MSBA 7004
Operations Analytics

Class 5-2: Process Analysis (V)

Multiple Flow Units, Project Management and Critical Path

2023

Outline

- **Process flow analysis when multiple types of flow units exist**
- Basic project management **concepts**
- Introduce **tools** available to manage projects including the critical path method (CPM)

Process Analysis: Multiple Flow Units

Resource	Unit Load (minutes/unit)		
	Product A	Product B	Product C
1	2.5	2.5	2.5
2	1.5	2	2.5
3	12	0	0
4	0	3	3
5	3	3	3

- If you produce only Product A, what is the capacity rate of the process (per hour)? Which resource is the bottleneck?
- If your product mix is 1 unit of A, 2 units of B and 2 units of C, what is your capacity rate? Bottleneck?

Process Analysis: Multiple Flow Units

Resource	Unit Load (minutes/unit)			
	Product A	Product B	Product C	1A+2B+2C
1	2.5	2.5	2.5	12.5
2	1.5	2	2.5	10.5
3	12	0	0	12
4	0	3	3	12
5	3	3	3	15

- When multiple flow units go through a process, the “product mix” needs to be considered while determining the unit load and the capacity
- The bottleneck depends on the product mix

Process Analysis: Multiple Flow Units

- How to identify the bottleneck when there are multiple flow units
  - $Unit\ load = total\ amount\ of\ time\ required\ to\ finish\ the\ combination\ of\ flow\ units$
  - $Capacity\ rate = \frac{Number\ of\ resources}{Unit\ load}$
  - Bottleneck is the resource with the lowest capacity rate, and the bottleneck changes when the "product mix" changes

Outline

- Process flow analysis when multiple types of flow units exist
- **Basic project management concepts**
- **Introduce tools available to manage projects including the critical path method (CPM)**

What is a *Project*?

A set of related **tasks or activities**, directed towards some major **output** and requiring a significant period of time to perform

Often thought of as a **one-time** occurrence, but projects are often repeated with slight modifications

Examples

- Construction: New plant or warehouse (implementing capacity, location and layout decisions), new international airport terminal
- New product development (new car model, Windows, Games)
- Implementing a new IT system
- Unique service activities (rock concert, museum exhibition)

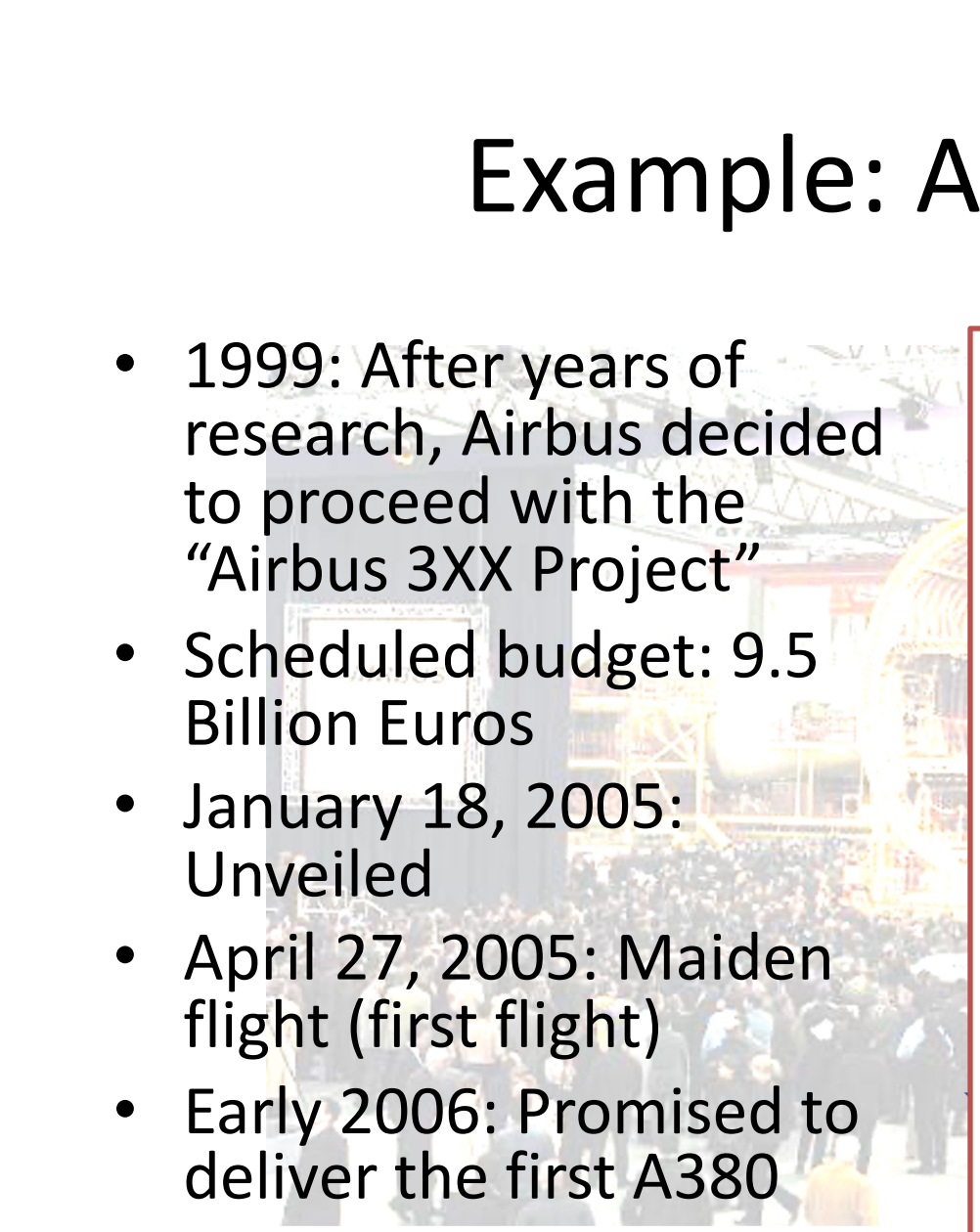
Example: Airbus 380

Example: Airbus 380

A380: 850 passengers.
Boeing 737: 180 passengers.

