University of Waterloo

Civil Engineering

CIV E 596 – CONSTRUCTION MANAGEMENT Course Outline Winter 2005

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Objectives:
This course focuses on the successful management of construction projects within budget, deadlines, and resource limits. Students will learn the basics of cost estimating, scheduling, bidding, and project control. The course focuses on the use of computer tools to train students on:

- Project delivery approaches and contract types
- Detailed cost estimation
- Planning and Scheduling
- Sharing multi-project resources
- Scheduling of Repetitive Projects (Infrastructure)
- Resource-constrained scheduling & Resource leveling
- Time-Cost Trade-off Analysis
- Analysis of project uncertainty
- Bidding Strategy Models
- Cash flow analysis
- Project control techniques

Textbook: Hegazy 2002, “Computer-Based Construction Project Management,” Prentice Hall.

References on Project Management:

- Books on Project Management and Construction Management;
- Trade magazines (e.g., ENR);
- International journals such as the Journal of Construction Eng. and Management (ASCE) and the Journal of Computing in Civil Eng. (ASCE);
- Databases such as “current contents” and “compendex”;
- International organizations such as Project Management Institute (PMI) and American Association of Cost Engineers (AACE);
- A lot of computer software programs;
- Internet search;
- Government publications such as statistics Canada, etc.

Evaluation:

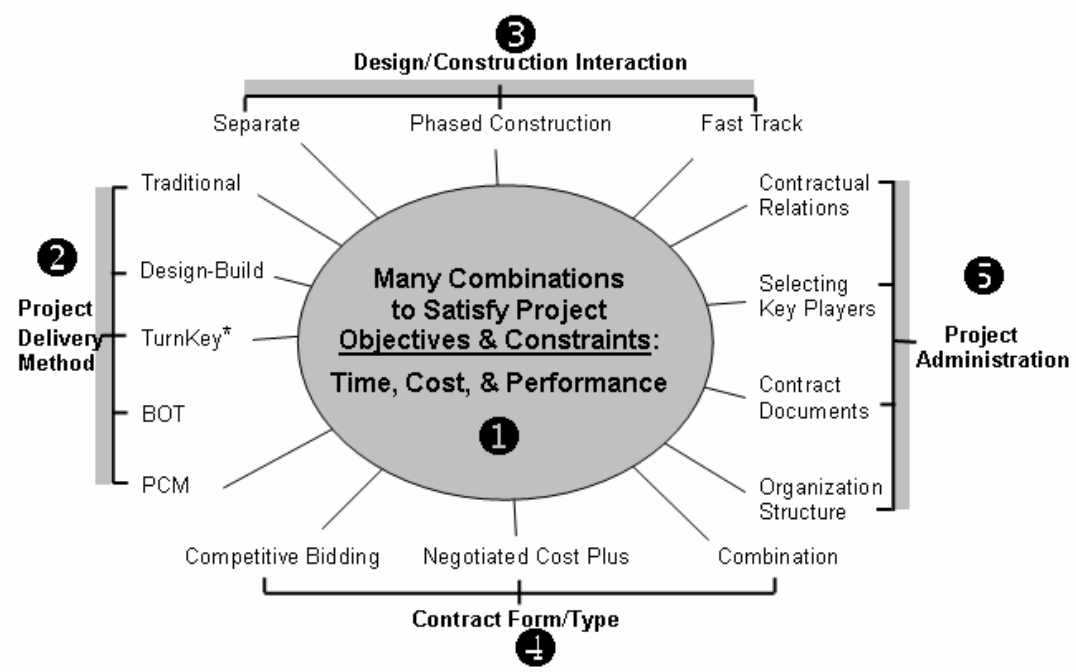
Assignments	10%
Midterm examination	20%
Project	20%
Final Examination:	50%

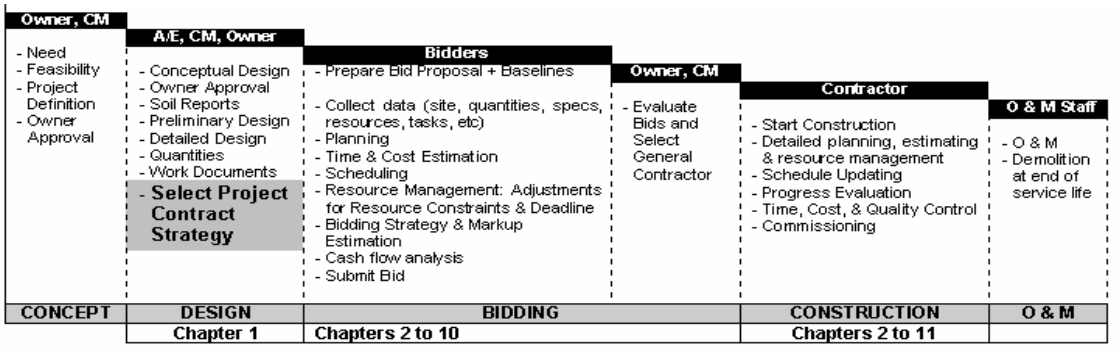
Chapter 1

- Anatomy of Construction Expenditures

- Project Life Cycle Phases

- Project Contract Strategy





Management Functions Made at the Different Phases of a Project Life Cycle

Review Questions:

- Construction Management concerns with controlling the: (1)_____; (2)_____; & (3)_____ of construction.

- Turn-Key projects are generally more risky to the _____ (contractor/owner).

- Building projects are often constructed based on _____ type of contracts.

- A bid bond is:_____; while a performance bond is:

_____.

- The differrence between Phased and Fast-Track construction is that: _____

_____.

- Addenda is _____; while a change order is:

_____.

- Preliminary site visit is done by:_____ for the purpose of_____; while the Secondary site visit is done by _____ for the purpose of _____.

-Three types of Matrix organizations are: (1) _____ ;(2)_____; & (3) _____, with _____ being the most suitable for construction projects.

- Important elements included in a call for bidders are: (1) _____; (2) _____.

- A bid package is prepared by:_____; and includes: (1)_____; (2)_____; & (3)_____.

- A drawback of a "cost plus a fixed-percent" contract is that _____.

- A drawback of a "cost plus a fixed-fee" contract is that _____.

- One benefit of the Turn-Key approach is:_____; and one of its drawbacks is:_____.

- Two advantages of the PCM approach are: (1)_____; and (2)_____.

- Draw simple sketches for the contractual relationships in the following cases. Use a (**$**) on your arrows to represent contract relationships and an (**A**) to represent agent relationships.

Turn Key PCM Owner manager

Planning: Part 1 – Network Diagrams

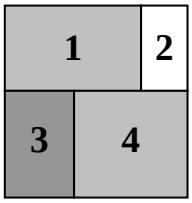
Planning Steps:

1. Work Breakdown Structure (WBS) linked to OBS

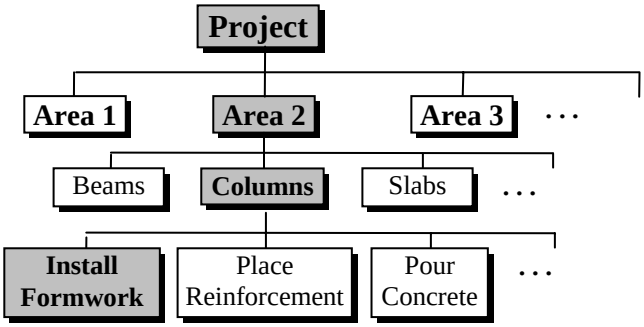
- Production activities: excavation, formwork, concreting, and so on. Each having costs, duration, etc.;
- Procurement activities: materials and manufactured equipment needed for any production activities.
- Management decision activities: activities that are related to management decisions such as vacations, special delays, approvals, etc.
- Hammock activities: activities that are dependent on other ones. Example is dewatering, which is required as long as subsurface work is being carried out;
- Dummy activities: activities needed for presentation purposes to maintain logical relationships.

The **MasterFormat** list developed by the Construction Specifications Institute – 16 divisions – is a good checklist for project activities.

