University of Waterloo

Civil Engineering Department

CIV E 710 - Advanced Project Management

Instructor: Dr. Tarek Hegazy, Ext.: 2174, Email: tarek@uwaterloo.ca

Description:

Various topics on advanced techniques for improving decision making on projects: bidding strategy models; process modeling and simulation; uncertainty and risk assessment; Monte-Carlo simulation; multiple-criteria decision analysis; conflict resolution; Planning of large infrastructure programs; delay analysis; Enterprise Resource Planning; and project control. Students will be introduced to the Project Management Institute's Body of Knowledge and will be prepared to take the Project Management Certification Exam. The course involves assignments, computer workshops, a project, and a final examination.

SUGGESTED REFERENCES:

(1) Hegazy 2002, "Computer-Based Construction Project Management," Prentice Hall.
(2) "A Guide to the Project Management Body of Knowledge," 3rd Edition, 2004, Project Management Institute, to be downloaded from www.PMI.org.
(3) Hendrickson, C. and Au, T. "Project management for Construction: Fundamental Concepts for Owners, Engineers, Architects, and Builders," Prentice Hall, 1989.

Evaluation

Assignments 20%; Group Work 40%; Final 40%

www.civil.uwaterloo.ca/tarek/710.html

Contents:

Tentative subjects:

Week	Subject
1	Introduction to Project Management
2	Competitive Bidding
3	Optimization
4	Uncertainty and Risk
5	Monte Carlo Simulation
6	Multiple Criteria Decision Analysis
7	Conflict Resolution
8	Discrete-Event Simulation
9	Process V3
10	Advanced Project Control
11	Delay Analysis
12	infrastructure projects
13	Enterprise Resource Planning

Reference Sources:

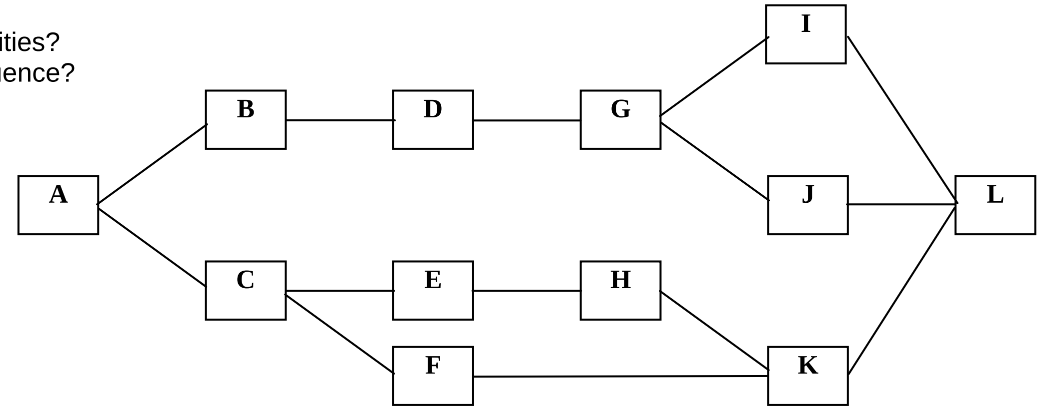
- Books on Project Management and Construction Management;
- Trade magazines (e.g., ENR);
- International journals:
  - Construction Engineering & Management (ASCE);
  - Computing in Civil Engineering (ASCE);
  - Infrastructure Systems (ASCE);
  - Constructed Facilities (ASCE);
  - Management in Engineering;
  - Computer Aided Civil & Infrastructure Engineering;
  - Cost Engineering International (AACE);
  - Automation in construction;
  - Construction Management & Economics;
  - Transportation Research Board TRB;
  - PMI Journal;
  - European Journal of Operations Research;
- Databases such as "compendex" & "CISTI";
- Organizations such as Project Management Institute (PM & American Association of Cost Engineers (AACE);
- Internet search & Web sites; and
- Government publications such as statistics Canada.

Setup of Your Computer Account

☐ Activate Excel, and Change macro security level to **low** (Tools – Macro – Security)
☐ Activate Microsoft Project and Change macro security level to **low** (Tools – Macro – Security)
☐ Download files from course web to your N drive.

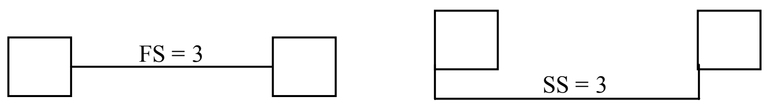
Planning

Activities?
Sequence?

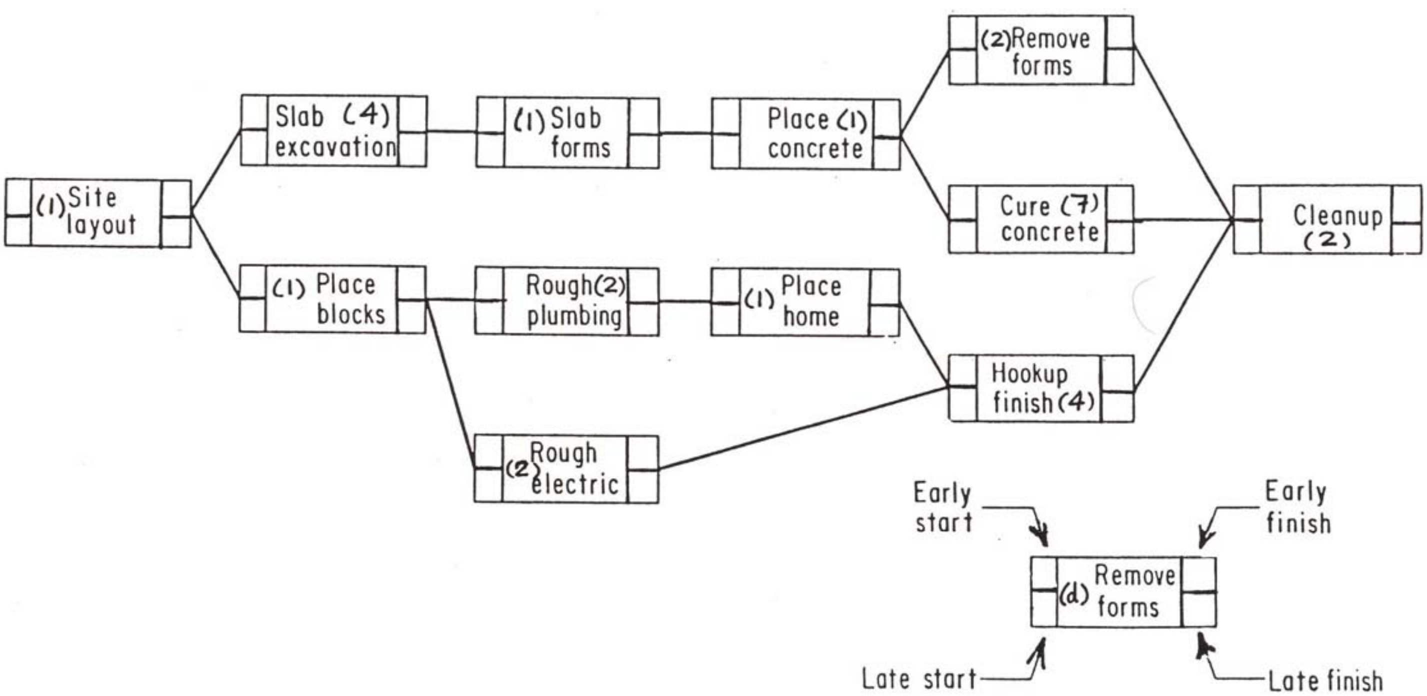


Types of logical relationships:

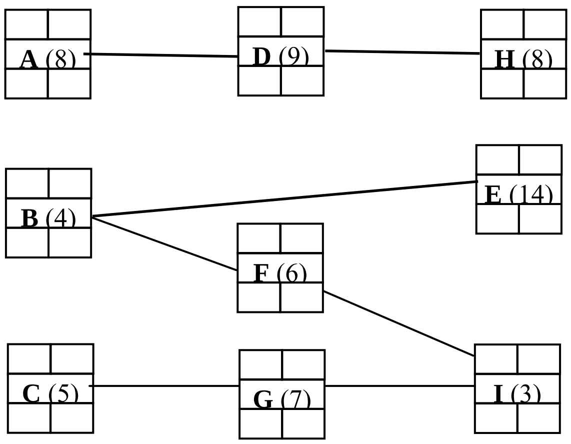
(Finish-to-Start, Start-to-Start, Start-to-Finish, and Finish-to-Finish).

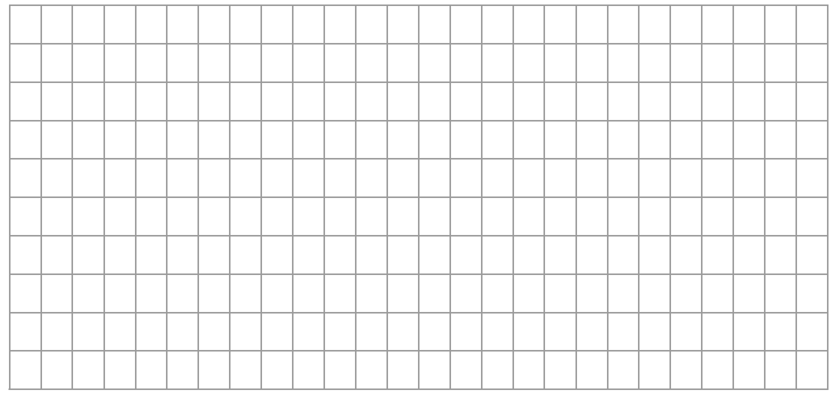


Scheduling



Exercise: Calculate activities' total floats, show the critical path, and draw a late bar chart.





If the following information is available, what is the optimum plan for the project?