Example: Airbus 380

- 1999: After years of research, Airbus decided to proceed with the "Airbus 3XX Project"
- Scheduled budget: 9.5 Billion Euros
- January 18, 2005: Unveiled
- April 27, 2005: Maiden flight (first flight)
- Early 2006: Promised to deliver the first A380



A Series of Delays

- Delay #1 (June 2005): Delivery slips by 6 months
- Delay #2 (June 2006): Another 6 months
  - Announcement caused a 26% **drop in the share price**
  - Led to the **departure of top management**
- Delay #3 (October 2006)
- Final delays 19-24 months: Inaugural commercial flight (October 25, 2007, Singapore Airline)
- Development cost 18 Billion Euros
- Airbus suffered huge losses as a result

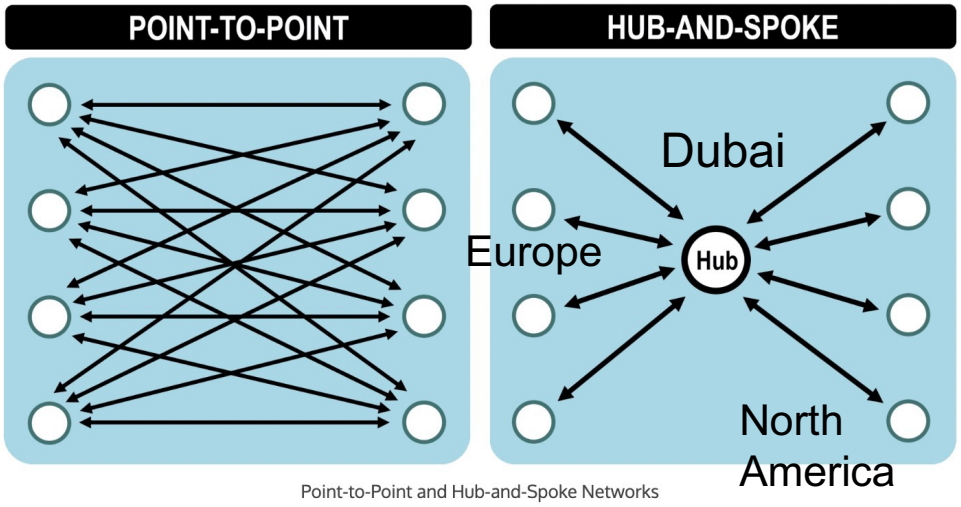
Why did Airbus 380 fail?

- Why did their project fail?
- Why did they choose to build large aircrafts?
- Why did Airbus 380 fail in the market?

Why did Airbus 380 fail?

- The development of the aircraft was a collaboration between 16 sites spread across 4 different countries (France, Germany, Britain and Spain).
  - Different design groups working on the project had used different software (computer-aided design (CAD) programs) to create the engineering drawings.
  - During installation, they discovered the parts designed by different teams didn't fit together. This cost the company $6 billion to put right and set the project back two years.

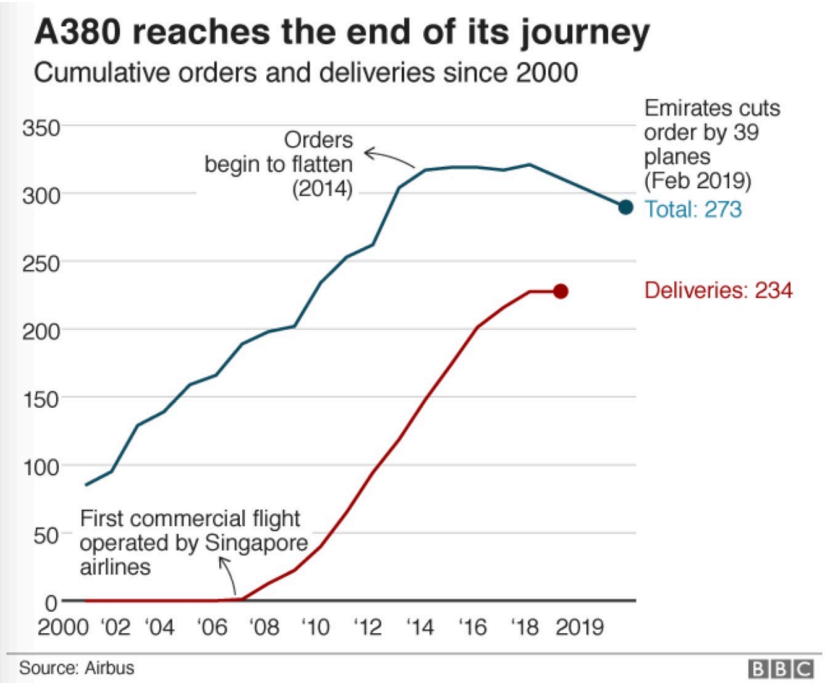
Why did Airbus 380 fail?



Point-to-Point and Hub-and-Spoke Networks

- •The A380 was built for hub and spoke operations - as Emirates focuses on
- •It suits large airports and is limited in operation at others
- •High maintenance cost, low second-hand market potential

- Air France announced it will phase out its ten Airbus A380s by 2022.
- Singapore airlines - which received the first A380 back in October 2007 - has also started to replace these aircrafts with A350s.
- Major Airlines canceled orders of A380 (2013 - 2019).
- Airbus stopped production of the A380 in 2021.



Why study project management?

- Projects are everywhere!
- Consider course projects
  - Are team projects complicated and difficult? Why?
  - Do projects seem difficult to get done on time? Do you miss deadlines?
  - Would you like to finish your project as quickly as you can, and get it completed on time?

- Projects are often mismanaged
- 44% of developers have had their game delayed by COVID-19

- In a recent study of IT systems project, the success rate of projects was only 16.2%

  (What do you think are the characteristics of a successful project?)

Well-planned. Clear Communication. Good Change Control. A Clear Vision. Risk Control. Critical Path Method (with time-cost analysis)

What does Project Management involve?

1. DEFINITION	2. PLANNING	3. EXECUTION	4. RETROSPECTIVE
Objectives Team Constraints Completion criteria	Work breakdown Activity list and sequences Project schedule Budget (time and cost) for each task and resources	Actual work Changes to objectives, activities, schedules, resources, etc. Prepare presentations Finish documentation	Review project success What went well/ not so well
Project proposal (Well-structured)	Gantt chart Critical path	Final deliverables	

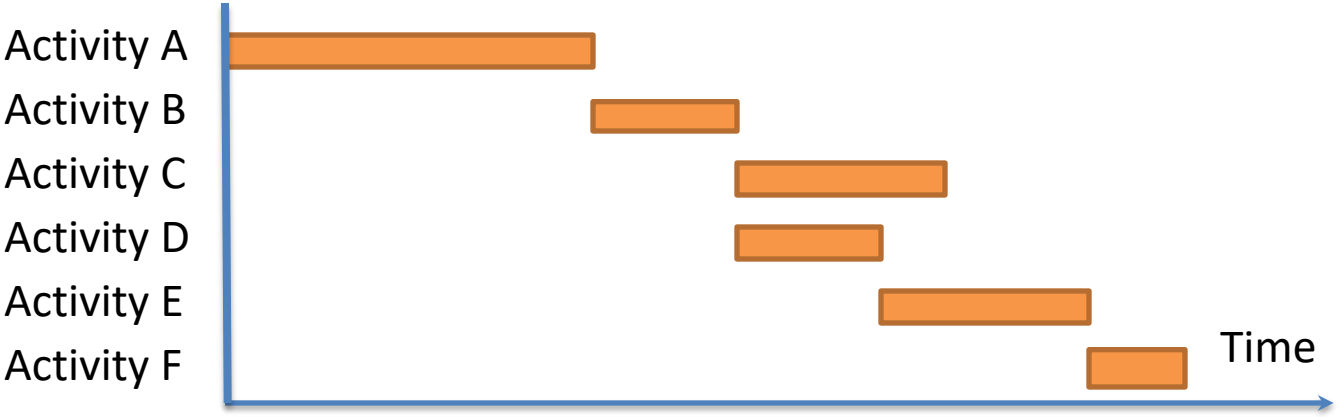
Network Representations of Projects

- Diagrams that represent activities, precedence relations, and durations

- Two common representations
  - Gantt chart
  - Critical path diagram

Example:
Starting McDonald's Franchise

ACTIVITIES	TIMES	PRECEDENCE
A. Obtain franchise	30 days	None
B. Rent facility	10 days	A
C. Equip facility	15 days	B
D. Recruit staff	10 days	B
E. Train staff	15 days	D
F. Pass safety inspection	5 days	C, E