Project Areas



WBS (work elements)



2. Identifying Activity Logical Relationships

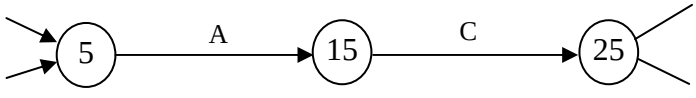
Jigsaw puzzle - Brainstorming
Which activities are parallel? Which activities must precede? Which activities must succeed
Remove redundant relations and produce a table of activities and IPAs
Calculate Sequence Steps

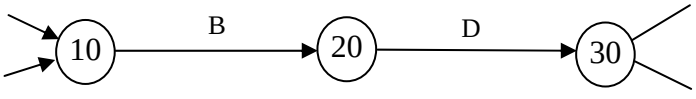
Activity	IPAs	SS	SS
A	----	-------	-------
B	A	-------	-------
C	A	-------	-------
D	A	-------	-------
E	B	-------	-------
F	D	-------	-------
G	B	-------	-------
H	C, E	-------	-------
I	F	-------	-------
J	G, H, I	-------	-------

1		2		3		4		5			

3. Drawing the Project Network Diagram

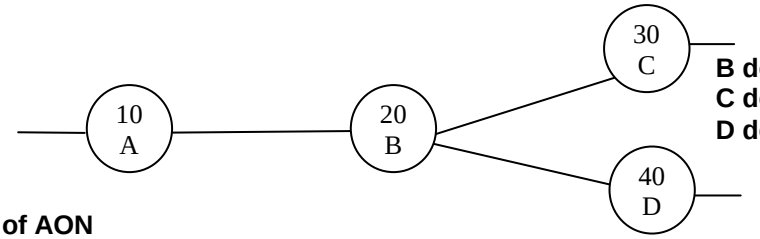
Activity on Arrow (AOA) - We may need to add dummy activities to preserve logical relations





C depends on A & B
D depends on B only.

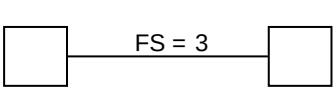
Activity on Node (AON)

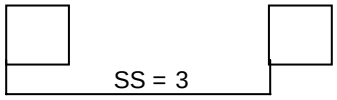


B depends on A
C depends on B
D depends on B

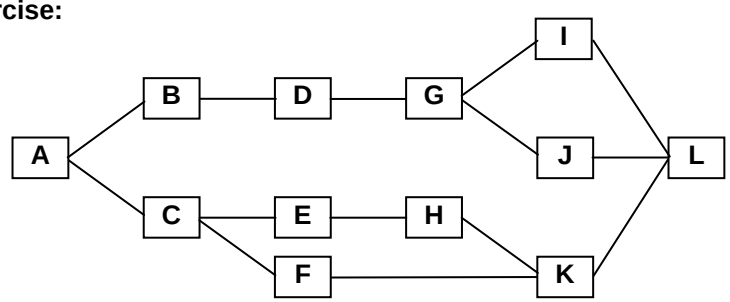
Benefits of AON

Does not need dummy activities.
The sequence step calculation also made the AON to look more organized and clearer to read.
The technique is also well suited to computer implementation.
Has a major advantage in terms of the types of logical relationships it allows
(Finish-to-Start, Start-to-Start, Start-to-Finish, and Finish-to-Finish).



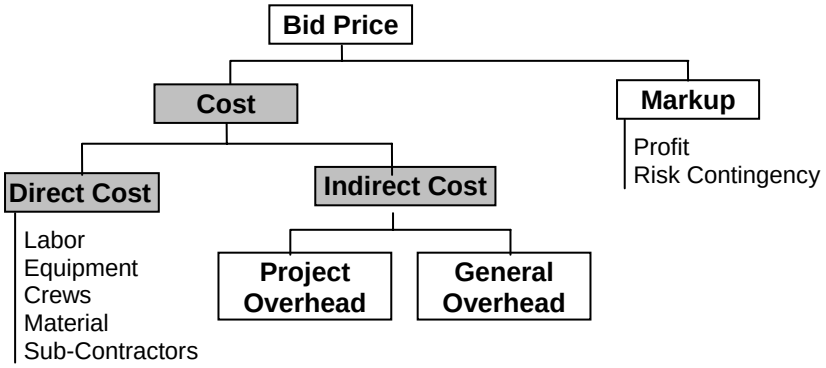


Exercise:



No.	Activity	Predecessors			Successors		
		P1	P2	P3	S1	S2	S3
1	**A**	---	---	---	---	---	---
2	**B**	---	---	---	---	---	---
3	**C**	---	---	---	---	---	---
4	**D**	---	---	---	---	---	---
5	**E**	---	---	---	---	---	---
6	**F**	---	---	---	---	---	---
7	**G**	---	---	---	---	---	---
8	**H**	---	---	---	---	---	---
9	**I**	---	---	---	---	---	---
10	**J**	---	---	---	---	---	---
11	**K**	---	---	---	---	---	---
12	**L**	---	---	---	---	---	---

Planning: Part 2 – Estimating



Detailed Estimating: An Example

If the **daily production** rate of the crew (CR-06) that works in a certain activity is **175 units/day** (e.g., ft^2/day) and the total crew cost per day is $1,800. The material needed for daily work is 4.5 units of M1 ($100/unit).
a) Calculate the time and cost it takes the crew to finish 1,400 units; and
b) Calculate the total unit cost. Consider an 8 hour work day.

Assignment 3

Description: The data you collected while compiling a bid for a new project are as follows:

No	Activity	Depend on	Estimate 1	Estimate 2	Estimate 3
1	**Site Layout**	-----	CR1, 8 hrs Q= 1, Prod.= 0.5 *	CR1, 12 hrs Q= 1, Prod.= 0.5	Subcontractor S1 Duration = 1
2	**Excavation**	1	CR2, 8 hrs Q= 600, Prod.= 100	CR2, 12 hrs Q= 600, Prod.= 100	Subcontractor S2 Duration = 3
3	**Forms**	2	CR3, 8 hrs Q= 300, Prod.= 100	CR3, 12 hrs Q= 300, Prod.= 100	Subcontractor S3 Duration = 1
4	**Concrete**	3	CR1, 8 hrs Q= 300, Prod.= 150	CR1, 12 hrs Q= 300, Prod.= 150	Subcontractor S4 Duration = 1
5	**Rough Plumbing**	1	CR5, 8 hrs Q=3000, Prod.= 1000	CR5, 12 hrs Q=3000, Prod.= 1000	Subcontractor S5 Duration = 2
6	**Place Blocks**	5	CR6, 8 hrs Q= 200, Prod.= 50	CR6, 12 hrs Q= 200, Prod.= 50	Subcontractor S6 Duration = 2
7	**Rough Elec.**	5	CR7, 8 hrs Q= 300, Prod.= 75	CR7, 12 hrs Q= 300, Prod.= 75	Subcontractor S7 Duration = 2
8	**Place Home**	6	CR8, 8 hrs Q= 1, Prod.= 0.5	CR8, 12 hrs Q= 1, Prod.= 0.5	Subcontractor S8 Duration = 1
9	**Remove forms**	4	CR9, 8 hrs Q= 300, Prod.= 75	CR9, 12 hrs Q= 300, Prod.= 75	Subcontractor S9 Duration = 2
10	**Cure Concrete**	4	One Quote for 7 days and $400		
11	**Hookup finish**	7, 8	CR11, 8 hrs Q= 30, Prod.= 10	CR11, 12 hrs Q= 30, Prod.= 10	
12	**Cleanup**	9, 10, 11	CR12, 8 hrs Q= 1, Prod.= 0.25	CR12, 12 hrs Q= 1, Prod.= 0.25	Subcontractor S12 Duration = 2

Notes: * Q = Quantity of work; Prod. = Regular production rate in an 8-hr day; S = subcontractor.
- Seasonal productivity factors for all activities are: Winter (0.7), Spring (1.0), & Fall (0.85).

Project Constraints:
Start date = June 1, 04;
Resource Limit is 4 L2;
Markup = 5%;
Retainage = 10%;
Interest/period = 1%;
Mobilization = 0%;
Indirects = $300/day;
Reports every 7 days;
Suppliers' credit = 20%;
Penalty =$10,000/day; &
Incentive =$2,000/day.

Labor:

Code	Basic $/hr
L1	25
L2	25
L3	25
L4	25
L5	25

Equipment:

Code	Basic $/hr
E1	50
E2	50
E3	50
E4	50
E5	50

Deadline = 90% of project duration when all activities use there first estimate (round up to nearest day).