Activity	Cost	Options	Resource need / day *
A	$16,000	Can be shortened 2 days for an extra $3,000	10
B	$15,000		5
C	$10,000		8
D	$18,000	Can be shortened 2 days for extra $1,000	15
E	$10,000		4
F	$10,000		3
G	$10,000		6
H	$16,000	Can be shortened 2 days for extra $2,000	8
I	$10,000		7

***** Max. available resources = 20 / day, Project Deadline = 20 days, Indirect cost = $1,000 /day

Strategy to Meet Deadline: ____

____

____

Strategy to allocate limited resources: ______________________________________

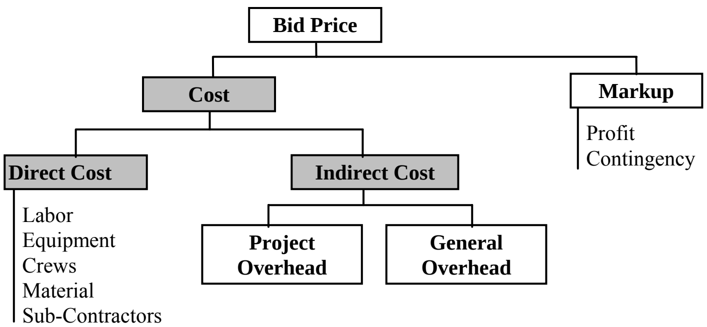
____

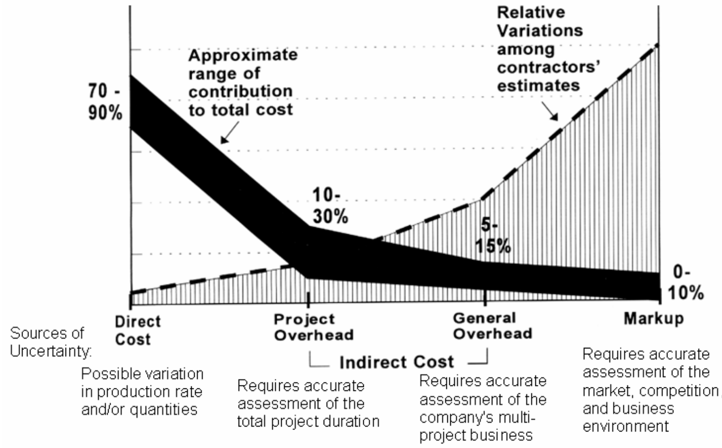
____

EasyPlan versus Microsoft Project

Costs? Deadline? Penalty? Incentive? Productivity Factors? Optimization? Actual Progress?

Bidding Strategy AND MARKUP ESTIMATION





Questions:

What is P(win) for a given markup?
What is Optimum markup?
What is P(win) at optimum markup?
How does the Lowest Bidder behave?

Analyzing the Bidding Behavior of Key Competitors

It is important therefore to strike a balance between profitability and the chances of winning. We, therefore, need to keep track of our past bids and depict any bidding pattern our key competitors use. Assumptions:

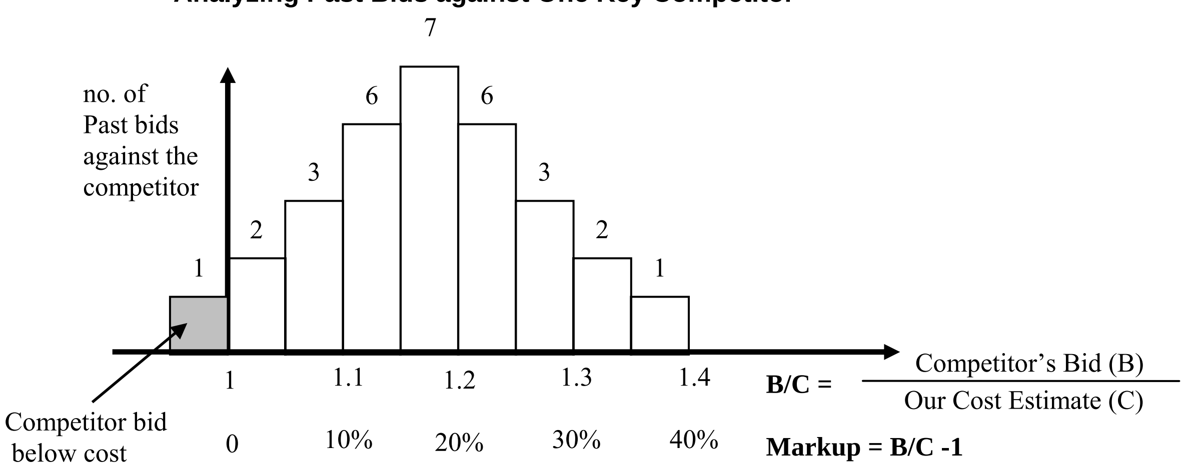
- Our cost estimate (C = direct cost + Indirect cost) is accurate = cost estimates of all bidders.

- Out Bid Price (B_i) of competitor i = C * (1 + markup)

  Thus, B_i/C ratio = 1 + markup and markup = $B_i/C - 1$

Let's now expand our analysis of "Company A" bidding behavior by retrieving all our records of past bids in which we competed against them. Let's assume we found 31 past bids and we have all the information regarding our cost estimates and the bid prices. From that information, we can create a histogram as:

Analyzing Past Bids against One Key Competitor



From the above histogram, we can answer the following questions:

1. If the B/C ratio used by "Company A" in a past bid was 1.25, it means the company used a markup of ____% of cost.

2. If we decide to use a 10% markup in a new bid against "Company A", how many times in the past did they underbid us at this level of markup?

3. What is our chances of winning "Company A" using 25% markup?

4. If we bid right at cost (no profit), then your B/C becomes?

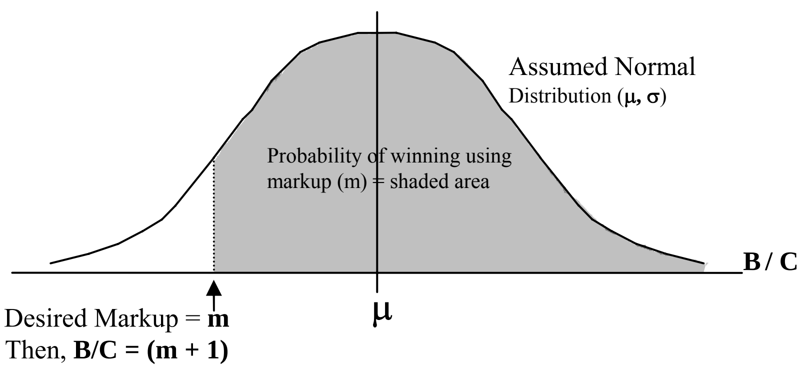
5. How many times did company A bid below cost?

6. What is the mean and standard deviation of the B/C ratio used by "Company A"?

Mean (μ) =

Standard Deviation (σ) = Sqrt $[(n\ \Sigma X^2 - (\Sigma X)^2) / n(n-1)] = 0.0931$

The μ and σ of B/C ratio, therefore, represent the competitor's behavior and can be used to evaluate the probability of winning him using any markup value, assuming a normal distribution:



Example: The mean and standard deviation of the company's B/C ratio are calculated to be 1.1 and 0.1, respectively. What is the probability of winning "Company A" in a new bid, using a 20% markup? Your cost estimate for the new project is $1,000,000. What is the expected profit at this markup?

Solution:

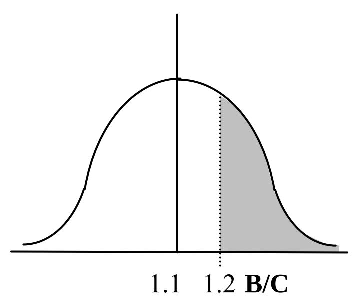
(a) At 20% markup, **B/C** =

We then use the standardized normal distribution table

Z = $(X-\mu)/\sigma$ =

and from the table (provides left side area), Probability =

Then, the probability of winning at 20% markup =



(b) Expected profit =

Bidding Strategy

Expected Profit of a given markup = (Profit value ($)) x (Probability of winning **all** competitors using the specified markup (%))

Repeat the calculations using various markup values and find the optimum markup as the one associated with maximum Expected Profit.

Markup (%) × Cost

1. Calculate the probability of winning **individual** competitors**,** then
2. Combine the probability of winning **all** competitors simultaneously.

To determine our probability of winning all competitors is done as follows:

Friedman in 1956:

a) Probability of winning (n) known competitors is:

$$P(Win_{all}) = P(Win_1) \times P(Win_2) \times \ldots \times P(Win_n)$$

b) (n) unknown competitors is:

$$P(Win_{all}) = P(Win_{Typical\ Competitor})^n$$

Gates in 1967:

a) Probability of winning (n) known competitors is:

$$P(Win_{all}) = \frac{1}{[(1-P(Win_1)) / P(Win_1)] + \ldots + [(1-P(Win_n)) / P(Win_n)] + 1}$$

b) (n) unknown competitors:

$$P(Win_{all}) = \frac{1}{n\,[(1 - P(Win_{Typical\ Competitor})) / P(Win_{Typical\ Competitor})] + 1}$$

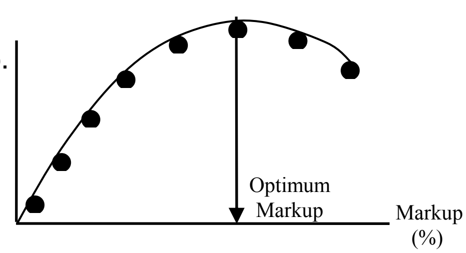
Notes:

- Pros & Cons of probabilistic models
- Subjective factors
- Other models

Friedman's and Gates' models give different results. A number of these studies concluded that Friedman's model is more correct when the variability of bids is only due to markup differences while Gates model is more correct when the variation in bids is only due to variations in cost estimates. Gates model produces higher markups than that of Friedman's. In this sense, Friedman model could represent a pessimistic approach while Gates' represents an optimistic one. Despite their differences, however, over the study period, both models have led, approximately, to the same total of potential profits.