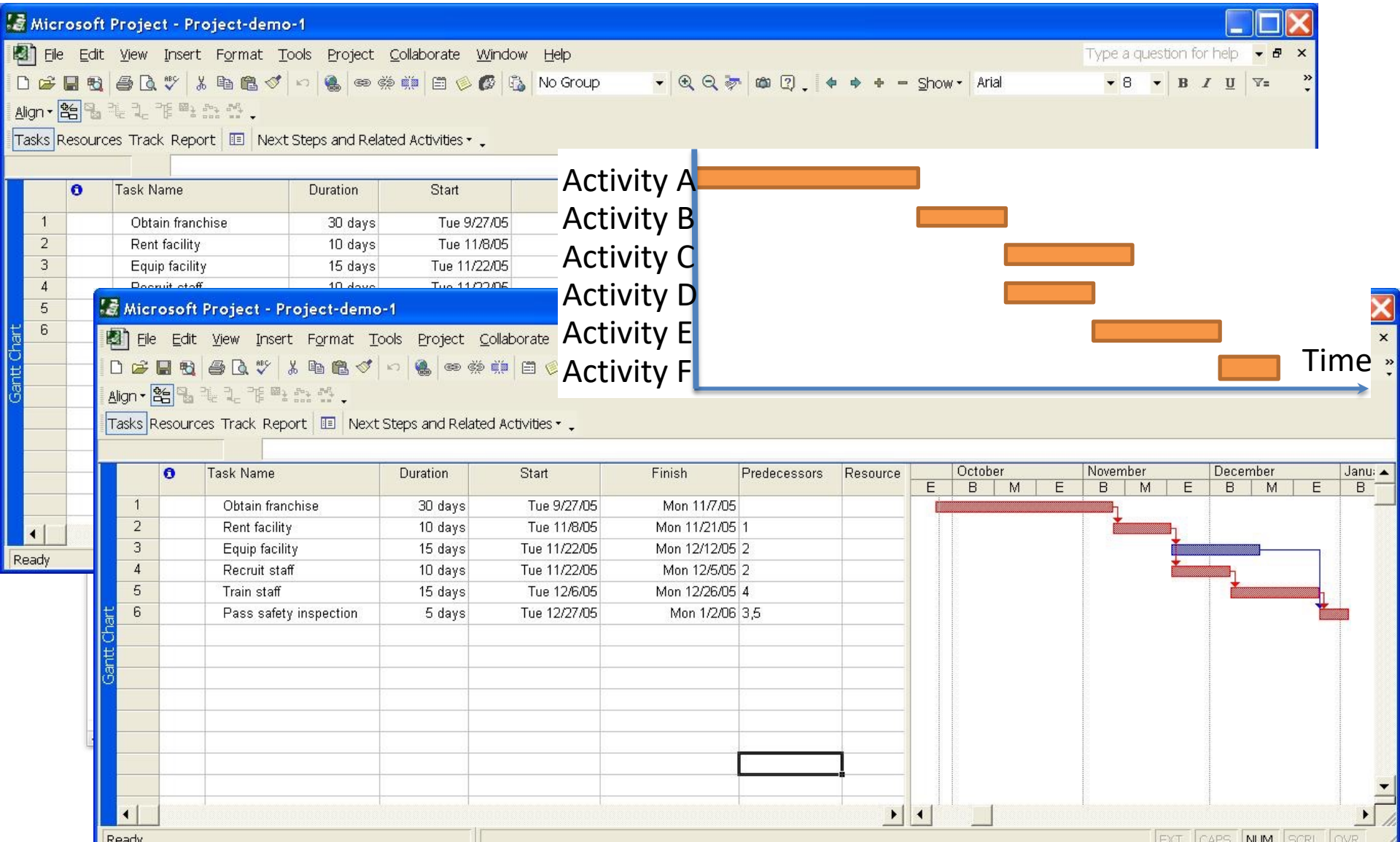


Project Management Softwares

50+ offerings in the market

- Jira, Microsoft Project, Smartsheet, etc.

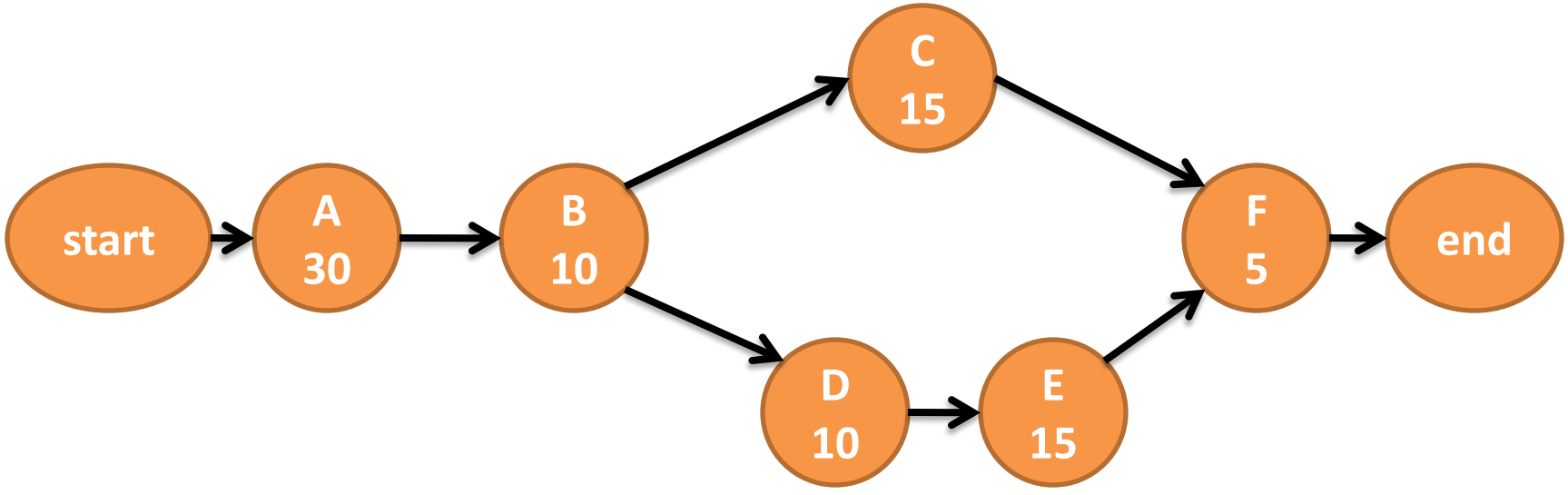
Microsoft Project



Basic Questions that We Face

- What activities are **critical** to ensure the timely completion of the project?
- Which activities can be delayed, if necessary, without delaying the project completion, and by how much?
- Is it worthwhile to incur extra costs in order to accelerate some of the activities?