Crews:

Code	Composition
CR1	L1+L2
CR2	L3+E1
CR3	L4+2L2+E2
CR4	L4+3L2+E3
CR5	L5+2L2
CR6	L3+E4+L2
CR7	L4+E4+L2
CR8	E5+3L2
CR9	L4+2L2+E2
CR11	E4+2L3
CR12	4L2+E3

Subs:

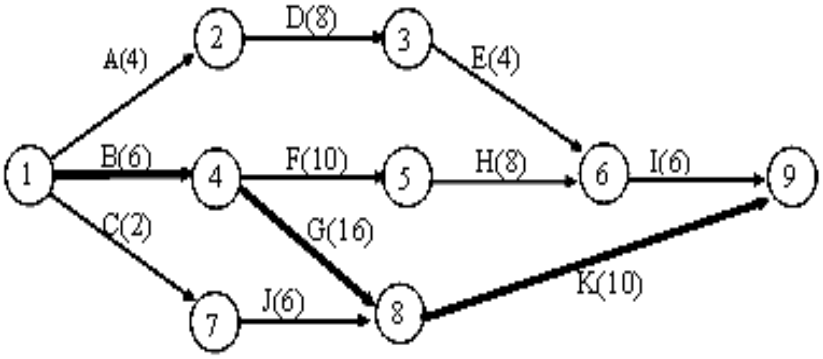
Code	Basic Cost
S1	$1,200
S2	$5,350
S3	$4,500
S4	$3,500
S5	$3,000
S6	$5,000
S7	$5,200
S8	$2,800
S9	$6,909
S12	$7,000

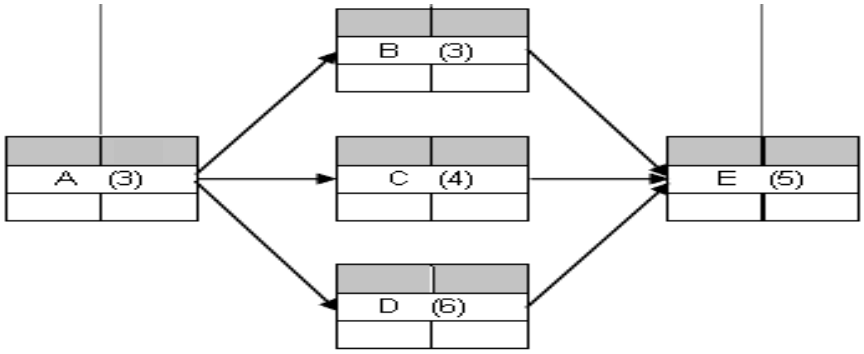
Requirements:

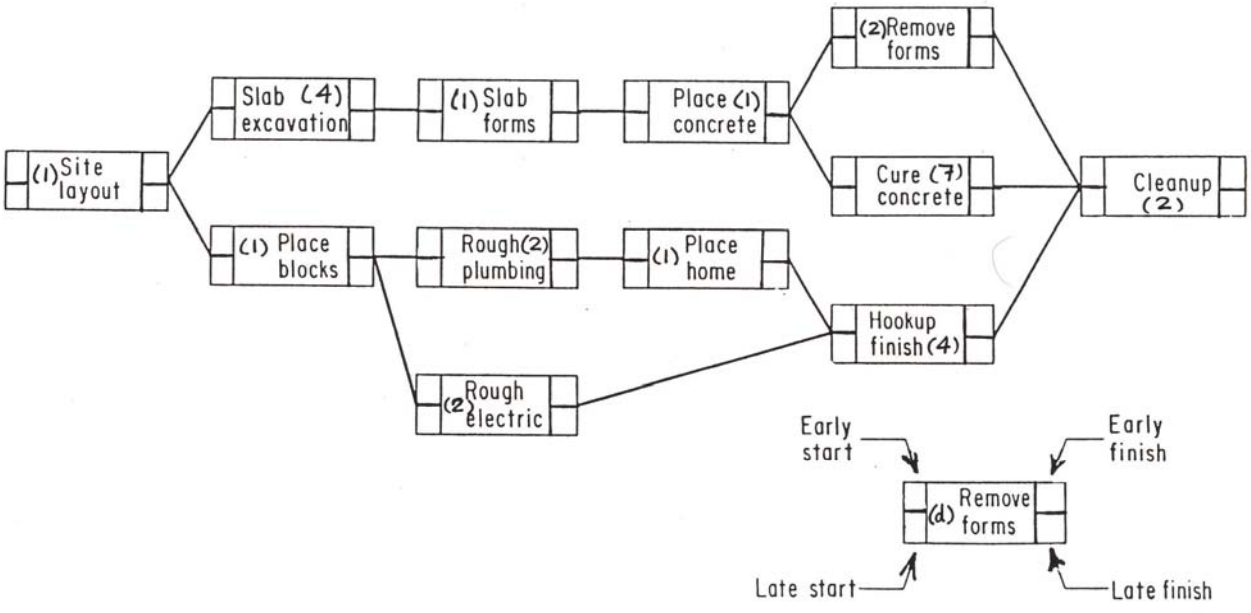
What is your best bid proposal if project start date is June 1, 2004.

Compare project cost and time for three project start-date possibilities:
Feb. 1, 2004
June 1, 2004
Oct. 1, 2004.

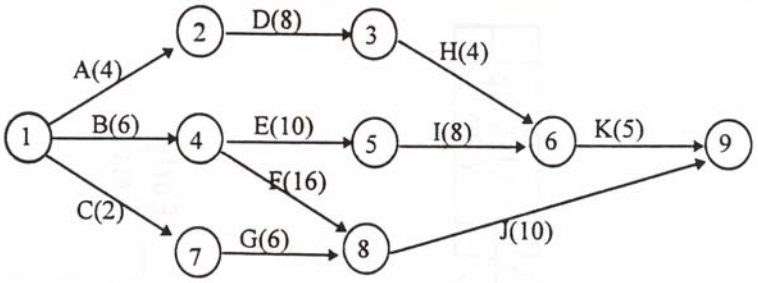
Scheduling


A(4)
D(8)
E(4)
B(6)
F(10)
H(8)
I(6)
C(2)
G(16)
J(6)
K(10)
1
2
3
4
5
6
7
8
9

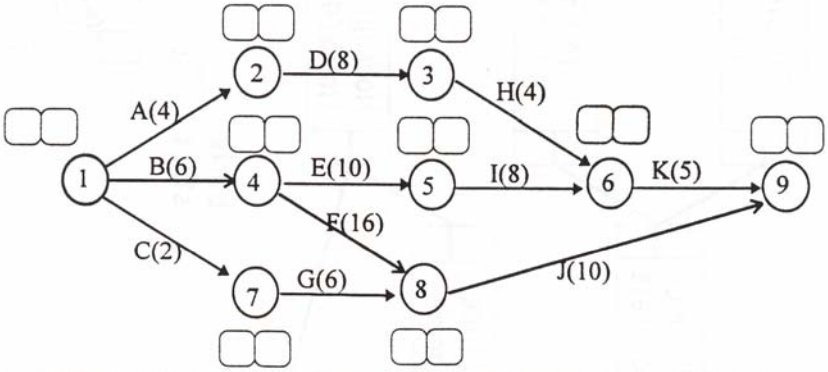

A (3)
B (3)
C (4)
D (6)
E (5)


(1) Site layout
Slab (4) excavation
(1) Slab forms
Place (1) concrete
(2) Remove forms
Cure (7) concrete
Cleanup (2)
(1) Place blocks
Rough (2) plumbing
(1) Place home
Hookup finish (4)
(2) Rough electric
Early start
Early finish
(d) Remove forms
Late start
Late finish

REVIEW PROBLEM



- Calculate ES, LF, & TF for all activities. What are the critical ones ?
- Draw an Early Bar Chart for the project.
- What is the effect of delaying activity H by two days on the total project duration ?



Activity	Duration	ES	LF	TF=LF-ES-d	Critical
A	4				
B	6				
C	2				
D	8				
E	10				
F	16				
G	6				
H	4				
I	8				
J	10				
K	5				

ACTIVITY	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	27	28	29	30	31	32
A																																
B																																
C																																
D																																
E																																
F																																
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H																																
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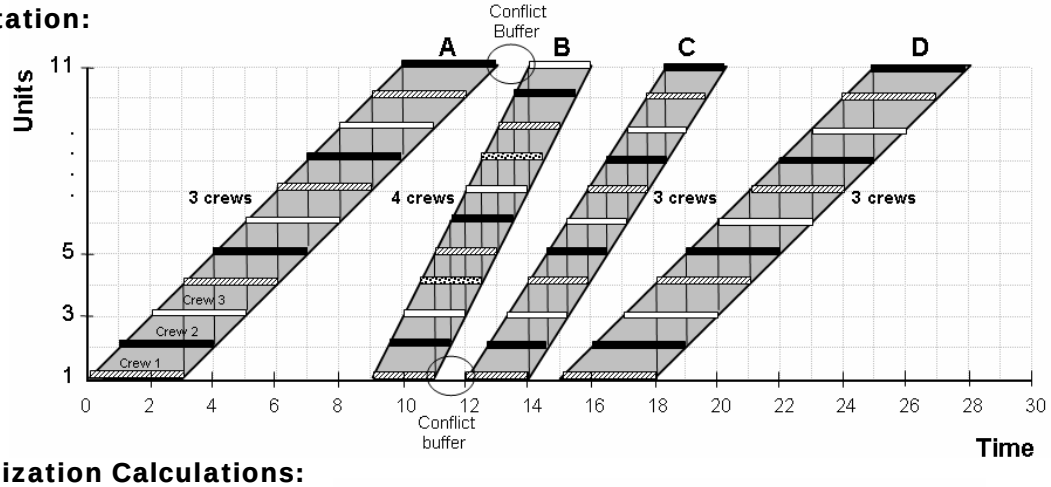
Scheduling Repetitive & Linear Projects