The Optimum-Markup Estimation Process

1. Assume a percentage markup in the range from (1 - 20%), with 1% increment.
2. At each markup, calculate the <u>EXPECTED PROFIT</u>, as follows:
   - Profit = Cost x markup (%).
   - Probability to win each competitor (from his past history);
   - Combined probability $P(win_{all})$, using Friedman's or Gates' models; then
   - Calculate Expected Profit = Profit × $P(win_{all})$.
   - Tabulate the Markup and Expected Profit values
   - Increment Markup and repeat the calculations in this step.
3. Plot Markup versus Expected Profit.
4. Choose the Optimum Markup from the Plot.



Example

A contractor wants to determine the optimal bid to submit for a job with estimated cost $1,000,000, bidding against 3 key competitors with the following historical data.

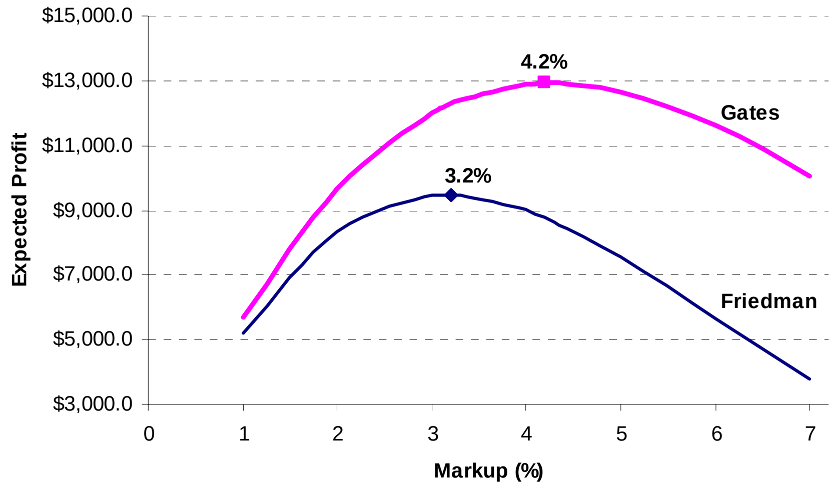
Competitor	No. of Occurrences	B/C Mean (μ)	B/C Standard Deviation (σ)
A	5	1.081	0.052
B	6	1.032	0.044
C	8	1.067	0.061

Solution

Optimum Markup Plot

From this plot, we can evaluate our probability of winning the bid at any markup value.

$$P(Win) = \frac{\text{Expected Profit}}{\text{Markup x Cost}}$$



Important Bidding Relationships

From the previous discussion and the solved example given, let's discuss some of the observed relationships:

- When the σ of the B/C ratio of a competitor is small, it indicates that this competitor uses a consistent markup policy. It is possible in this case to establish a markup to win him.

- Friedman's model, in most cases, determines a lower optimum markup than that of Gates'. In this sense, Gates' model is more optimistic as it assumes that you can still win the bid at a high markup.

- When the level of competition is high (large number of bidders) and the economic conditions are not favorable, winning bids becomes difficult and bidders reduce there bids to become more competitive;

- In construction, an average bidder behavior is exhibited as having bid/cost ratio mean of 1.06 and a standard deviation of 0.065. For building construction, markup may vary from 2 to 10% while for highway and heavy civil construction, it can reach up to 20%. The average number of competitors bidding for a job is around 6.

- Researchers studied the relationship between markup and number of competitors, as follows:

$$\frac{M2}{M1} = \left(\frac{N1}{N2}\right)^{0.7}$$

- Markup also is affected by project size (as indicated by its cost estimate C), as follows:

$$\frac{M2}{M1} = \left(\frac{C1}{C2}\right)^{0.2}$$

Bidding Strategy Using EasyPlan

The previous records of a past bids against 4 key competitors is in the following table. Using Friedman and Gates models, determine the markup needed to optimize expected profit in bidding against competitors A, B, and C in a new job with an estimated total cost of $4,000,000.

Job No.	Contractor's cost estimate ($)	Bid price of competitors ($)		
		A	B	C
1	1,550,000	1,900,000	1,700,000	1,750,000
2	2,000,000	----	2,000,000	2,200,000
3	1,300,000	1,500,000	1,400,000	1,650,000
4	1,200,000	----	1,600,000	1,400,000

Assignment

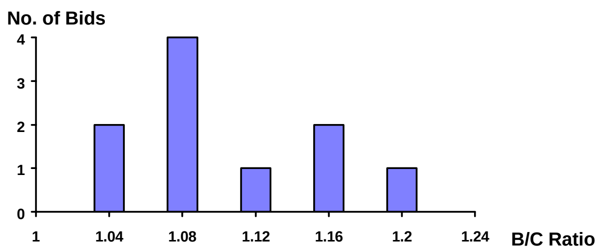
1. The previous record of a contractor's bidding encounters against 3 competitors is:

Job no.	Contractor's Cost Estimate ($ millions)	Bid Price of Competitors ($ millions)		
		A	B	C
1	0.85	1.05	1.1	0.95
2	1.6	2.1	1.8	1.6
3	0.7	----	----	0.9
4	2.0	2.4	----	2.2

Using Friedman and Gates models determine the markup needed to optimize expected profit in the following cases, and comment on the results:
a) bidding against A, B, & C in a new job with estimated total cost of $10,000;
b) bidding against A, B, & C in a new job with estimated total cost of $5,000,000;
c) Comment on the impact of project size in (a) and (b) on the estimated optimum markup; and
d) bidding against 6 typical competitors with behavior close to that of competitor B.

2. If a typical competitor has a B/C ratio with = 1.05 and = 0.09, what is the markup associated with a 30% probability of winning 4 typical competitors?

3. Analysis of the bidding behaviour of a typical competitor against you, as a contractor, has revealed that his **Bid/your-cost** in 10 previous bids take the following histogram.



a) Based on that behavior, what is the markup value that this competitor uses on average? What is the your probability of winning this competitor if you use a markup of 14%?
b) In a new project with a $1,000,000 estimated cost, what is your optimum markup strategy against 4 typical competitors using Friedman's model? What is the expected profit at optimum markup?
c) Optimum markup generally ___________________(increases/decreases) with number of competitors; and
d) Which model (Friedman/Gates) is more sensitive to the number of competitors and why?

4. Read one research paper on competitive bidding and prepare a 5-minute presentation.

Quantitative Risk Analysis Techniques

The PERT Approach for Project Risk Assessment

The program evaluation and review technique (**PERT**) was developed by the late 1950's. The objective was to evaluate the risk in meeting the time goals of the execution of projects whose activities had some uncertainty in their duration estimates. To represent the uncertainty in duration estimates, the PERT technique recognizes the probabilistic, rather than deterministic, nature of the operations involved in high-risk activities. Accordingly, the PERT technique incorporates three durations for each activity into its methodology. The 3 estimates are:

Optimistic duration (a): estimated time (comparatively short) of executing the activity under very favorable working conditions. The probability of attaining this duration is about 0.01;

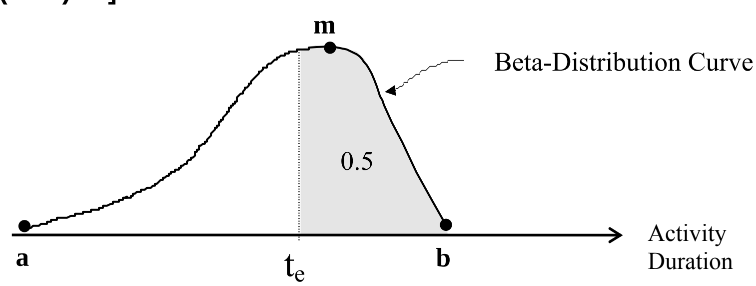
Pessimistic duration (b): estimated time (comparatively long) of executing the activity under very unfavorable working conditions. The probability of attaining this duration is also about 0.01; and

Most Likely duration (m): estimated time of executing the activity that is closest to the actual duration. This estimates lies in between the above two extremes.

In PERT, the given estimates of times and the likelihood of occurrence are represented by a **beta curve**, as shown below. However, with the three estimates of time for each activity, we cannot perform traditional CPM analysis to determine project duration. Therefore, we need to get a single weighted average duration for each activity. The formulas for the expected duration, called expected elapsed time, ($\mathbf{t_e}$) are as follows: $\mathbf{t_e = (a + 4\,m + b) / 6}$

The t_e value is a sort of an average with more weight given to the most likely time. As shown in Fig. 12.4, the t_e point divids the area under the beta curve into two equal aprts, meaning, the activity has a 50-50 chance of being accomplished earlier or later than t_e. Also, to represent the variability and level of uncertainty in the activity duration, the activity variance is calculated as follows: $\boldsymbol{\sigma t_e^2 = [(b - a) / 6]^2}$

In effect, the variance σt_e^2 is larger when optimistic and pessimistic estimates are far apart, representing high uncertainty in the activity duration estimate.



Step 1: Individual Activity Durations

a = Optimistic duration (1 in 100 chance) = Minimum duration
m = Most Frequent duration (most likely)
b = Pessimistic duration (1 in 100 chance) = Maximum duration
t_e = activity expected duration = (a + 4 m + b) / 6
σt_e^2 = activity duration variance = $[(b - a) / 6]^2$

Step 2: CPM Calculations

Using the activities' t_e durations, CPM calculations are performed following the forward and backward passes to determine the project duration (T_E). Activity floats and also calculated and critical activities identified.

Step 3: Distribution of Project Duration

Since the probability is 0.5 that each activity will finish at its t_e durations, there is a probability of 0.5 for the entire project being finished at time T_E. However, the expected project duration does not follow a beta curve as did the activities comprising the project. Assuming that the project is executed a large number of times, the resulting population of project durations may be assumed normally distributed.