Critical Path Diagram

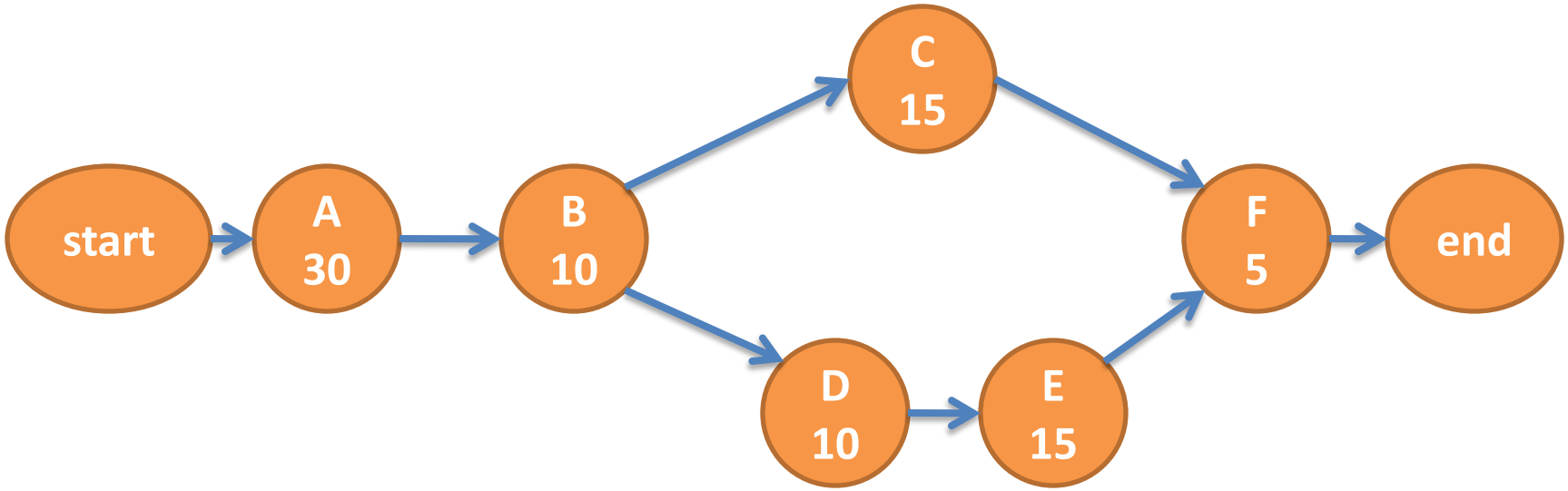


ACTIVITIES	TIMES	PRECEDENCE
A. Obtain franchise	30 days	None
B. Rent facility	10 days	A
C. Equip facility	15 days	B
D. Recruit staff	10 days	B
E. Train staff	15 days	D
F. Pass safety inspection	5 days	C, E

The Critical Path

- Identify all paths between the start node and the end node (**Enumeration Method**)
- For each path, add the activity times for all activities on that path
- Find the maximum path time
  - This path is called the **critical path**
  - This is the time required to finish the project

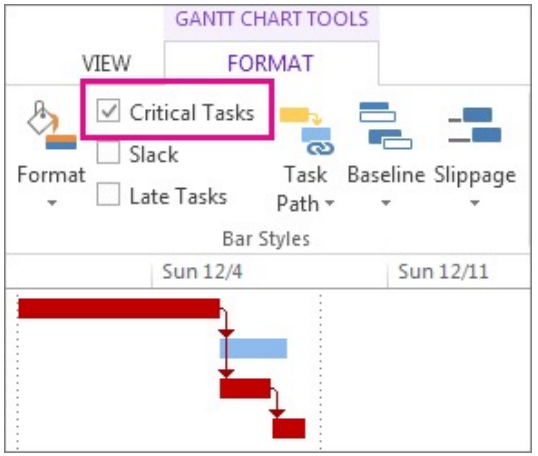
Critical Path Diagram



- Path 1: A-B-C-F (30+10+15+5=60days)
- Path 2: A-B-D-E-F (30+10+10+15+5=70days)

Why is the critical path important?

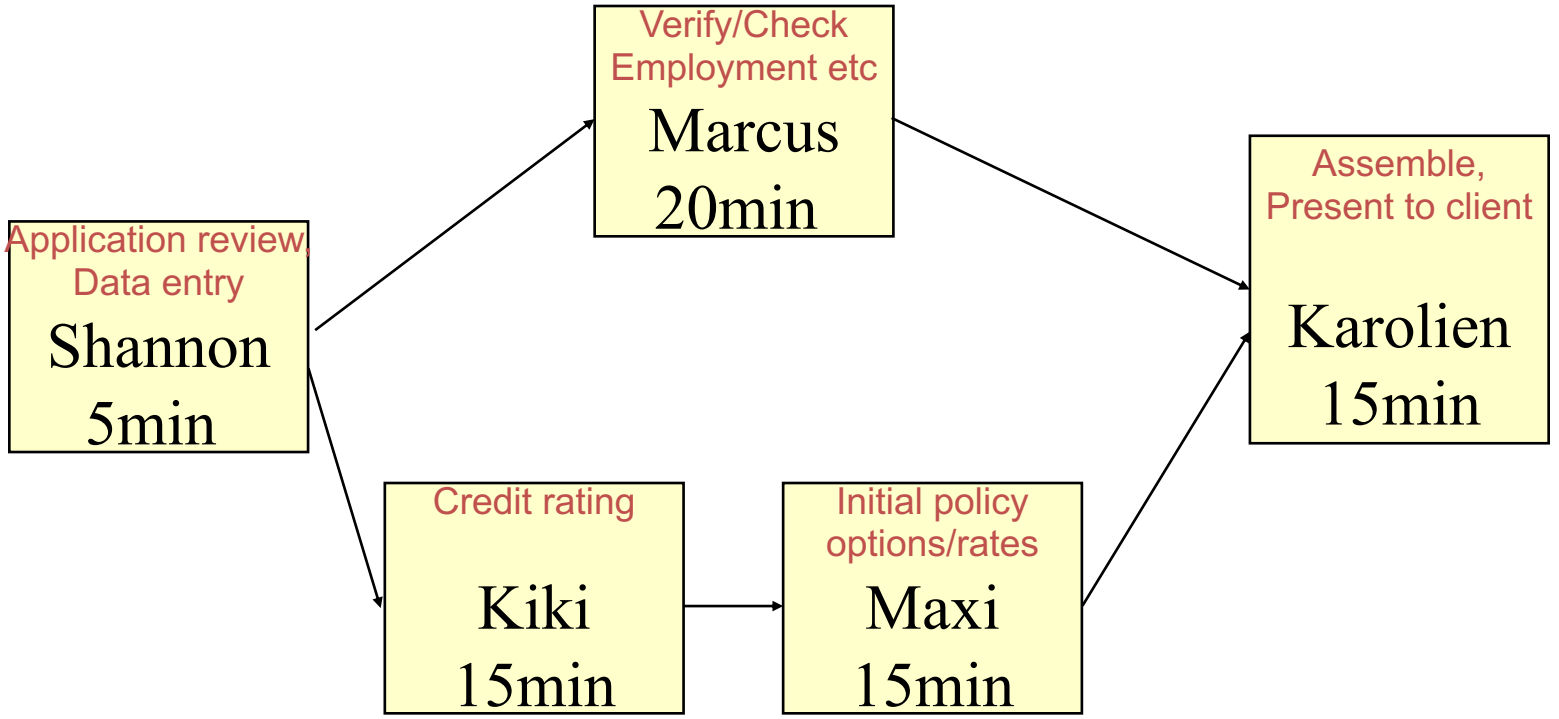
- Determines the project duration
- All activities on the critical path are **critical activities**
  Any delay in critical activities will delay the whole project
- This information allows us to allocate resources among activities to find appropriate tradeoffs between **project duration** and **project cost**



