Evaluation and Review Technique (PERT)

122

Activity durations

- Activity durations generally fall into two categories:
  - Deterministic durations
    - Single-point durations that predict one outcome
  - Stochastic durations
    - Multi-point durations which recognize that durations are not perfectly predictable
    - These durations are often characterized with three points—the optimistic, likely, and pessimistic durations

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Risk (uncertainty)

- Weather
  - Add duration to each activity based on weather data
  - Add an activity, or activities, called "weather" at the end of a schedule along the critical path
- Deliveries / material availability
- Labor issues
- Differing site conditions
- Scope changes
- Financial challenges
- Other…

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Measuring uncertainty

- The risk process begins with:
  - identifying the sources of risk, and
  - developing a *Risk Register*
- Then, based upon the risks:
  - evaluate how an activity's durations may vary
- A common method for estimating variation is to establish *optimistic*, *likely*, and *pessimistic* durations
  - Often, the deterministic duration is the likely duration
- Two common methods used to determine the effect of risk on activity and project duration are:

  PERT and Monte Carlo simulation

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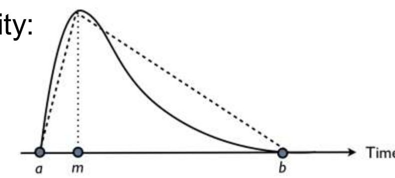
PERT

- Program Evaluation and Review Technique (PERT)
  - Deals with the issue of risk
  - Three Time Estimates per Activity:
    - Optimistic time estimate (a)
    - Most Likely time estimate (m)
    - Pessimistic time estimate (b)



  - Calculates likely outcomes based on random or historical variances
  - Can calculate activity mean time estimate and variance

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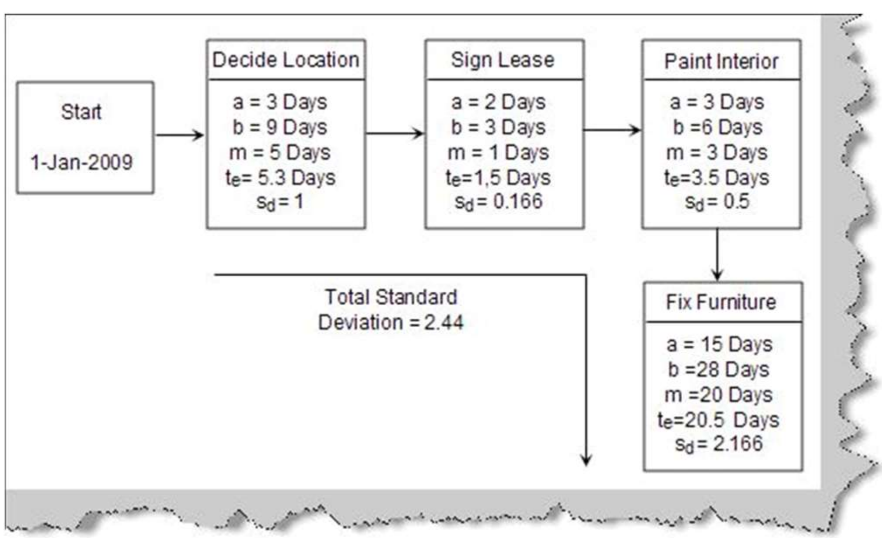
PERT



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PERT

Distributions of uncertainty using three points of duration to fit to a special Beta (PERT-Beta) probability density function (PDF).

- Assume the following durations for a roadway sub-base design:
  - Optimistic (T_o) = 32 days
  - Most Likely (T_m) = 38 days
  - Pessimistic (T_p) = 50 days

The *expected value*, or *mean* of this PDF is:

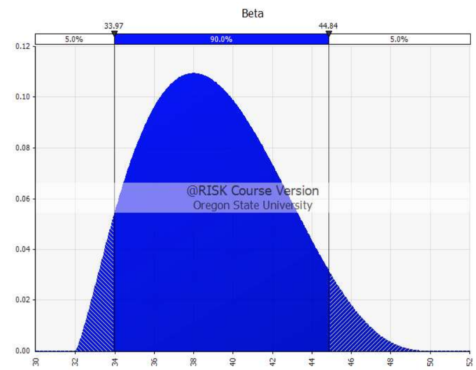
$$T_e = (T_o + 4T_m + T_p) / 6$$

(32 + 4*38 + 50) / 6 = 39 days

The standard deviation (σ) is:

$$\sigma = (T_p - T_o) / 6$$

(50 - 32) / 6 = 3 days



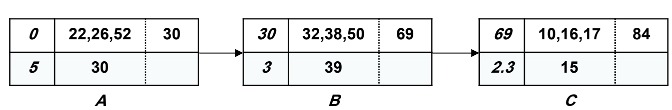
PERT

- Now, suppose that the roadway design had three critical-path activities:
  A. Soils investigation
  B. Sub-base design
  C. Base design