The normal distribution of project duration is defined by its mean (μ) and standard deviation (σ) values, determined as follows:

$$\mu_{TE} = T_E = \Sigma\, t_e \quad \text{of critical activities;} \quad \sigma_{TE} = \sqrt{\Sigma\, \sigma_{te}^2} \quad \text{of critical activities}$$

Step 4: Analysis of Project Completion Probabilities

Using the project normal distribution, it is possible now to find the probability values associated with specific project duration. By scaling the project distribution to the standard normal distribution, we can obtain probabilities from standard probability tables and make conclusions, as follows:

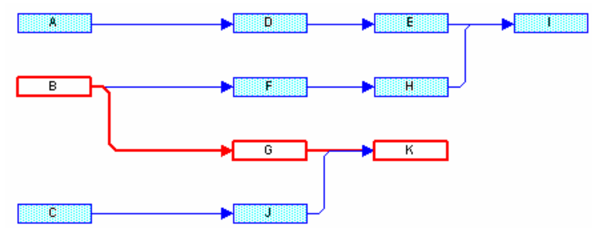
$$Z = \frac{\text{Desired Completion Date} - \mu_{TE}}{\sigma_{TE}}$$

Using Z and standard Probability Tables → **Get Probability** →
- = 0.5 reasonable
- > 0.5 not necessarily good (unrealistic)
- < 0.5 no good

Example Using MS Project:
Let's consider a simple example of a project network similar to the one we use for our case study but with three possible durations as shown below. Calculate the probability of the project being completed in 30 days of less.

Step 1: Activity Durations

Activity	a	m	b	t_e	σ_{te}^2
A	3	4	5		
B	2	6	9		
C	1	2	4		
D	2	8	10		
E	1	4	6		
F	7	10	12		
G	12	16	20		
H	7	8	10		
I	3	6	9		
J	5	6	8		
K	6	10	14		

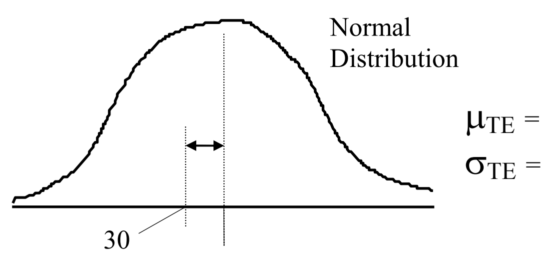


Step 2: CPM Critical path is **B-G-K**

Step 3: Project Duration Distribution

$\mu_{TE} = T_E = \Sigma\, t_e$ of critical activities = days

$\sigma_{TE} = \sqrt{\Sigma\, \sigma_{te}^2}$ = days



Step 4: Analysis of Project Completion Probability

Using the project normal distribution, it is possible now to find the probability of finishing the project in 30 days or less.

Probability (Project duration <= 30 days): Z = ――――――― =

From Standard Probability Tables: Probability (<= 30 days) = %

Note: Can we examine the probability of an activity becoming critical?

Criticisms to PERT Technique

- Requires three estimated durations for each activity.
- Assumes continuous not discrete distribution for durations.
- Beta distribution is debatable.
- It focuses on a single critical path and ignores close-to-critical paths.
- It assumes independent activity durations.
- It ignores the risk that occurs at path convergence points.

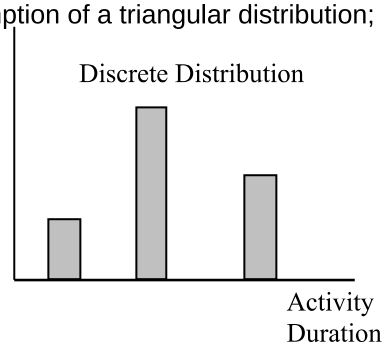
Monte Carlo Simulation for Project Risk Assessment

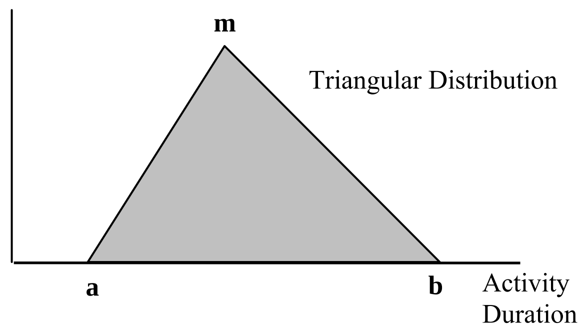
Monte Carlo Simulation was introduced in an effort to overcome the limitations of PERT. The method basically uses randomly generated numbers to determine possible activity durations. The technique essentially generates various scenarios associated with the project, each involves a random set of durations for the project activities. Each of these scenarios is then used to produce a CPM-type deterministic schedule. At the end, we can analyze the results of all these scenarios to understand the resulting range of variability in project duration.

To generate the random project scenarios, the Monte Carlo Simulation technique requires information about the duration of activities and their distributions. The number of activity duration sets may vary from 40 to 1000. The outcome of the technique is basically an estimate of expected time and variance of project completion time. Accordingly, the probability of meeting a particular completion date is determined and <u>also the probability that a particular activity could become critical</u>.

Step-By-Step

1. Determine the duration distribution of each activity. It is possible to use discrete values or to use the simplified assumption of a triangular distribution;





2. Generate one project scenario by randomly generating one possible duration for each activity in the project (based on its distribution). Perform CPM calculations for this scenario and determine the project duration;

3. Repeat step 2 for the number of desired simulations (scenarios) and then tabulate the results;

4. Project Duration Distribution: Calculate the mean (μ) and (σ) values for the resulting project durations; and

5. Using the (μ) and (σ) values, determine the probability of the project being completed on or before any given date similar to step 4 in PERT analysis.

Example Using Excel & CPM.xls:

1. To enable a comparison with PERT analysis, let's consider the three estimates as discrete values for each activity. Let's now generate 500 random scenarios of the project. We then calculate the CPM duration of each. Then, we tabulate the results, as follows:

2. Project Duration Distribution: We now calculate the mean (μ) and standard deviation (σ) of all project durations.
   Mean (μ) = ; and (σ) = days.

   It is interesting to note that these values are larger than those estimated using PERT. These results point out to some of the frequently cited limitations of PERT, which result in underestimating the project duration.

3. Using the (μ) and (σ) values, we determine the probability of the project being completed in 30 days or less, as follows:

   Probability (Project duration <= 30 days): Z = ——— =

   From Standard Probability Tables: Probability (<= 30 days) = %

Activity	Scenario 1	Scenario 2		Scenario 500
A	3	4		5
B	2	9		2
C	1	2		8
D	8	8		1
E	4	12		7
F	10	16	…	12
G	16	7		12
H	8	10		9
I	9	8		6
J	8	5		8
K	14	10		6
CPM Duration	32	43		29

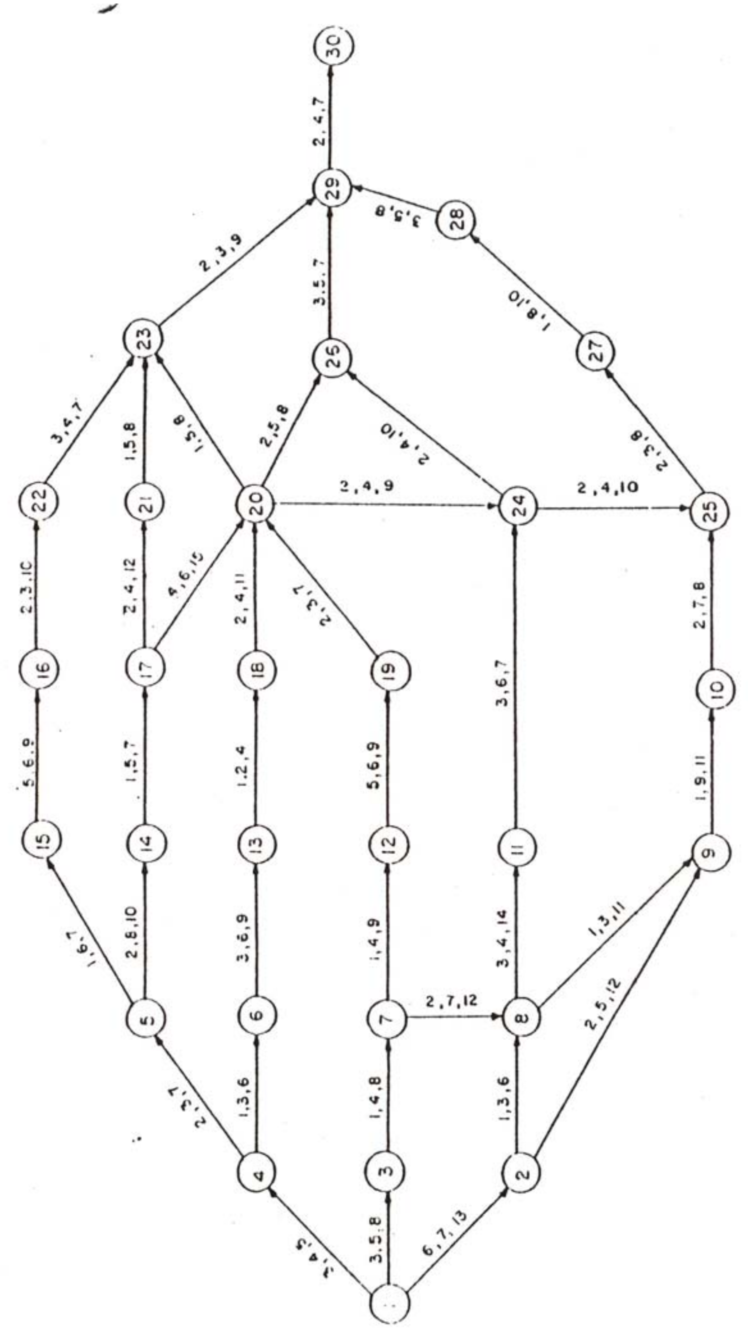


Figure 5-7

Three time estimates associated with each activity. From these data other computations are made, which are listed in Table 5-1.

Figure 5-8 shows a network similar to that of Figure 5-7. The values of t_e for each activity are calculated from the three durations shown in Figure 5-7. The values of T_E and T_L are calculated in accordance with the rules of CPM for determining early and late event times. These values are recorded on each node of the network in Figure 5-8. The management has given three schedule times as shown on the network, as follows:

Event	Schedule time
23	40
25	30
30	50

It is best to determine the probability of these events occurring at the specified times.