Comparison: Critical Path and Bottleneck

CRITICAL PATH	BOTTLENECK
Determines the project *duration*	Determines the process *capacity*
To *shorten* the project duration, focus on the critical path	To *increase* the process capacity, focus on the bottleneck
Critical path may *change* when adding resources to critical activities	Bottleneck may *shift* when adding resources to bottleneck

Analyzing Process Performance: Mortgage Application



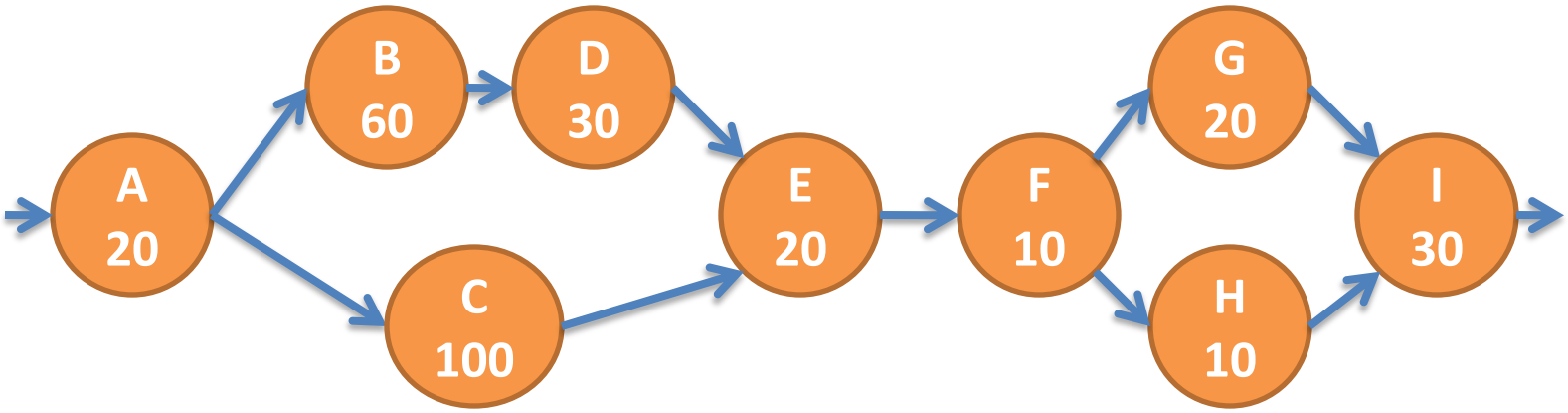
- Who is the bottleneck?
- What is the critical path?

Another Example

- Designing and building a playground

Code	Activity	Time (days)	Immediate Predecessors
A	Planning	20	None
B	Purchasing	60	A
C	Excavation	100	A
D	Sawing	30	B
E	Placement	20	C, D
F	Assembly	10	E
G	Infill	20	F
H	Outfill	10	F
I	Decoration	30	G, H

Example: Critical Path Diagram



- How long will it take to complete the project?

Path	# Days
A-B-D-E-F-G-I	190
A-B-D-E-F-H-I	180
A-C-E-F-G-I	200
A-C-E-F-H-I	190

Adding Cost Information

- Activity times are not independent of costs
  - Can be reduced at a cost (by adding resources)
- "**Crashing**" an activity refers to reducing the time it takes to complete the activity
  - **"Crash time"** is the minimum possible time to complete an activity
  - **"Crash cost"** is the cost associated with the crash time
  - We allow partial crashing with proportional cost

Time-Cost Trade-off

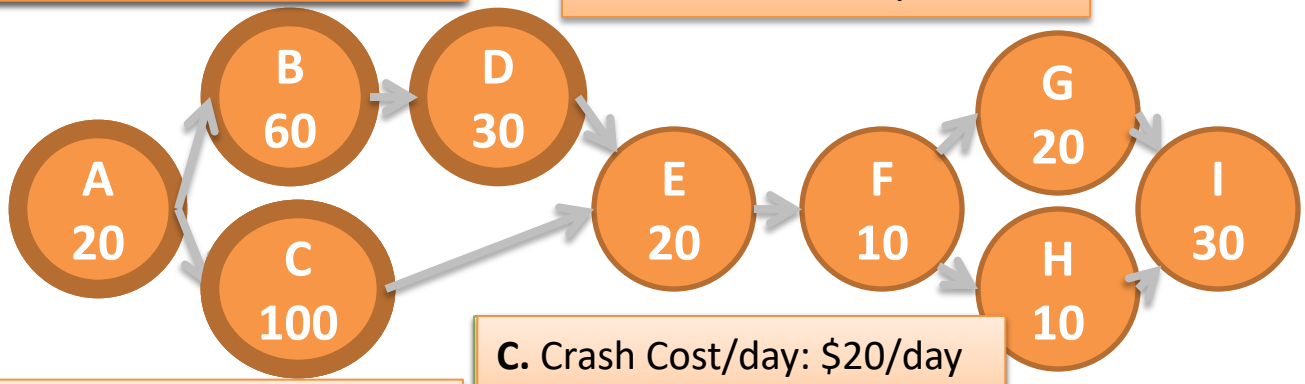
Code	Activity	Time (days)	Immediate Predecessors	Cost	Crash Time (days)	Crash Cost
A	Planning	20	None	$300	15	$450
B	Purchasing	60	A	$2100	50	$2140
C	Excavation	100	A	$4000	75	$4500
D	Sawing	30	B	$2850	20	$3000
E	Placement	20	C, D	$500	**Cannot be crashed**	
F	Assembly	10	E	$200		
G	Infill	20	F	$400		
H	Outfill	10	F	$600		
I	Decoration	30	G, H	$1350		