Key:

ES	T_o, T_m, T_p	EF
σ	T_e	

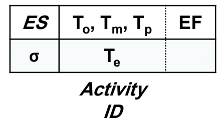
Activity ID

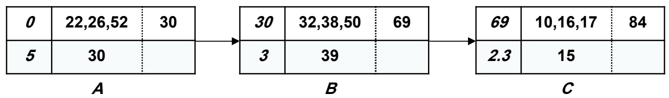


Calculate the PERT project duration along a critical path

PERT

Key:





- These results provide important planning information about the overall project:
  - The sum of the means tells us what the likely duration is for the project
  - The calculation for total standard deviation (σ) provides confidence levels for completion date

Activity	Mean duration	*Standard deviation (σ)*	*Variance (σ^2)*
A	30	5.0	25.0
B	39	3.0	9.0
C	15	2.3	5.3
Sum	84		39.3

Variance for the path (V_{path})

- *Standard deviation* for the path as a whole: $\sigma_{path} = (V_{path})^{1/2} = (39.3)^{1/2} = 6.27$ days

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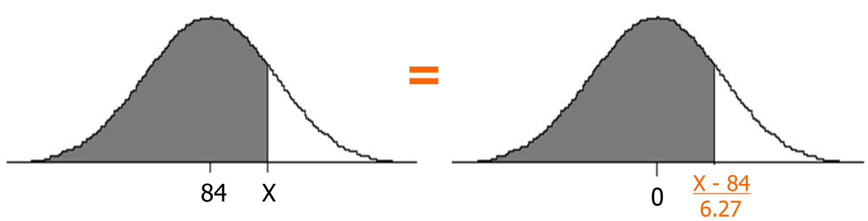
PERT

- When many activities with different PDF's are included in PERT, it is acceptable to assume that the project duration is normally distributed.
- From the example, the project duration ~ N (84 , 6.27^2).
- The probability of completing the project in less than X days = the shaded area



Transforming to the standard normal distribution ~ N (0,1)

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PERT

Mean = 84 days

SD = 6.27 days

What is the likelihood of finishing in 90.3 days or less?

(90.3 – 84) / 6.27 = 1.00

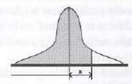
So, 84.13% (based on normal curve table)

What is the likelihood to finish in 88.7 days or less?

What is the likelihood to finish between 82 and 89 days?

Table 4.3
AREA UNDER A STANDARD NORMAL CURVE

x = The number of standard deviations to the right of the mean



The area under the curve (as shown in the table) always includes the portion containing the mean.

X	0	1	2	3	4	5	6	7	8	9
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5754
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7258	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7518	.7549
0.7	.7580	.7612	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7996	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9649	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9919	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990

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Monte Carlo simulation

- Some projects are extremely complicated, and some activities may use PDFs other than PERT
  - E.g., normal, triangular, uniform, and so forth
- In these cases, simple mathematical solutions are not available
- Activities still get assigned a range of durations, but a computer simulation is used to establish project confidence levels

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Monte Carlo simulation

- Process:
  - Assign a distribution to each individual activity in a schedule
  - Run many simulations with a duration randomly selected for each activity
  - Accumulate durations for the whole project
  - Overall project duration mean and standard deviation are calculated using the results

- Software: Oracle Crystal Ball, Excel add-in @Risk

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Monte Carlo simulation

Distribution for Project Completion/Finish

0.250

Interfering Float Formula

Interfering Float = Total Float – Free Float

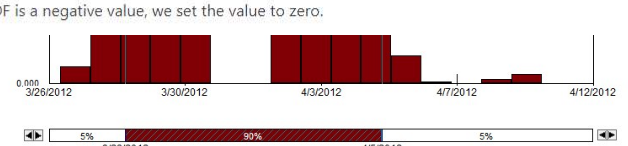
Independent Float (INDF)

Interfering Float is the maximum amount of time an activity can be delayed without delaying the early start of the succeeding activities and without being affected by the allowable delay of any predecessor activity.

Independent Float Formula

Independent Float (INDF) = Earliest Successors' Early Start – Earliest Predecessors' Late Finish – Activity's duration

when the INDF is a negative value, we set the value to zero.



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