The probabilities for events 23, 25, and 30 are recorded in Table 5-1. The computation of these probabilities requires the determination of the value of $Z(23)$, $Z(25)$, and $Z(30)$. As explained before, $Z = [(T_s - T_E)/\sigma T_E]$. T_E can be redefined here as the total duration obtained from the longest path leading to the event in question. The longest paths in case of events 23, 25, and 30 are

Event 23: 1, 4, 5, 14, 17, 20, 23.
Event 25: 1, 4, 5, 14, 17, 20, 24, 25.
Event 30: 1, 4, 5, 14, 17, 20, 24, 25, 27, 18, 29, 30.

Reading from Table 5-1 the variance of the activities in the chain of activities leading to events 23, 25, and 30, the following is obtained:

For event 23

$$\sigma T_{E(23)} = \sqrt{0.11 + 0.69 + 1.77 + 1.00 + 3.35 + 1.37}$$
$$= \sqrt{8.29} = 2.88$$

For event 25

$$\sigma T_{E(25)} = \sqrt{0.11 + 0.69 + 1.77 + 1.00 + 3.35 + 1.37 + 1.77}$$
$$= \sqrt{10.06} = 10.17$$

Pre-ceding Event	Suc-ceeding Event	t_e	σt_e^2	T_E of Suc-ceeding Event	T_L of Suc-ceeding Event	T_s	Z	PR
1	2	7.83	1.37	7.83	14.34			
1	3	5.17	0.69	5.17	6.51			
1	4	4.00	0.11	4.00	4.00			
2	8	3.17	0.69	16.17	17.51			
2	9	5.67	2.79	20.17	21.51			
3	7	4.00	1.37	9.17	10.51			
4	5	3.50	0.69	7.50	7.50			
4	6	3.17	0.69	7.17	13.67			
5	14	7.33	1.77	14.83	14.83			
5	15	5.33	1.00	14.83	33.36			
6	13	6.00	1.00	13.17	19.67			
7	8	7.00	2.79	16.17	17.51			
7	12	4.33	1.77	13.50	16.84			
8	9	4.00	2.79	20.17	21.51			
8	11	5.50	3.35	21.67	25.50			
9	10	8.00	2.79	28.17	19.51			
10	25	6.33	1.00	35.84	35.84			
11	24	5.67	0.45	31.17	31.17			
12	19	6.33	0.45	19.83	23.17			
13	18	2.17	0.25	15.34	21.84			
14	17	4.67	1.00	19.50	19.50			
15	16	6.33	0.45	21.16	39.69			
16	22	4.00	1.77	25.16	43.69			
17	20	7.17	3.35	26.67	26.67			
17	21	5.00	2.79	24.50	43.19			
18	20	4.83	2.25	26.67	26.67			
19	20	3.50	0.69	26.67	26.67			
20	23	4.83	1.37	31.50	48.02	40	2.94	0.9983
20	24	4.50	1.37	31.17	31.17			
20	26	5.00	1.00	35.84	46.85			
21	23	4.83	1.37	31.50	48.02			
22	23	4.33	0.45	31.50	48.02			
23	29	3.83	1.37	51.85	51.85			
24	25	4.67	1.77	35.84	35.84	30	−1.79	0.0368
24	26	4.67	1.77	35.84	35.84			
25	27	3.67	1.00	39.51	39.51			
26	29	5.00	0.45	51.85	51.85			
27	28	7.17	2.25	46.68	46.68			
28	29	5.17	0.69	51.85	51.85			
29	30	4.17	0.69	56.02	56.02	50	−1.56	0.0569

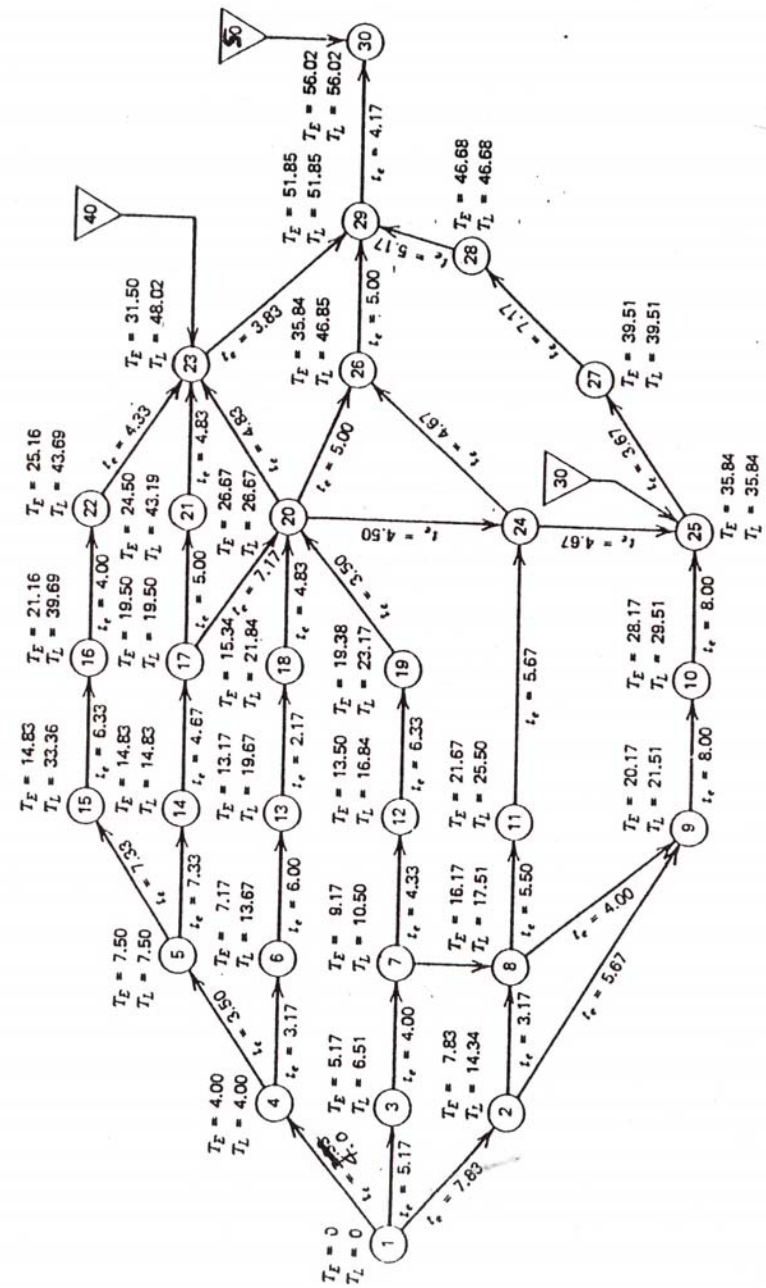


Figure 5-8

or event 30

$$\sigma T_{E(30)} = \sqrt{0.11 + 0.69 + 1.77 + 1.00 + 3.35 + 1.37 + 1.77 + 1.00 + 2.25 + 0.69 + 0.69}$$

$$= \sqrt{14.69} = 3.83$$

he value of Z for these events is obtained from the formula

$$Z = \frac{T_s - T_E}{\sigma T_E}$$

or event 23

$$Z = \frac{40 - 31.50}{\sqrt{8.29}} = 2.94$$

or event 25

$$Z = \frac{30 - 35.84}{10.06} = -1.79$$

or event 30

$$Z = \frac{50 - 56.02}{14.69} = -1.56$$

Referring to the Table of Values of the Standard Normal Distribution unction in Appendix 1, probabilities of these events occurring on the pplicable schedule time are obtained, as shown in Table 5-1.

It should be noted that the probability of an event being finished at ts T_E is 0.5. Computation of Z and the probability of an event being inished at a time other than T_E is necessary when T_s for a certain event s given.

This capability of PERT to use probabilistic durations and to predict he probability of finishing a project by a certain duration is most useul in research and development projects, where it is used in preference o CPM.

5-8 SIMULATION OF PERT NETWORKS

Until now only the mechanics of PERT analysis have been discussed. Management that obtains the information from such analysis has to understand the significance of these figures.

It is difficult to obtain the estimates for three durations; if estimators do not understand the significance of pessimistic and optimistic times, they may give times that, although different, are not actually the optimistic and pessimistic durations. Input of this nature can produce erroneous results. Further, it cannot be conclusively established that beta distribution represents the estimates of times. This could be done if the activity had actually been performed for a large number of times and historical data for actual times was available, which is not the case. The weighted average formula itself is arbitrary. It cannot be said with certainty that the expected time obtained from it will be closer to the actual time than the most likely time. If management has knowledge of this background, it can interpret the information more realistically. The basic need is to know the probability of finishing a project by a certain scheduled time, and this becomes possible because it can be determined from the three durations.

There is another important thing to consider about variance and standard deviation. To determine standard deviation, variance of the critical path is summed up and its square root is computed. Another path in the network may have a duration slightly less than that of the critical path. If the sum of variances on this subcritical path is greater than the sum on the critical path, the subcritical path may, in fact, be more likely to be critical. For instance, if the critical path has a duration of 80 and a standard deviation of two, there is a probability of 0.9987 that the project will be finished between 74 and 86 time units. Now if the subcritical path has a duration of 78 days but a standard deviation of 5, there is a probability of 0.9987 that the work on the subcritical path will be finished between 63 and 93 time units. There is every likelihood of the subcritical path becoming critical. If the probability of completing the critical path by time 82 is 0.8413, the probability of finishing the work on the subcritical path by the same time is 0.7881. The probability of finishing work at the same time both on the critical and subcritical path is $0.8413 \times 0.7881 = 0.6630$.

Still another aspect of analysis that must be considered is the slack. The slack computed in PERT is determined by the duration t_e. Since the activity duration can vary, the slack is subject to corresponding variation. Assuming that the management is aware of the implications and can provide meaningful estimates of the range of expected duration, how can it know the probability of an activity becoming critical or find a suitable range of float for every activity? This is achieved by simulation. Instead of estimating three durations, activity times for each activity can be selected by the Monte Carlo sampling technique. Values are taken from a given frequency distribution. A project dura-

Assignment

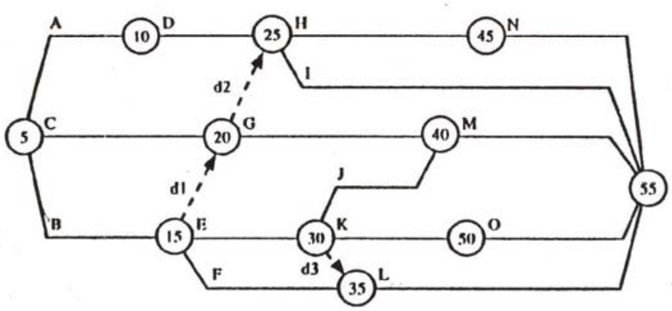
Download file CPM.xls and use it to solve the following two questions.