- Determine a cost effective way to reduce the project completion to 175 days

Keep a Score Card While Crashing Activities

B. Crash Cost/day: $4/day
Crash Limit: 10 Days

D. Crash Cost/day: $15/day
Crash Limit: 10 Days



C. Crash Cost/day: $20/day
Crash Limit: 25 Days

A. Crash Cost/day: $30/day
Crash Limit: 5 Days

Path	# Days
A-B-D-E-F-G-I	190
A-B-D-E-F-H-I	180
A-C-E-F-G-I	200
A-C-E-F-H-I	190

Cost	# Days	Critical Paths	Crashable Tasks	Best Option

Keep a Score Card While Crashing Activities

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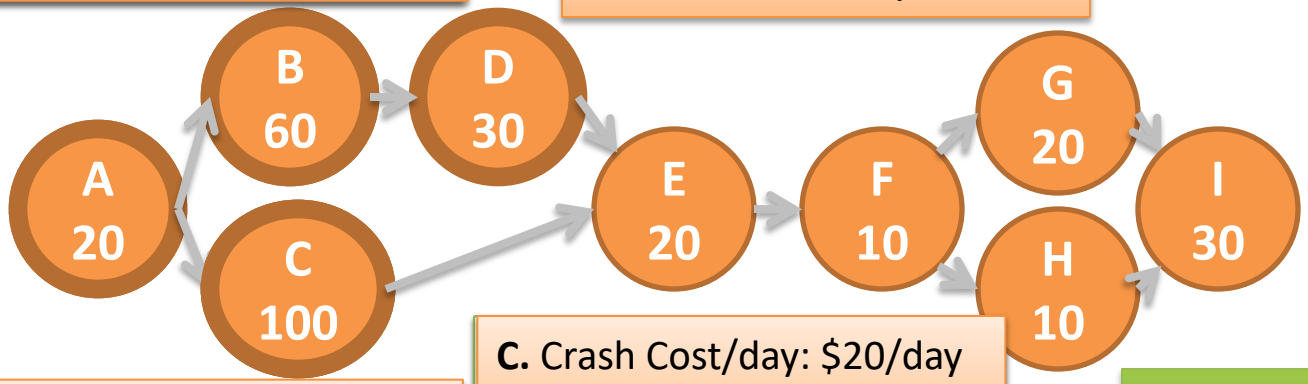

C. Crash Cost/day: $20/day
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A. Crash Cost/day: $30/day
Crash Limit: 5 Days

Path	# Days
A-B-D-E-F-G-I	190
A-B-D-E-F-H-I	180
A-C-E-F-G-I	200
A-C-E-F-H-I	190

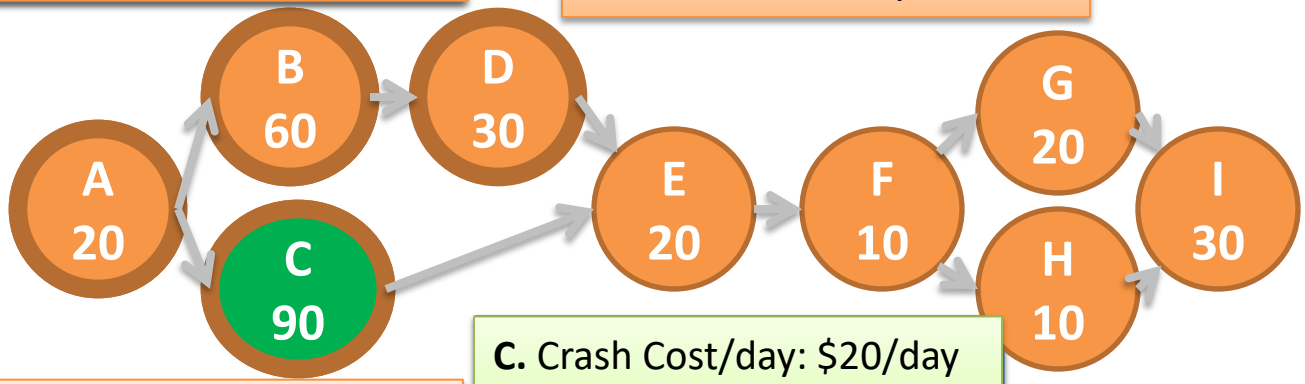
How much can we crash C?

Cost	# Days	Critical Paths	Crashable Tasks	Best Option
$12,300	200	A-C-E-F-G-I	A, C	C

Keep a Score Card While Crashing Activities

B. Crash Cost/day: $4/day
Crash Limit: 10 Days

D. Crash Cost/day: $15/day
Crash Limit: 10 Days



C. Crash Cost/day: $20/day
Crash Limit: **15** Days

A. Crash Cost/day: $30/day
Crash Limit: 5 Days

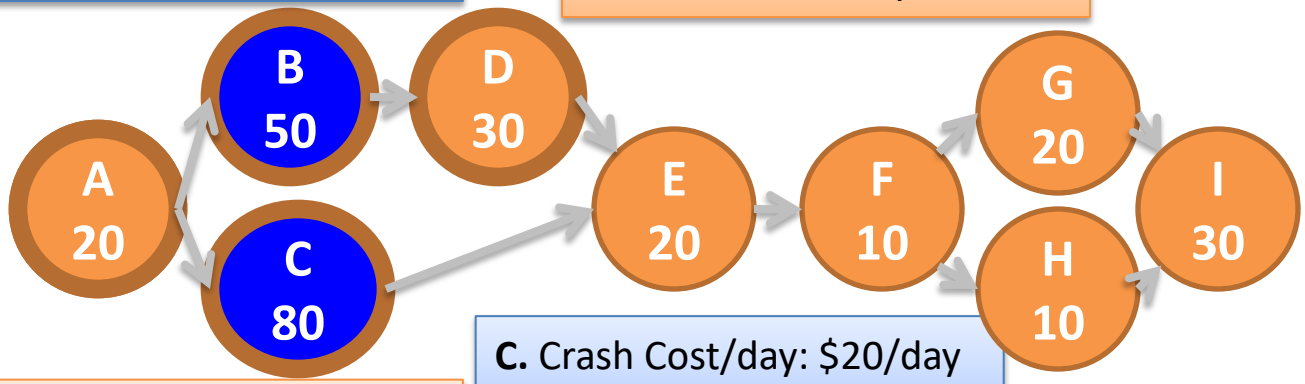
Path	# Days
A-B-D-E-F-G-I	190
A-B-D-E-F-H-I	180
A-C-E-F-G-I	190
A-C-E-F-H-I	180