- Problems with CPM & PDM
- Resource-Driven Scheduling
- Crew Work Continuity
- Learning Phenomenon

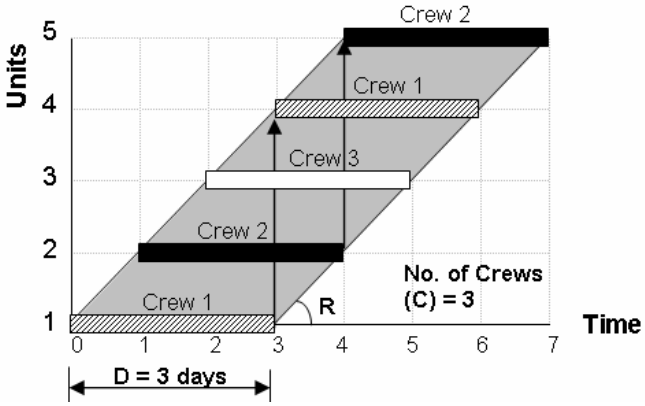
Integrated CPM & LOB Calculations:

New Representation:

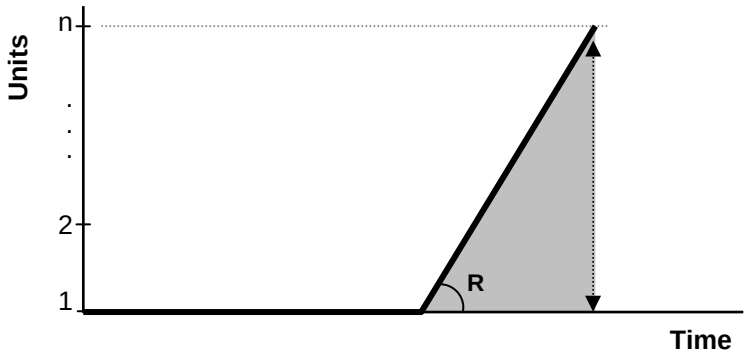


Crew Synchronization Calculations:

Crews (**C**) = (**D**) x (**R**)

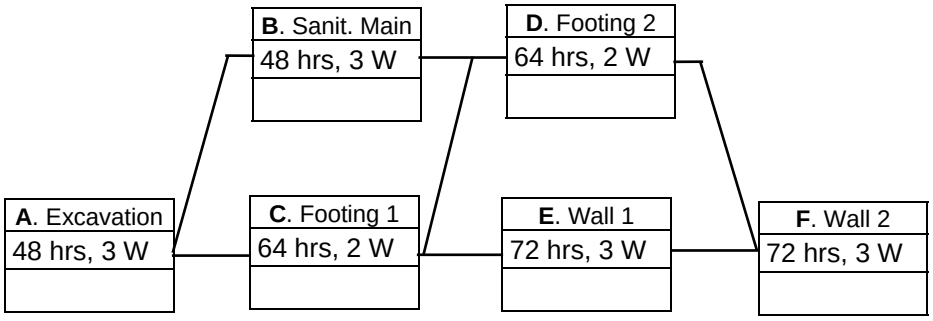


Calculating a Desired Progress Rate (R):



Example:

For this small project, the work hours and the number of workers for each activity are shown. if you are to construct these tasks for 5 houses in 21 days, calculate the number of crews that need in each activity. Draw the schedule and show when each crew enters and leaves the site;

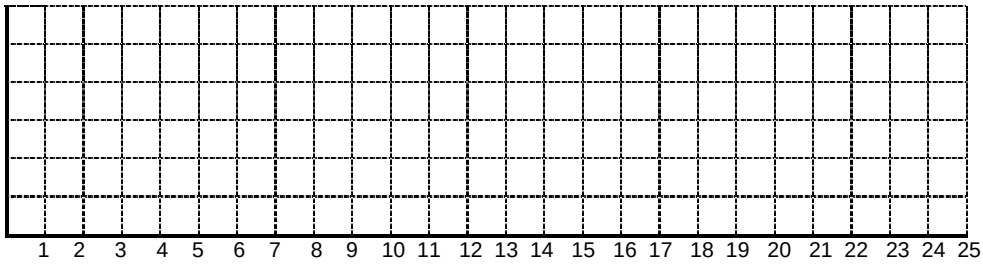


Step 1: CPM Calculation

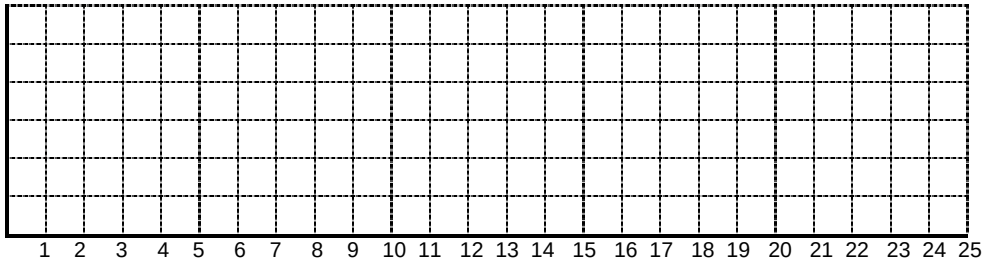
Step 2: LOB Calculations Deadline $T_L = 21$; $T_1 =$ ___ ; $n = 5$

Activity	Duration (D)	Total Float (TF)	Desired Rate (R) $(n-1) / (T_L-T_1+TF)$	Min. Crews (C) = D x R	Actual Crews (C_a)	Actual Rate (R_a) = C_a / D
A						
B						
C						
D						
E						
F						

Step 3: Draw the Chart



Draw the critical path



Assume:

- Same no. of Crews
- Activity A in unit 2 has double the duration
- Unit 4 does not need excavation.

Computer Exercise

Basic scheduling for repetitive projects

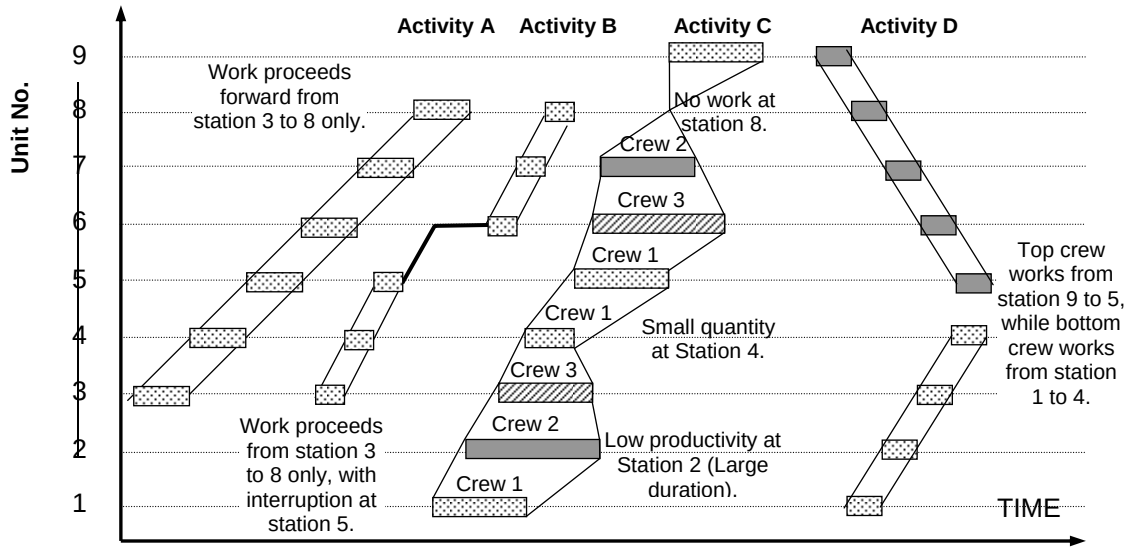
- ☐ Activate the **BAL-1.mpp** file. Look at the activities of this one unit of a small project. The duration of this unit is _____ days. Now, we have 5 units to construct within 45 days. Go ahead and activate the macro Auto_Open by selecting Tools-Macro-Macros,

- ☐ Change the number of crews in activity D into 4 crews. Do you still meet the deadline? If not, try to meet it without changing the crews. Try using interruption.