Question 1: Use Monte Carlo analysis to determine the project duration distribution for the following project.

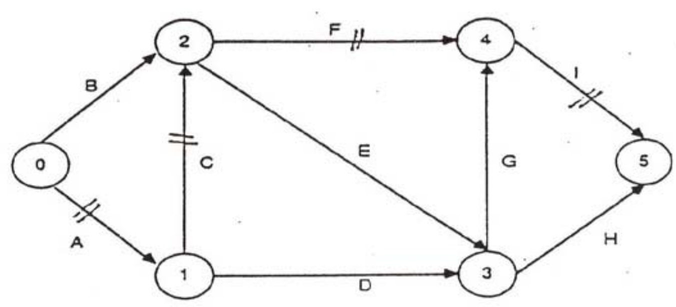
For the project activities shown in Fig. 10-4, we have historical data recorded from like activities in past projects, as given in (10-2).

Act	Durations	Act	Durations	Act	Durations	
A	6,6,7,7,7	F	7,6	K	(4, 6, 8)	
B	6,5,6,8,8	G	(3, 6)	L	3,3,3,3,3,3	(10-2)
C	(8)	H	$(\bar{X} = 4; \sigma = 1)$	M	4,5,3,3,6	
D	4,5,6,6,7	I	6,6,6,6,8	N	2,1,2,2,3	
E	5,5,5,7,7,7,	J	5,5,5,6	O	4,1,6,2,4	

For new activities C, G, H, and K we estimate the following: C will take 8 days; G will take either 3 or 6 days with equal probability; K will take either 4, 6, or 8 days with equal probability; and H is normal with a mean and standard deviation as shown above.



Question 2: Use Monte Carlo Simulation to determine project duration distribution. Activities durations have normal distributions with mean values below. Compare & comment on the following cases: σ= 10%; σ= 20%; and σ= 40%.



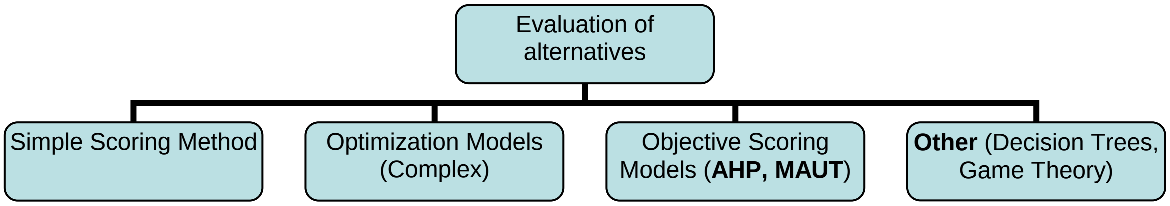
PRECEDENCE RELATIONS AND DURATIONS FOR A NINE-ACTIVITY PROJECT EXAMPLE

Activity	Description	Predecessors	Duration
A	Site clearing	—	4
B	Removal of trees	—	3
C	General excavation	A	8
D	Grading general area	A	7
E	Excavation for trenches	B, C	9
F	Placing formwork and reinforcement for concrete	B, C	12
G	Installing sewer lines	D, E	2
H	Installing other utilities	D, E	5
I	Pouring concrete	F, G	6

:

Decision Analysis

Selection among alternatives



<u>1. Simple Scoring Method:</u>

- Determine the weight of each decision criteria before looking at any proposals.

- Total sum of all weights = .

- List all the alternatives to choose from.

- With respect to each criteria, evaluate and relatively score your preference of each alternative (give 1.0 to the most preferred and 0.0 to the undesirable).

- Calculate the total score of each alternative.

		Relative Score (0 to 1.0)		
Criteria for Evaluation	Weight	Alternative I	Alternative II	Alternative III
A	50%	1.0	0.8	0.5
B	25%	0.7	1.0	1.0
C	25%	0.5	1.0	0.5
	Σ =			
Final Score = Σ Weight x Score				

- Which alternative to choose?

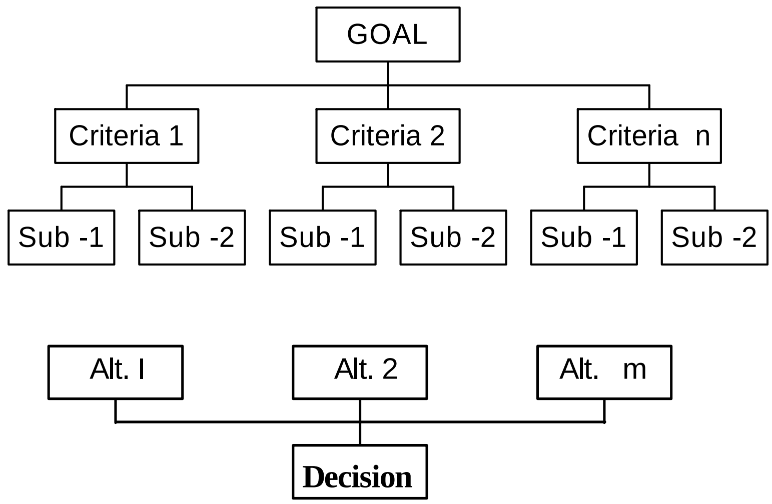
- How to determine the relative scores?

- What if more than one person to perform the analysis?

- What if the individuals differ in importance?

Multiple-Criteria Decision Analysis - The Analytical Hierarchy Process (AHP) – Saaty 1980

1. Identify the hierarchy of criteria that satisfy your goal and identify their MEASURABLE sub-criteria (Top-Down).
2. Identify all the possible alternatives (Bottom-Up).



3. Link the sub-criteria to the alternatives and insert any intermediate levels if necessary.
4. Set the priorities on the elements of each level by conducting pair-wise comparisons in terms of the level above it. Establish the matrix of priorities:

$$\begin{array}{cc} & \begin{matrix} a & b & c & \ldots\ldots & n \end{matrix} \\ \hline \begin{matrix} a\\ b\\ c\\ .\\ n \end{matrix} & \begin{bmatrix} 1.0 & & & & 2 \\ & 1.0 & & & \\ & & 1.0 & & \\ & & & & \\ 1/2 & & & & 1.0 \end{bmatrix} \end{array}$$

Scale of comparisons is:

1	Equal importance
3	Moderate importance
5	Strong or Essential importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate levels

5. Calculate the weight of each criterion in that level.

IMPORTANT: Consistency check.

λmax, Criteria Index (C.I.), Random Index (R.I.)

Consistency Ratio (C.R.) = C.I. / R.I. $\leq$ 0.1 Good Consistency

Example – Expert Choice Software - Bonus

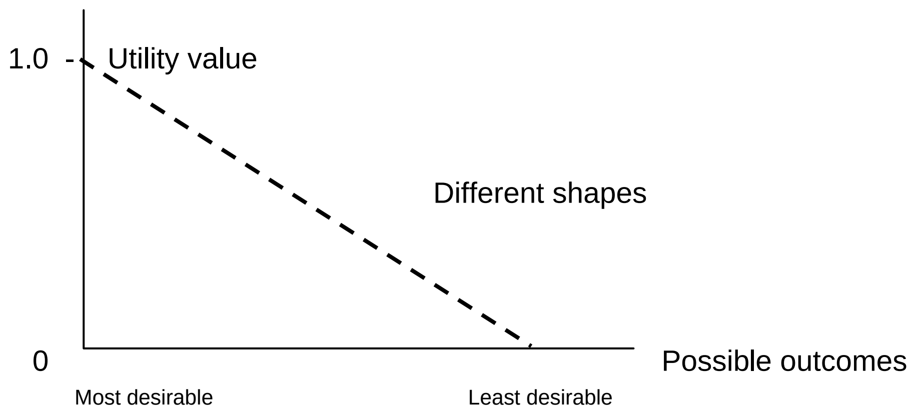
Multiple-Criteria Decision Analysis – Multi-attribute Utility Theory (MAUT)

1. Selects the alternative that provides maximum utility. For example, using j attributes, the total score of alternative i becomes: $U_i = \Sigma W_j \times u_{ij}$, where uij is the value if the jth attribute utility function associated with the ith proposal.

2. Establish selection criteria and relative weights, then construct utility functions to represent the decision makers' satisfaction over range of achievement levels.

   It is important to note that utility function for each attribute is constructed before the evaluation process to reflect stakeholders' desirability. As such, subjectivity in the evaluation is reduced.