Cost	# Days	Critical Paths	Crashable Tasks	Best Option
$12,300	200	A-C-E-F-G-I	A, C	C
$12,500	190	A-C-E-F-G-I and A-B-D-E-F-G-I	A, B, C, D	B and C

Keep a Score Card While Crashing Activities

B. Crash Cost/day: $4/day
Crash Limit: **0** Days

D. Crash Cost/day: $15/day
Crash Limit: 10 Days



C. Crash Cost/day: $20/day
Crash Limit: **5** Days

A. Crash Cost/day: $30/day
Crash Limit: 5 Days

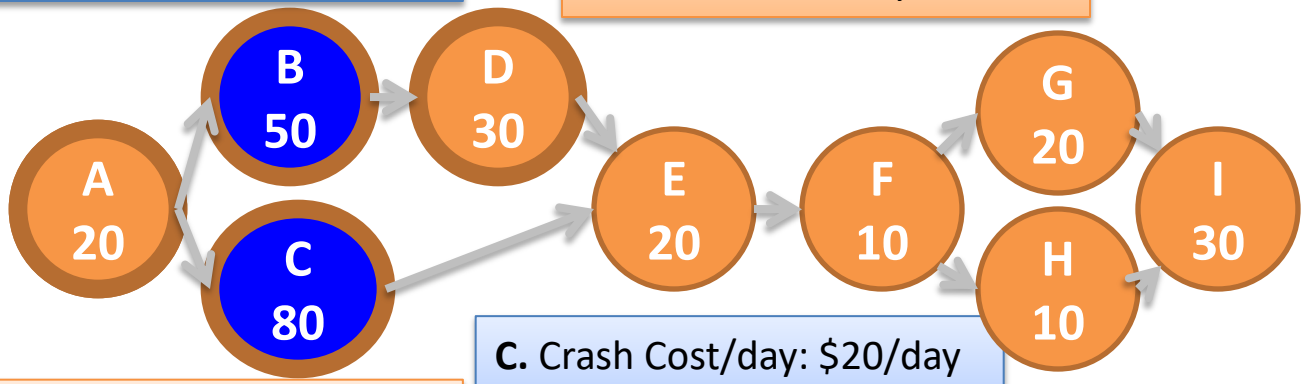
Path	# Days
A-B-D-E-F-G-I	180
A-B-D-E-F-H-I	170
A-C-E-F-G-I	180
A-C-E-F-H-I	170

Cost	# Days	Critical Paths	Crashable Tasks	Best Option
$12,300	200	A-C-E-F-G-I	A, C	C
$12,500	190	A-C-E-F-G-I and A-B-D-E-F-G-I	A, B, C, D	B and C
$12,740	180	A-C-E-F-G-I and A-B-D-E-F-G-I	A, C, D	A

Keep a Score Card While Crashing Activities

B. Crash Cost/day: $4/day
Crash Limit: **0** Days

D. Crash Cost/day: $15/day
Crash Limit: 10 Days



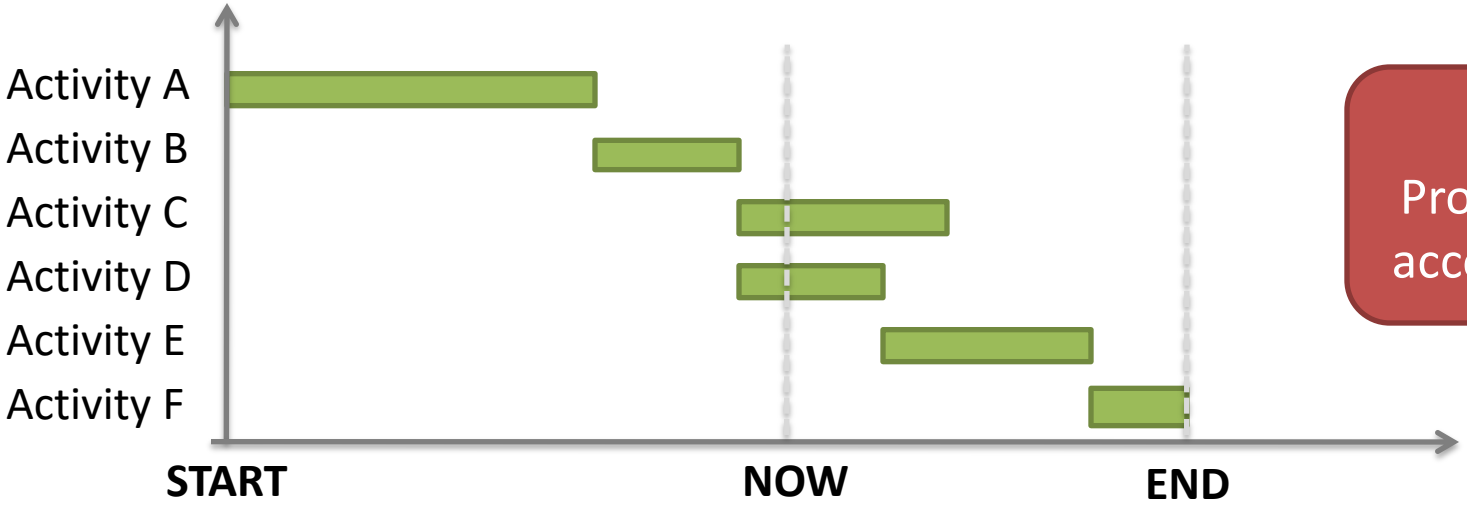
C. Crash Cost/day: $20/day
Crash Limit: **5** Days

A. Crash Cost/day: $30/day
Crash Limit: 5 Days

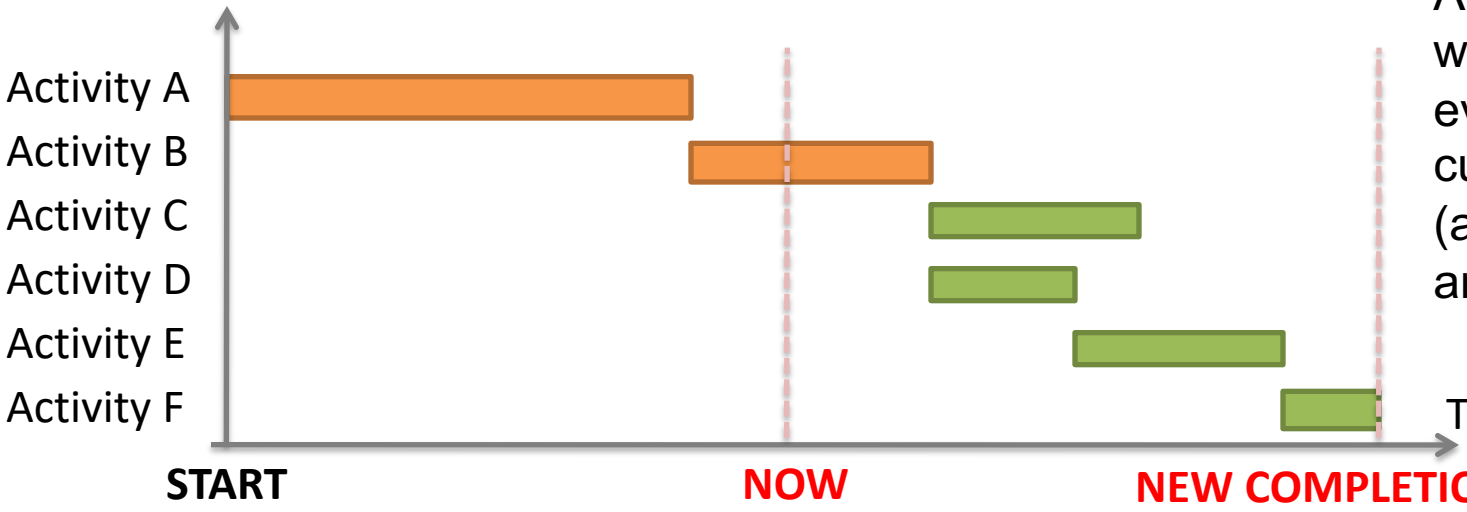
Path	# Days
A-B-D-E-F-G-I	180
A-B-D-E-F-H-I	170
A-C-E-F-G-I	180
A-C-E-F-H-I	170