More Advanced Linear scheduling Model

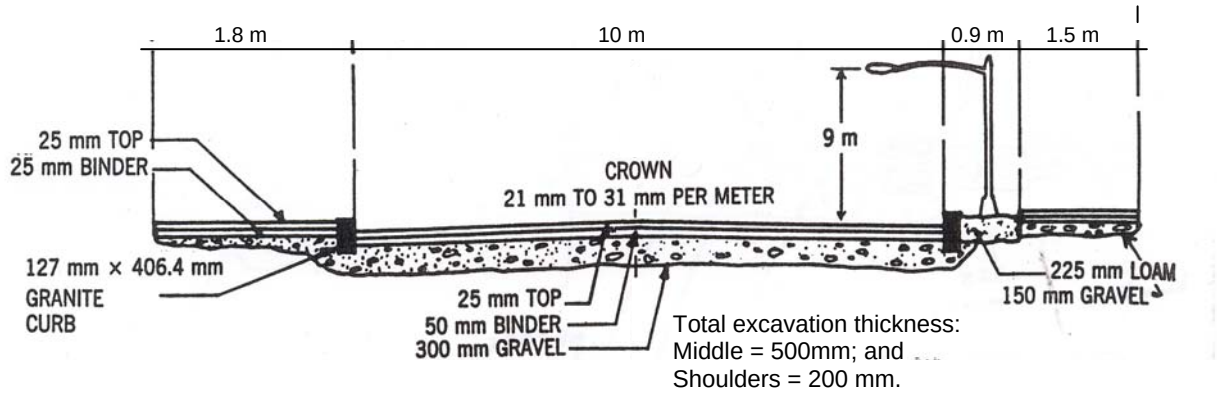
Flexible features for scheduling the activities include: color-coded or pattern-coded crews; varying quantities; productivity impact; crew interruption time; crew staggering; crew work sequence; and activities' progress speeds (slopes of lines). It is noted that the schedule is efficiently arranged with crew work continuity maintained. Also, overlapping is avoided by simply showing the activities of each path in the work network separately. In addition:

1. Activities are not necessarily repeated at all sections.
2. Activities can proceed in an ascending or descending flow. This provides work flow flexibility and provides for a way to fast-track projects;
3. Each activity has up to 3 methods of construction (e.g., normal work, overtime, or subcontractor) with associated time, cost, and crew constraints. The model can then be used to select the proper combination of methods that meet the deadline, cost, and crew constraints;
4. Activities can have non-standard durations and costs at selected sections;
5. Work interruption (layoff period) can be specified by the user at any unit of any activity; and
6. Conditional methods of construction can be specified by the user.



LINEAR SCHEDULING: Highway Example

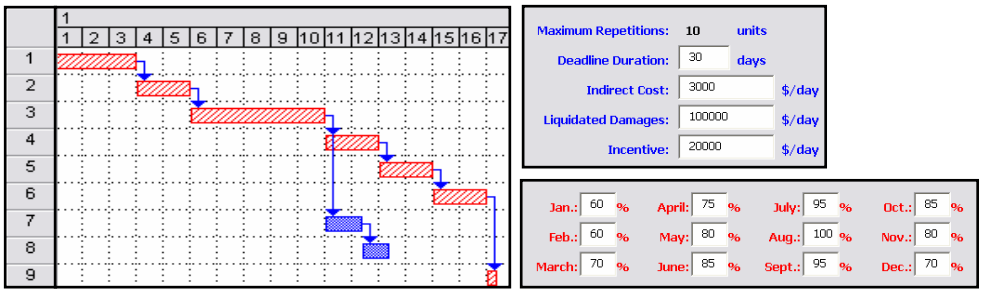
A three-kilometer highway stretch is divided to ten sections for planning purposes. Each section is 300 meters. The cross section is shown below along with activities' details.



☐ For the highway project discussed earlier, let's develop an optimum schedule considering different realistic options of crews and how they move among the ten stations. The data are as follows:

			Estimate 1		Estimate 2		Estimate 3	
Activity	Applicable Sections	Max. Crews	Cost ($)	Time (days)	Cost ($)	Time (days)	Cost ($)	Time (days)
1. Excavation, East	1 to 5	2	21,000	3	30,000	2	----	----
2. Sub-base, East		2	7,800	2	----	----	----	----
3. Base, East		3	72,000	10	80,000	8	100,000	5
4. Binder, East		1	30,000	1.2	----	----	----	----
5. Asphalt, East		1	14,400	1	----	----	----	----
6. Curbs, East		1	31,200	2	38,000	1	----	----
7. Lighting, East		2	19,245	2	25,000	1	----	----
8. Sidewalks, East		2	10,950	2	----	----	----	----
9. Paint, East to West	1 to 10	1	198	0.2	----	----	----	----
10 to 17. Same as 1-8 but at West	10 to 6	Same as activities 1 to 8.						

☐ The logical relationships within each section are the same, but the deadline for finishing the whole highway is 30 days. Seasonal productivity factors are also as shown below.

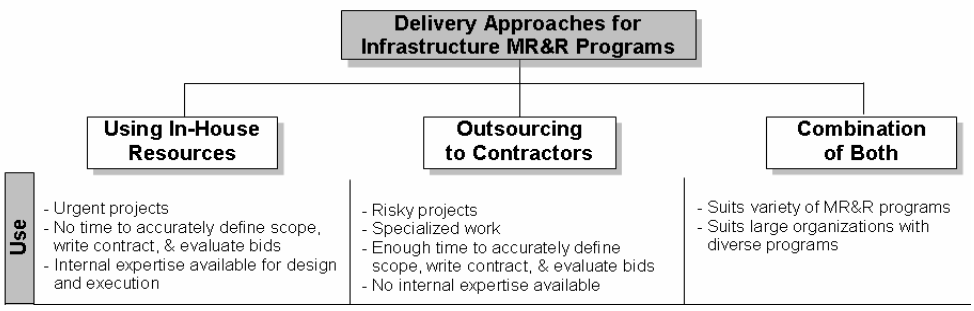


How will your plan differ if you start the whole project from one side as opposed to employing different sets of crews from both sides?

☐ Activate the **BAL-2.mpp** file, which will run the macro Auto_Open from the Tools-Macro-Macros,

Infrastructure Networks with Distributed Sites: A Bigger Challenge

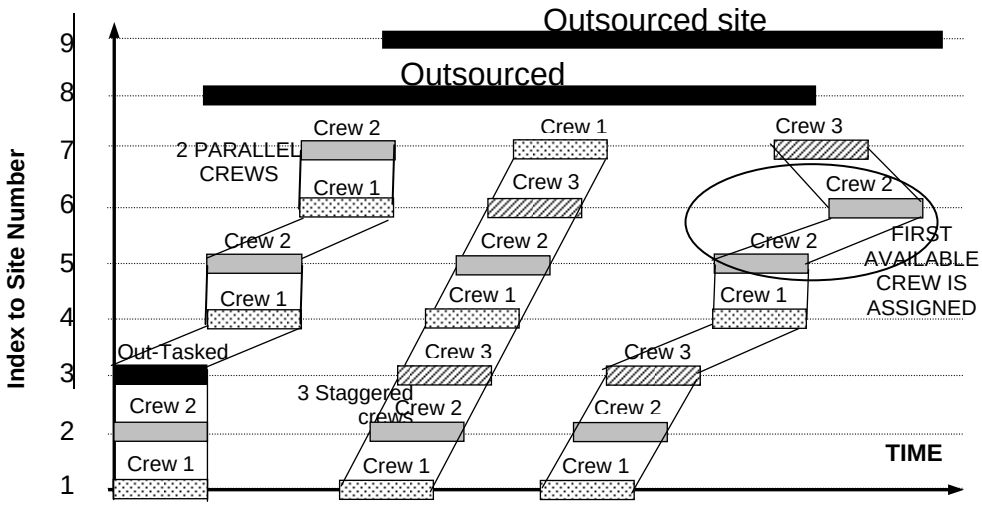
Buildings, Hispitals, Schools, Highway Spots, Bridges