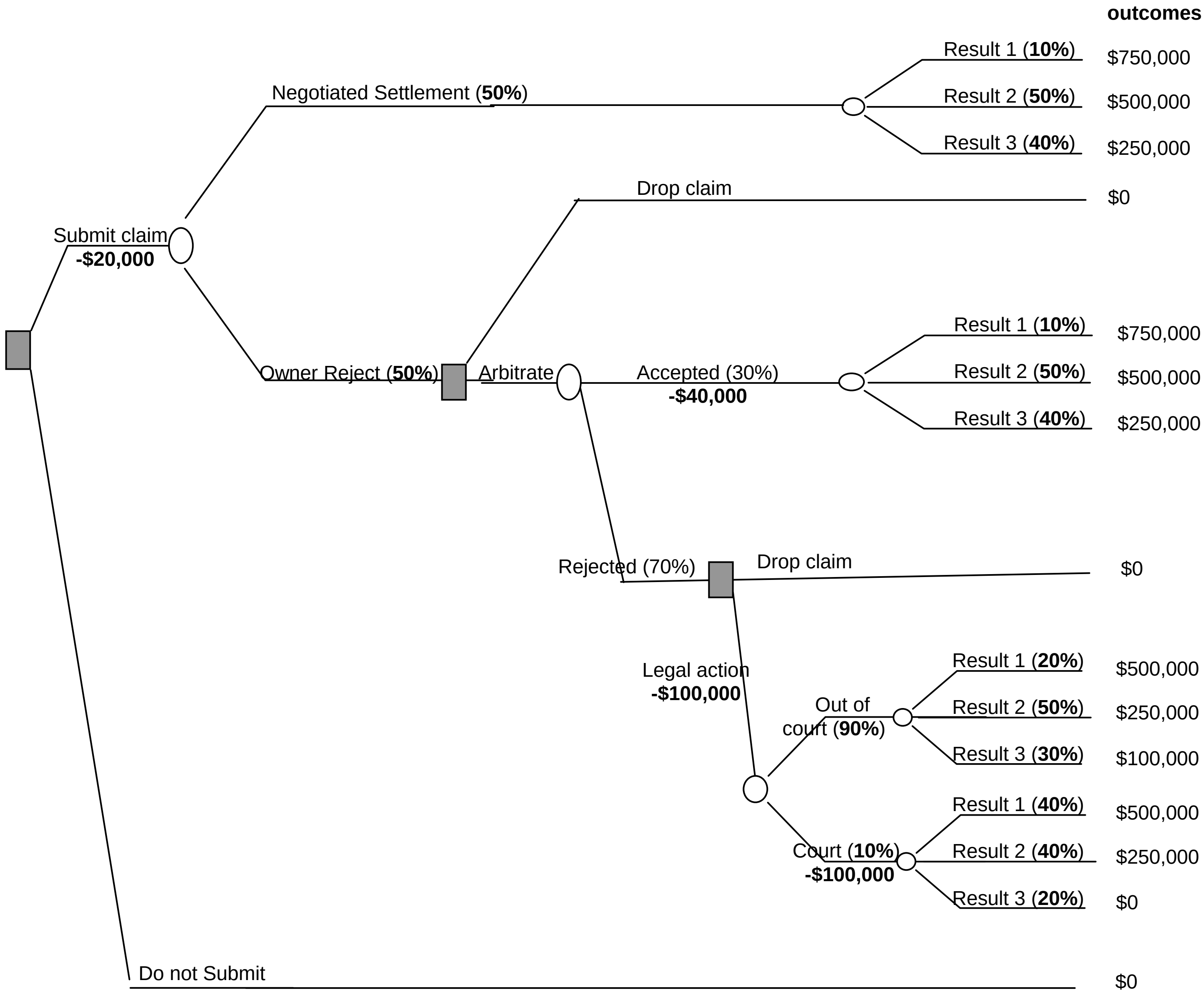
For one attribute



3. Example is the selection of a suitable contractor.

Decision Trees

Used when decisions are sequential, that is, one decision precipitates another, and so on. Thus, the decisions occur over a period of time that extends to the future. The technique assumes the probabilities of events are known and future consequences can be reasonably estimated.



After constructing the decision tree, the **Expected Value** at every node is calculated.

Assignment on the AHP technique:

In selecting an equipment to purchase for a large project, you as a project manager has set the following six criteria: **Reliability (R), Mobility (M), Production (P), Training (T), Cost (C), and Service (S)**

Pair-Wise Comparison among the criteria is as follows:

	R	M	P	T	C	S
L	1.00	4.00	3.00	1.00	3.00	4.00
F	0.25	1.00	7.00	3.00	0.20	1.00
S	0.33	0.14	1.00	0.20	0.20	0.17
V	1.00	0.33	5.00	1.00	1.00	0.33
C	0.33	5.00	5.00	1.00	1.00	3.00
M	0.25	1.00	6.00	3.00	0.33	1.00

Also, Pair-Wise Comparisons among theree alternative equipments, with respect to each criteria are as follows:

R	A	B	C
A	1.00	0.33	0.50
B	3.00	1.00	3.00
C	2.00	0.33	1.00

M	A	B	C
A	1.00	1.00	1.00
B	1.00	1.00	1.00
C	1.00	1.00	1.00

P	A	B	C
A	1.00	5.00	1.00
B	0.20	1.00	0.20
C	1.00	5.00	1.00

T	A	B	C
A	1.00	9.00	7.00
B	0.11	1.00	0.20
C	0.14	5.00	1.00

C	A	B	C
A	1.00	0.50	1.00
B	2.00	1.00	2.00
C	1.00	0.50	1.00

S	A	B	C
A	1.00	6.00	4.00
B	0.17	1.00	0.33
C	0.25	3.00	1.00

Questions:

Use the AHP manaul calculations to decide on which equipment to purchase (A, B, or C).
Apply the AHP process to the same problem on a spreadsheet file. Check your calculations.

DISCRETE-EVENT SIMULATION

Discrete-event simulation is a useful tool for analyzing real-world systems, particularly those having cyclic nature, to improve operational efficiency and efficiently manage resources. Examples include the process of serving a queue of customers in a bank, manufacturing a product, operating a design office, and executing a large earth-moving operation. The main advantage of the simulation process is that it can consider the level of risk involved in each operation by using the probability distribution of these operations. Accordingly, during the simulation, each cycle of the process will have a random value from these distributions. In the project management domain, the first computerized simulation system was the CYCLONE system (Halpin 1973). Since its introduction, research in this domain has been growing increasingly. Over the years, several other systems have been developed based on the CYCLONE such as INSIGHT (Paulson 1978), RESQUE (Chang 1987), UM-CYCLONE (Ioannou 1989), COOPS (Liu and Ioannou 1992), DISCO (Huang et al. 1994), CIPROS (Tommelein and Odeh 1994), and HSM (Sawhney and AbouRizk 1995). Other general-purpose tools have also been introduced for application in construction such as ithink (also known as Stella) (Senogles and Peck 1994; High 1994) and SLAM II (Gonzalez-Quevedo et al. 1993; Pritsker 1986). Until recently, however, the software available for simulation modeling has been either too complex, too limited, or too costly (Paulson 1995).

The process of developing a traditional simulation model typically requires the user to be familiar with specific terminology and the modeling schematics of a particular software, in addition to the ability to write proprietary computer code. This may not be suitable for many construction practitioners who are otherwise familiar with the operational details needed for accurate simulation. Several researchers have, therefore, employed different ways to simplify the modeling process and to make it more attractive to practitioners. These include efforts to introduce simulation techniques imported from other domains (e.g., PETRI NETS by Wakefield and Sears 1997) and other efforts to enhance the operational characteristics of currently used tools (e.g., Shi and AbouRizk 1997). Discussion on these efforts was included in Shi and AbouRizk (1997).

A SIMPLIFIED APPROACH TO SIMULATION

Using Process V3, the simulation model can be constructed by drawing nodes and linking them with self-connecting arrows. As shown in Fig. 1(a), the nodes are called "activities" while the arrows are the "work-paths" representing the process flow and accordingly the movement of resources and objects. The activities and work-paths are the essential blocks for creating a model of any operation or process. The main characteristics of an activity are illustrated in Fig. 1(b). Activities are the points at which work-paths start and end. They can control the routing among alternative paths, maximum number of objects permitted to queue for a work-path, the maximum number of simultaneous activations of a work-path, and the priority assigned to the activity.

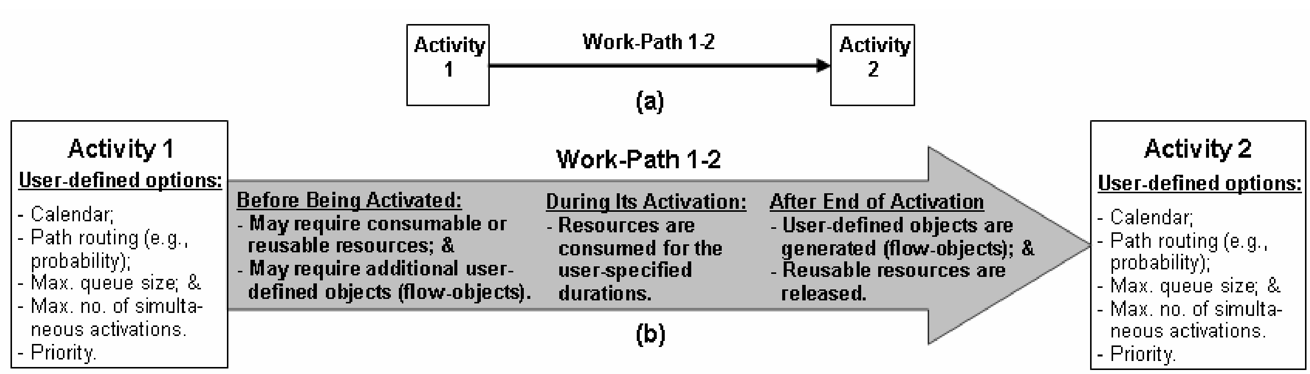
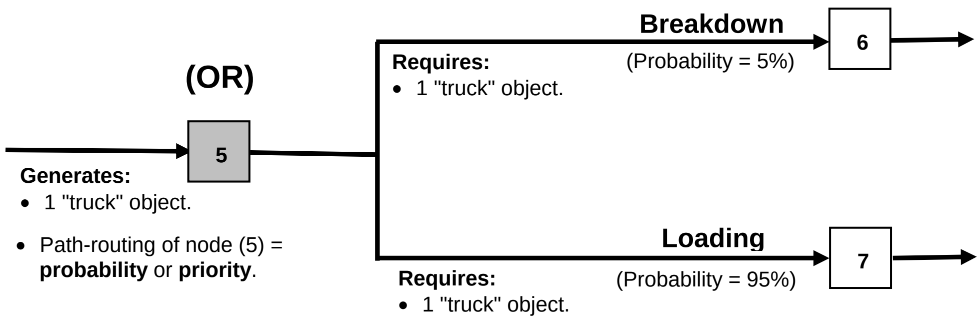