Cost	# Days	Critical Paths	Crashable Tasks	Best Option
$12,300	200	A-C-E-F-G-I	A, C	C
$12,500	190	A-C-E-F-G-I and A-B-D-E-F-G-I	A, B, C, D	B and C
$12,740	180	A-C-E-F-G-I and A-B-D-E-F-G-I	A, C, D	A
$12,890	175	**A-C-E-F-G-I** and **A-B-D-E-F-G-I**		

Other Project Management Tools?

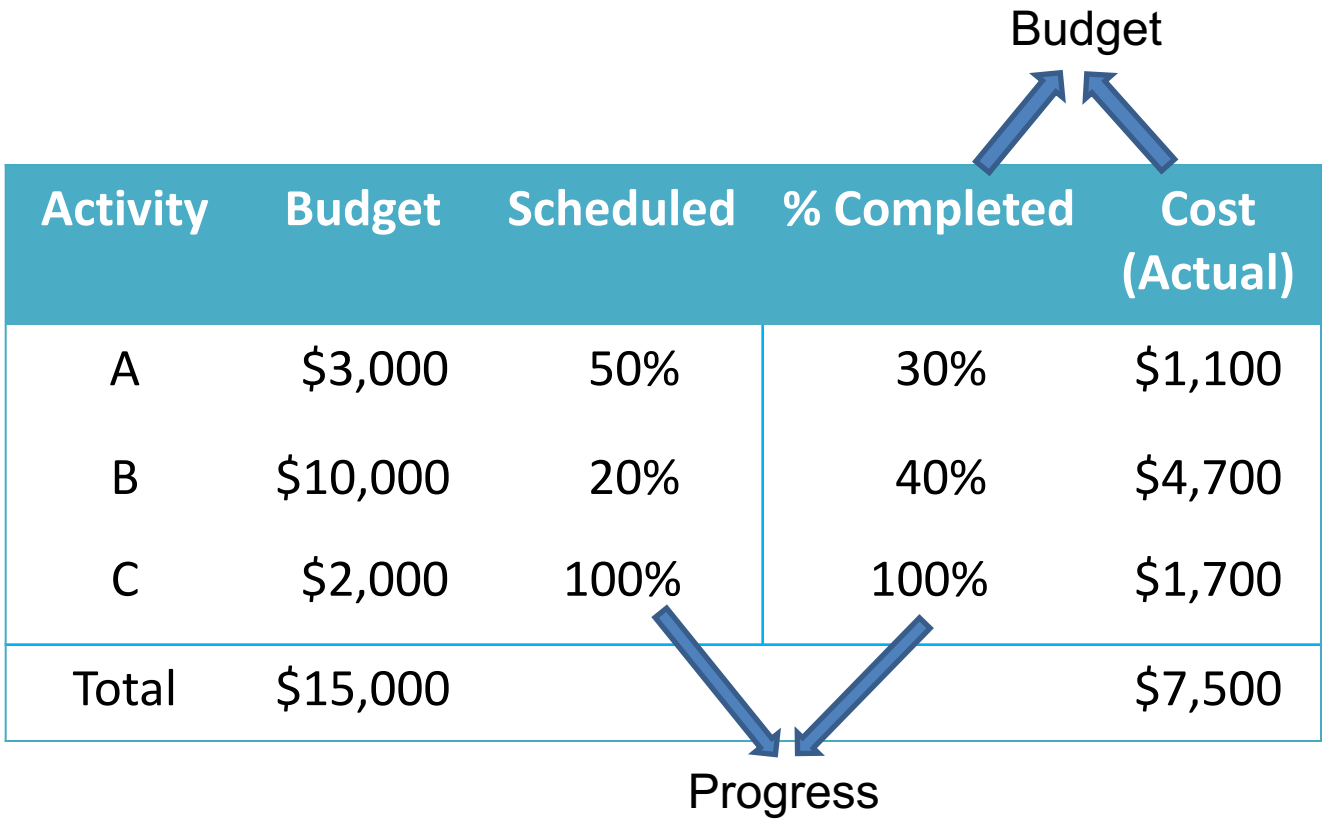


But …
Projects never go according to plan!



At any time point, we need to evaluate our current progress (according to time and cost).

Estimating New Completion Time and Budget



Activity	Budget	Scheduled	% Completed	Cost (Actual)
A	$3,000	50%	30%	$1,100
B	$10,000	20%	40%	$4,700
C	$2,000	100%	100%	$1,700
Total	$15,000			$7,500

In terms of progress, you can see if you are behind schedule or ahead of schedule.

In terms of the cost, you can see if you are over budget or under budget.

Elements of Time and Cost Analysis

Time

Budget

BCWS	*Budgeted* cost (“value”) of work *scheduled* (planned) to date
BCWC	*Budgeted* cost (“value”) of work *completed* (accomplished) to date
ACWC (or just “Actual”)	*Actual* cost (“value”) of work *completed* to date

Example 1.

BCWS = $100
BCWC=$105
ACWC=$95

Project is $5 worth of work ahead of schedule (BCWC-BCWS=$5), and $10 under budget (ACWC-BCWC=-$10)

Example 2.

BCWS = $100
BCWC=$80
ACWC=$95

Project is $20 worth of work behind schedule, and $15 over budget

Time-Cost Analysis: Example

Activity	Budget	Scheduled	% Completed	ACWC (Actual)	BCWS	BCWC
A	$3,000	50%	30%	$1,100		
B	$10,000	20%	40%	$4,700		
C	$2,000	100%	100%	$1,700		
Total				$7,500		

Is the project ahead of or behind schedule?

$1,400 or (6900-5500)/5500 = 25.5% ahead of schedule

Is the project over or under budget?

$600 or (7500-6900)/6900 = 8.70% above the budget