Delivery approaches for MR&R programs

Effect of Site order

Scheduling of crews along multiple sites

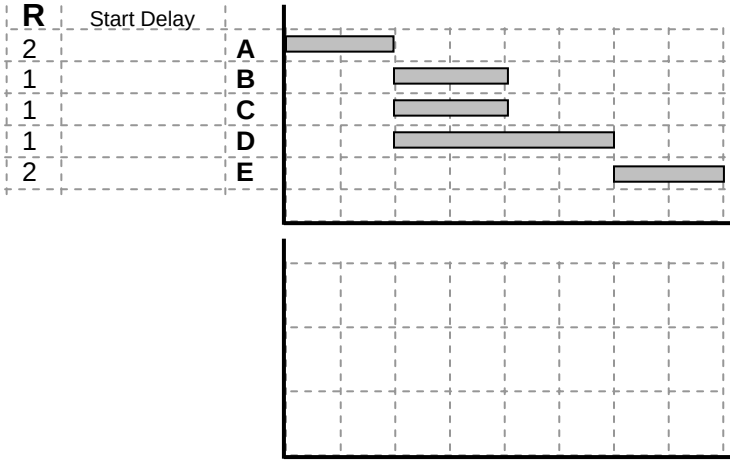


☐ From the BAL-3 directory, activate **BAL-DEMO.Exe**. Go to the resource bank, view all sites, and change the productivity factors only for the first four sites to: January 0 .7, February 0.8 and March 0.9, and leave all others as 1.0s. In BAL main screen, activate the BAL-Schedule button to access MS Project. Use Project-Information to change project start data to Jan. 2, 2002. Use the BAL Schedule toolbar button, then the Project Data button. Change the deadline to March 25, 2002. Go to the Activities tab and scroll through the activities. Change the maximum number of crews for activity "Subbase" to 3. Save and proceed. Try to meet the deadline. Use optimization options. After every trial notice the arrangement of the sites, the number of crews used, and the method of construction used. Try manually to shift the sites that take long durations later in the order. Notice the effect on time and cost. Best duration obtained is ____ days and minimum cost is_____.

Resource Leveling vs Resource Allocation

Resource Leveling:

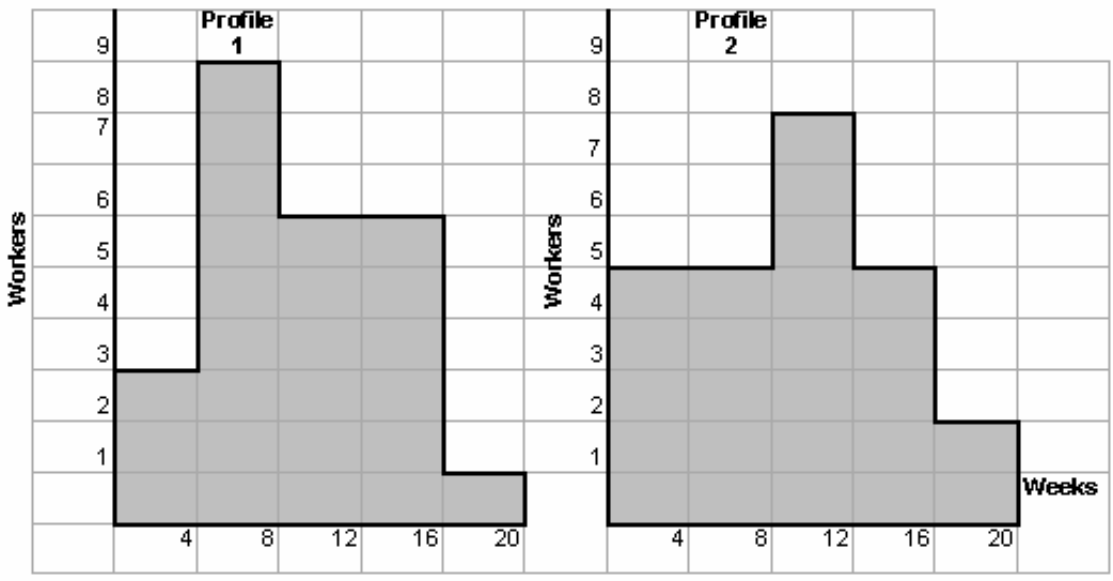
- How to smooth resource demands?
- No problem with time or resources.
- Strategy?
- Method of moments?
- Method of double moments?
- Multi-Resources?
- Desired (best) profiles?



Resource Profile:

Example:

Two schedule alternatives have associated resource profiles as shown below, which alternative would you choose and why? Also calculate the total **worker-weeks** needed for both cases:



Mx =

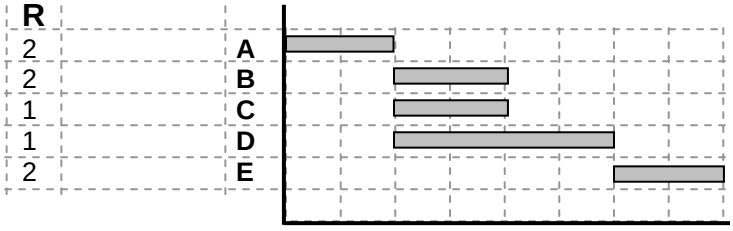
My =

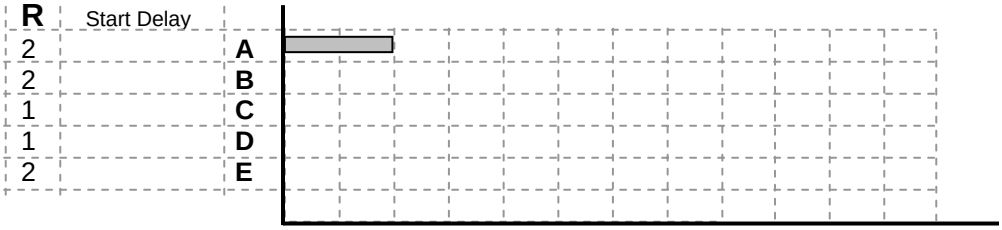
Resource Allocation:

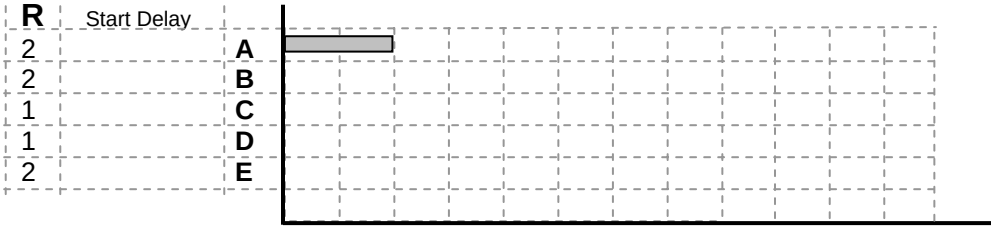
- Allocate limited resources to top-priority activities.
- Strategy?
- Heuristic rules
- Inconsistency among existing software
- Excel Implementation
- EasyPlan Optimization

Floats?

Resource limit = 2 / day

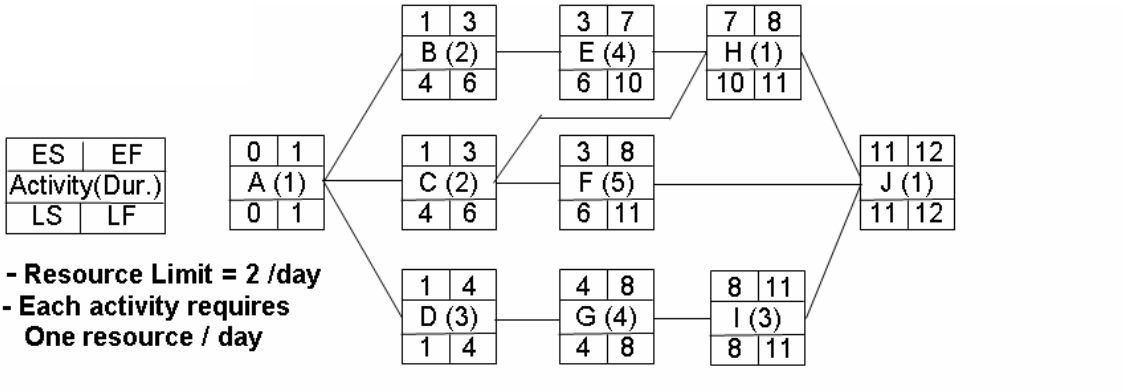






Priority Rules:

Resource Allocation Example:

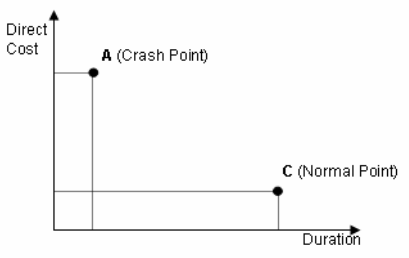


Time	Eligible Activities	Resources (limit = 2)	Duration	Rule (ELS)	Decision	Finish Time

Microsoft Project Solution?

Case of Multi-Resources? Case of Multi-Resources Multi-Skills?

Meeting Deadline

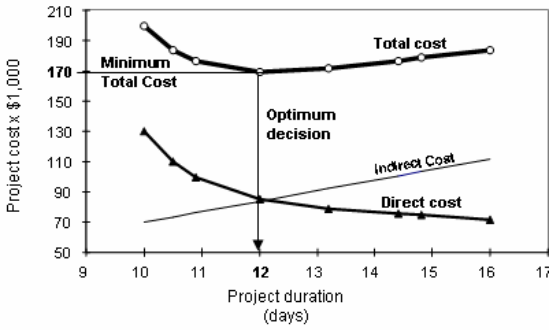


- Activity time-cost relationship? Linear vs Discrete
  (Cheap & Slow versus **Fast & Expensive)**

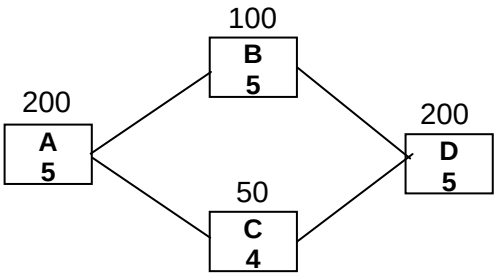
- Cost Slope?

- Project time-cost relationship?

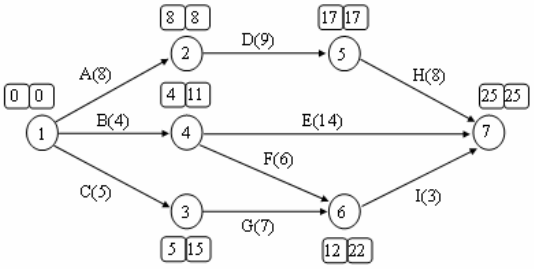
- Strategy to meet deadline?



Example 1: Durations and cost slopes are shown. We need to meet a 12-day deadline.



Example 2: Normal and crash data for the tasks are shown.
What is the optimum project duration?
How can the project be finished in 20 days?



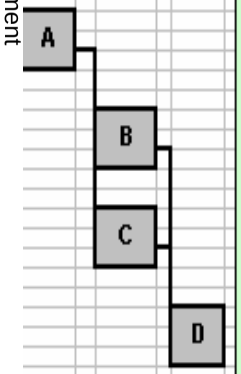
Activity	Normal Duration	Normal Cost	Crash Duration	Crash Cost	Critical	Crash Cost/Day
A	8	16,000	6	19,000		
B	4		No crashing			
C	5					
D	9	18,000	7	19,000		
E	14		No crashing			
F	6					
G	7		No crashing			
H	8	16,000	6	18,000		
I	3		No crashing			

Notes: - Total "Normal" cost of all other tasks = $70,000
- Daily indirect cost is $1,000/day.

Cash Flow:

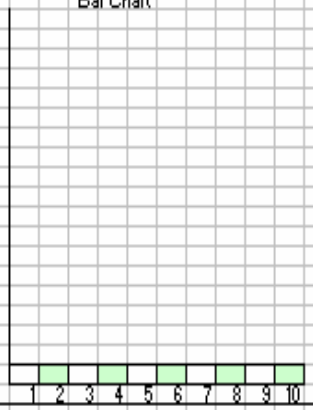
Deadline = 10 days
Resource Limit = 2 /day
Indirect cost = $100 /day

Markup = 10%
Retention = 5% (Hold back)



Network	R = 2	Method1 $	Method1 D	Method2 $	Method2 D	Method3 $	Method3 D	Start Delay	Method
A	2	2k	3	2k	3	5k	2		
B	2	1K	5	2k	2				
C	2	2k	5	3k	3	5k	2		
D	2	1k	5	2k	2				

Bar Chart



Direct $	Ind. $	Budget (Markup = 10%)	Adjust.	Budget (Markup = 10%)
	$100 per day			
Sum=	Sum=	Sum =		Sum =

Terms used every period:

- Cost = Estimate of directs + indirects.
- Expenses <= Cost, if suppliers can give you credit.
- Budget = Cost + Markup * Cost = Cost (1 + Markup)
- Income = Owner payment = Budget - holdback.

If everything goes well:

- Expenses <= Cost
- Income = Budget
- Profit = Cost * Markup

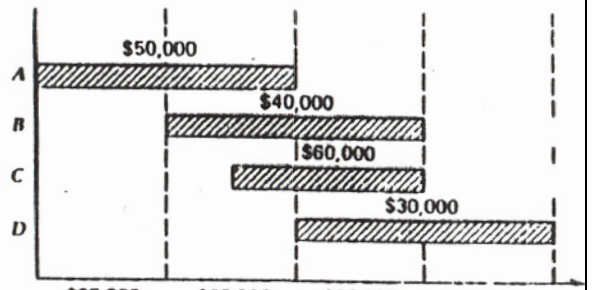
S-Curve

Draw the Cash Flow Chart.
What is the effect of bid unbalancing?

Example: Overdraft Calculations

Data:

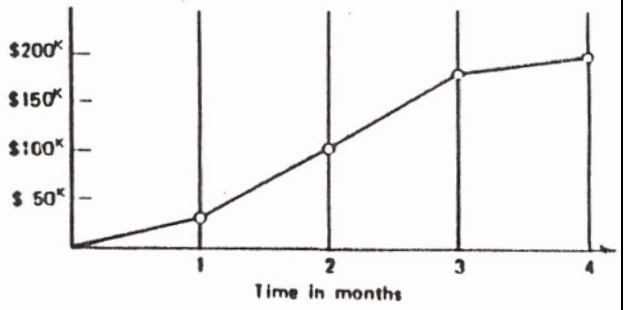
- Direct costs (evenly distributed) on the bar chart;
- Indirect costs = $5000 per month;
- Contractor's markup = 5%;
- Reporting period = monthly;
- Owner retainage = 10% (no retainage after work is 50% complete);
- Payments made 30 days after invoice made; and
- Interest rate is 1% monthly.



Monthly direct costs	$25,000	$65,000	$75,000	$15,000
Monthly indirect costs	$ 5,000	$ 5,000	$ 5,000	$ 5,000
Total monthly costs	$30,000	$70,000	$80,000	$20,000
Cumulative monthly costs	$30,000	$100,000	$180,000	$200,000

OVERDRAFT CALCULATIONS

	Month 1	2	3	4		
Direct cost	$25,000	$65,000	$75,000	$15,000		
Indirect cost	5,000	5,000	5,000	5,000		
Subtotal	30,000	70,000	80,000	20,000		
Markup	1,500	3,500	4,000	1,000		
Total billed	31,500	73,500	84,000	21,000		
Retainage withheld	3,150	7,350	0	0		
Payment received			$28,350	$66,150	$84,000	$31,500
Total cost to date	30,000	100,000	180,000	200,000	200,000	
Total amount billed to date	31,500	105,000	189,000	210,000	210,000	
Total paid to date			28,350	94,500	178,500	210,000
Overdraft end of month	30,000	100,300	152,953	108,333	25,416	(-)5830
Interest on overdraft balance [a]	300	1,003	1,530	1,083	254	0
Total amount financed	$30,300	$101,303	$154,483	$109,416	$25,670	



[a] A simple illustration only. Most lenders would calculate interest charges more precisely on the amount/time involved employing daily interest factors.

Assignment:

Question 1:

In a small project, the total cost of work is shown in the following table. The contractor adds a mark-up of 8% to the estimated cost. The contract allows for monthly invoicing and payment of the amount certified less 10% retention one month later. The retention money is repaid with the last owner payment.

Month	1	2	3	4	5	6	7	8	9
Total Cost	$3,000	$3,000	$4,000	$6,000	$6,000	$8,000	$6,000	$4,000	$2,000

The contractor will make deferred payments of the above costs, according to the following table:

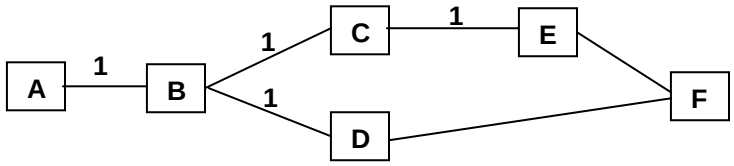
Labor	25% of monthly cost	Delay = 1.12 weeks
Equipment	25% of monthly cost	Delay = 8.20 weeks
Materials	50% of monthly cost	Delay = 4.00 weeks

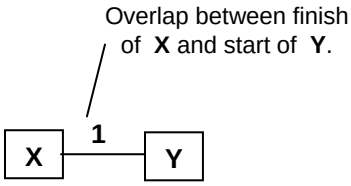
The current interest rate on borrowed capital is 14% per annum. Calculate the following:

- **a)** Average delay between incurring a cost liability and the contractor making payment. Assume one month is 4.33 weeks.
- **b)** Total interest charges (use the average delay value of question "**a**") and show all manual overdraft calculations. Compare your calculations to EasyPlan's.
- **c)** The maximum amount of cash needed to execute the contract.
- **d)** Contractor's net profit considering interest charges.
- **e)** Using EasyPlan, compare the interest charges if invoices are made every 2 vs every 3 months?

Question 2:

The activities involved in the construction of a small workshop building are as follows:





The activities details are shown in the following table. The contractor needs to draw the cash flow curves to have a clear picture about the financial implications of the contract. From these graphs, calculate the net profit if interest rate is 8% per annum on outstanding monies. The gross profit margin is 10% of budget value and retention is 5%. Measurement and invoicing are made monthly with owner payment delay of one month. All retention is repaid with the last owner payment. What is the largest amount of cash needed and when is it required? What is the impact of 20% down payment on interest charges (note: down payment is deducted from the first two payments). Compare your manual calculations to EasyPlan's.

Activity	Duration (m)	Budget
A. Excavation	2	$9,000
B. Concrete bases	3	$12,000
C. Erect frames	1½	$18,000
D. Concrete floor slab	1	$15,000
E. Fix cladding	1½	$6,000
F. Install equipment	1	$20,000

Bonus (1%): Develop a spreadsheet with all the variables involved and apply it to question 1 or 2.

Project Control

Organize site? Recording of site events? Work Status? Comparing Planned versus Actual? Progress Payments? Managing Changes? Updating? Corrective Actions? Delay Resposibility? Forecasting/ Time Extension? Cost compensation? Productivity Assessment? Saving All As-Built Details? Lessons Learned?

a) **Organized Site** = Safety + Productivity + Good Circulation + Cost & Time Savings

(1) identifying necessary facilities and determining their appropriate sizes;
(2) determining the inter-relationships among the facilities on the site; and
(3) optimizing the placement of the facilities on the site plan.

b) **Recording Site events**

Calculate activity % complete, Camcorders, Time-Lapse Camera, Minutes, **Project Web Site**

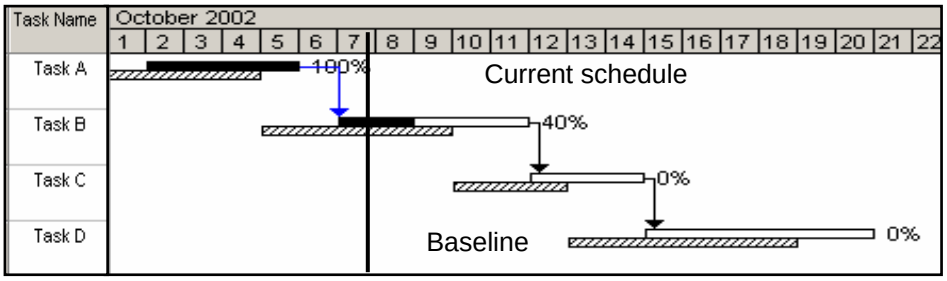
Activity % Complete

- **Slow-down**: % complete actual < % complete planned
  - Reason?
  - Document?
- **Work Stop**: % Actual complete = 0
  - Responsibility and reason
    - Owner (O)
    - Contractor (C)
    - Neither (N)
- **Acceleration**: % complete actual > % complete planned
  - Reason?
  - Owner Directed?
  - Contractor own?
  - Document?

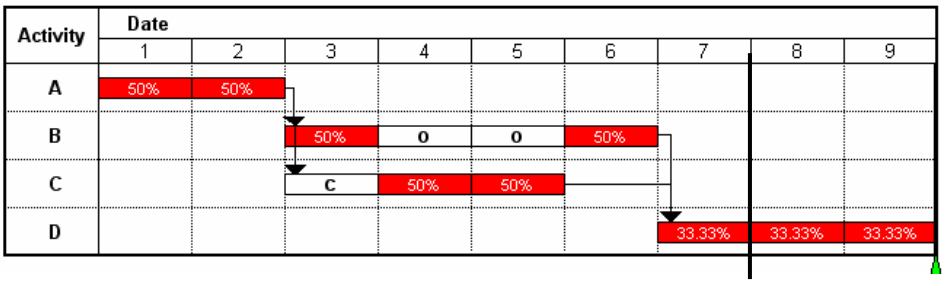
Calculation methods, pages 291& 292

c) **Using Software**

Project % complete?
Page 293
How to show Delays?
Slow versus Fast?
Reasons for work stops?

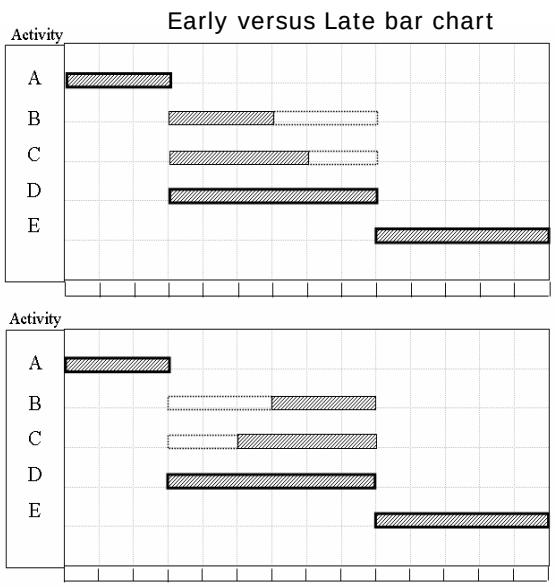


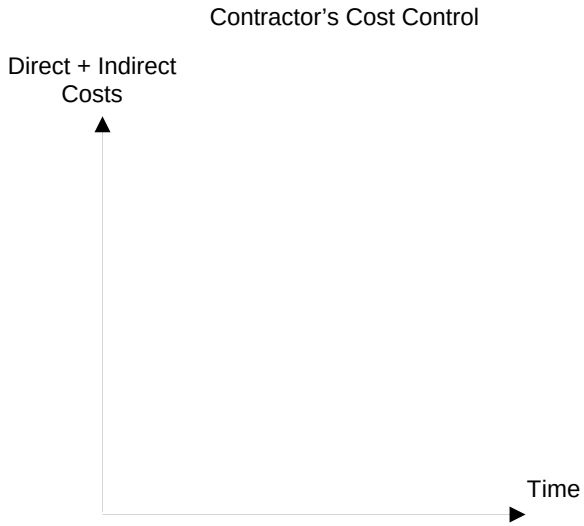
Can we readily decide which party is responsible for the two days delay beyond the deadline?



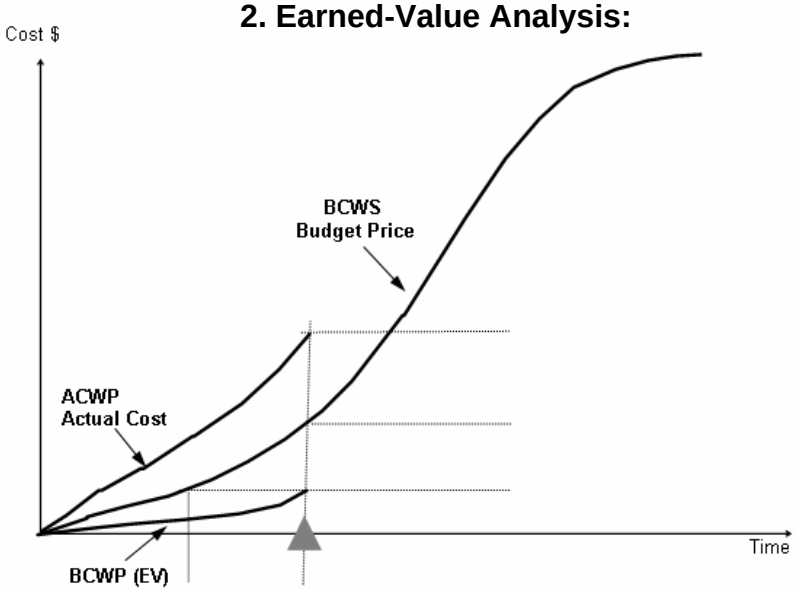
d) **Techniques for Performance Evaluation**

1. S-Curve Envelop:





2. Earned-Value Analysis:



$$\text{Schedule Performance Index (SPI)} = \frac{BCWP}{BCWS}$$

$$\text{Cost Performance Index (CPI)} = \frac{BCWP}{ACWP}$$

e) **Agenda for Success:**

- Get Good Designers: Beware of Bargain Shopping;
- Watch Low Bids Carefully: Work at Cost Spells Trouble;
- Fail to Plan and you Plan to Fail;
- Keep the Work Site Organized;
- Monitor the Gaps;
- No Pay Causes Delay;
- Time = Money;
- Communication; and Documentation.