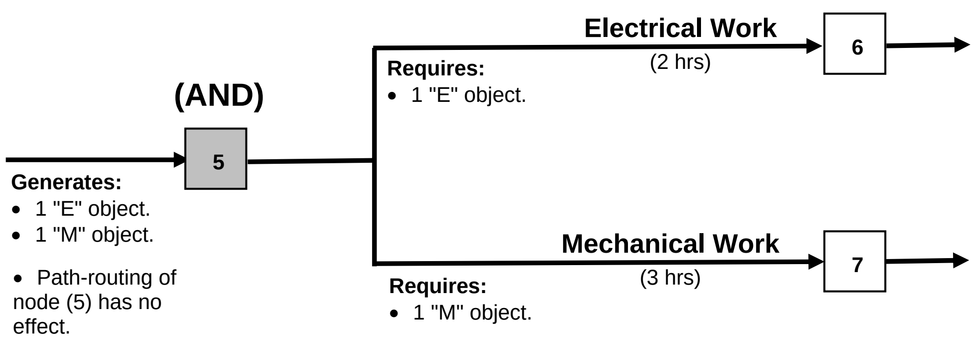
Figure 1: Basic Simulation Elements

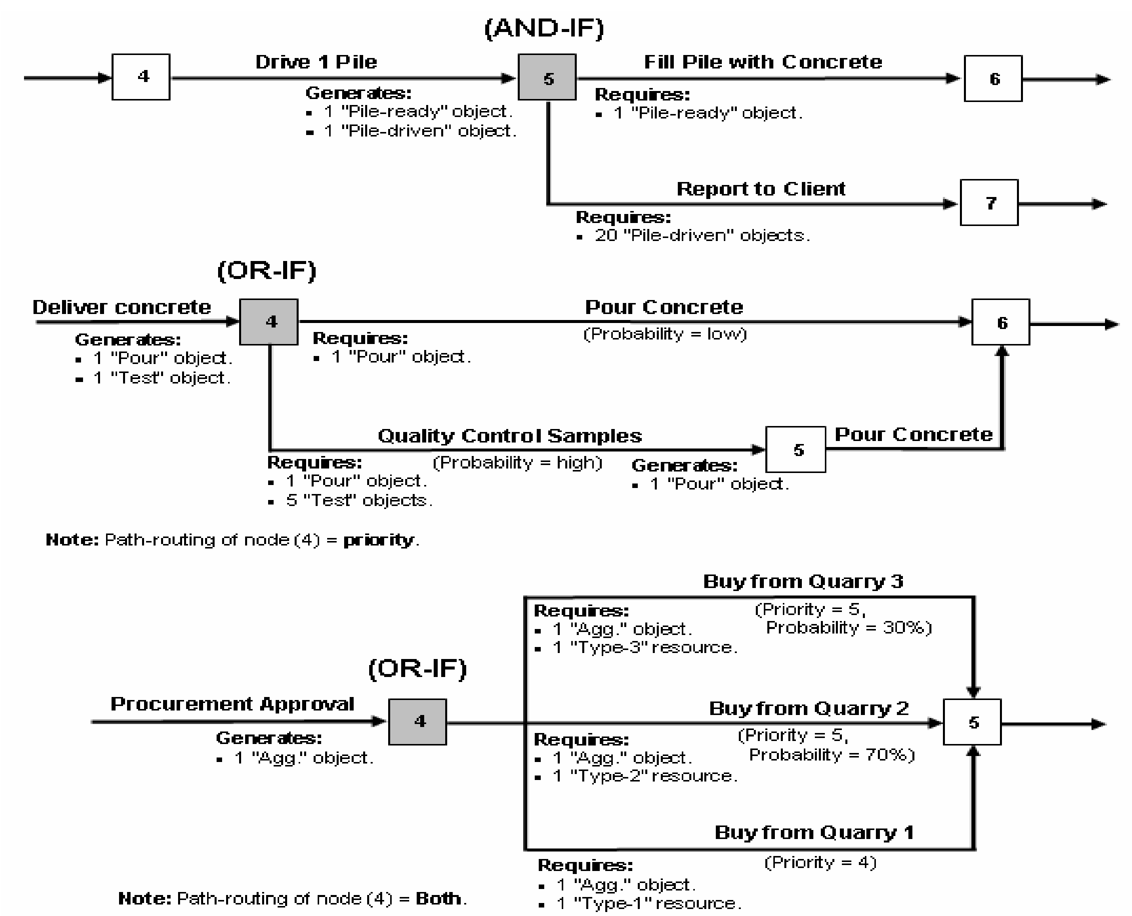
The work-path, on the other hand, models an actual step within a process. As illustrated in Fig. 1(b), the software allows the user to configure a work-path's properties by specifying its input requirements and the outputs to be generated at the end of its activation. The input requirements include resources either consumable or reusable, in addition to any number of user-defined flow-objects (explained later). Resources are assigned durations to spend on the work-path when it is activated, afterwards, reusable resources are released for use by other work-paths. Along with the released resources are any flow-objects set by the user to be generated at the end of activation.

Flow-objects are also essential to the modeling process. They flow throughout the model with work-path activations and they maintain the logic by being specified as outputs of predecessors and as requirements to successors (Fig.

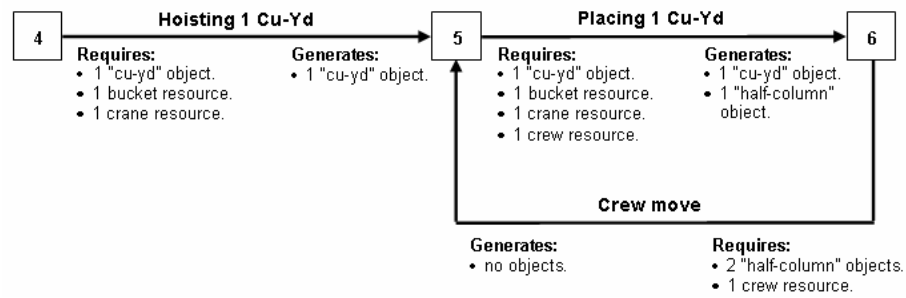
2). The user can change the default object or specify additional ones to represent meaningful quantities that flow through the model. When a work-path is activated, its start node (activity) counts the number of received flow-objects. Also, its end node counts the number of generated flow-objects. Flow-objects, thus, can be used for counting work-path activations for the purpose of conditional processing or to accumulate quantities important to the simulation such as production amounts. The use of flow objects to control the branching is illustrated below.







As an example of the above branching options, the following figure shows a simple concrete placing operation, in which one-Cu Yd buckets are hoisted, one at a time, and then placed in two-Cu Yd columns. It takes two buckets, therefore, for the concrete placing crew to move from one column to the other. In the model, work-path (5-6) for concrete placing requires a one “Cu Yd” flow-object generated by its predecessor (4-5) for hoisting of concrete to placement site. This ensures that concrete placing has to wait until concrete is hoisted even if its required resources are available. This also allows node 5 to count the number of Cu Yds that have been hoisted, and node 6 to count the Cu Yds placed. The concrete placing work-path (5-6), in turn, generates two flow-objects: one “Cu Yd” and one “half-column”. The latter is used to force the activation of work path (6-5) for the crew to move to next column when two “half-column” flow-objects are received. Branching is also illustrated as follows:



CASE STUDY

A case study of a simple but more detailed concrete-placing operation is considered. The process basically involves the dry batching of concrete materials into a truck at a batch plant located 2 miles from the job site. Each of the four trucks available can transport 5 batches to the site where they are dumped individually and sequentially into a concrete mixer. After each batch is mixed, it is placed into a concrete bucket and lifted by a crane to the placement location. The batch is then dumped, spread, vibrated, and finished by a concrete placement crew. The resources available for this job include 4 trucks, 1 concrete mixer, 2 concrete buckets, and 1 crane. The process starts with the 4 trucks in the truck queue place. A truck leaves the queue and the loading of the truck starts. After the truck is fully loaded with five batches, it begins the haul cycle. Upon reaching the mixer, providing the mixer is available, the truck dumps the 5 batches, one at a time, into the mixer. The batch is then mixed and placed in one of the two buckets for lifting to the work site. When the crane is available, it lifts the bucket to the work site for placement by the concrete placement crew.

The simulation model of this operation using Process V3 is shown below. The characteristics of all activities (nodes) and work-paths (arrows) are presented in Table 1. Activities are setup as shown in column 2. Priority values are assigned sequentially and in a reverse order to the different activities. This gives higher priority to finishing and placing concrete batches before new ones are processed. Also, all activities have been assigned an “unlimited” number of copies, except for activity 1. This is because activity 1, which receives 4 “Truck-avail.” objects at the beginning of the simulation, is required to load these trucks one-by-one and not simultaneously.

The resources and flow-objects required for each work-path are shown in column 4 of Table 1 and the outputs they generate are shown in column 5. Only three flow-objects (“Truck-avail.”, “Batch”, and “Bucket-empty”) were used in the model. Each work-path is activated only when it’s required resources and flow-objects become available. The truck-load, travel, dump, and return cycle is contained within activities 1-2-3-4-1. The “Truck-avail.” flow-object makes sure that the sequence of this cycle is maintained. At the end of the cycle, the “Dump to Skip” work-path (3-4) generates five “Batch” flow-objects to represent a truck-load being dumped to skip in five separate batches. After each “Batch” flow-object is used by the concrete mixing work-path (4-5), it flows through the concrete hoisting and depositing cycle 5-6-7-8. At the end of this cycle, the “Batch” flow-object is generated along with another object “Bucket-empty”. The “Batch” object is used to activate the “Spread Concrete” work-path (8-9) while the “Bucket-empty” object is used to activate the “Return Crane & Bucket” work-path (8-5). For counting purposes, the “Batch” flow-object can be traced at activity 9 to quantify the number of times concrete is placed at the job site.

Once the properties of all activities and work-paths are specified, the process simulation can be started. The software provides the user with the option to step through the simulation one-step at a time or to completely run the simulation for a certain period of simulation time. When the first option is used, the software highlights the activated activities and work-paths with a different color and provides details on the movement of objects and resources. Among the most useful outputs are activities' total effort, total cost, active time, idle time, and interrupted time.

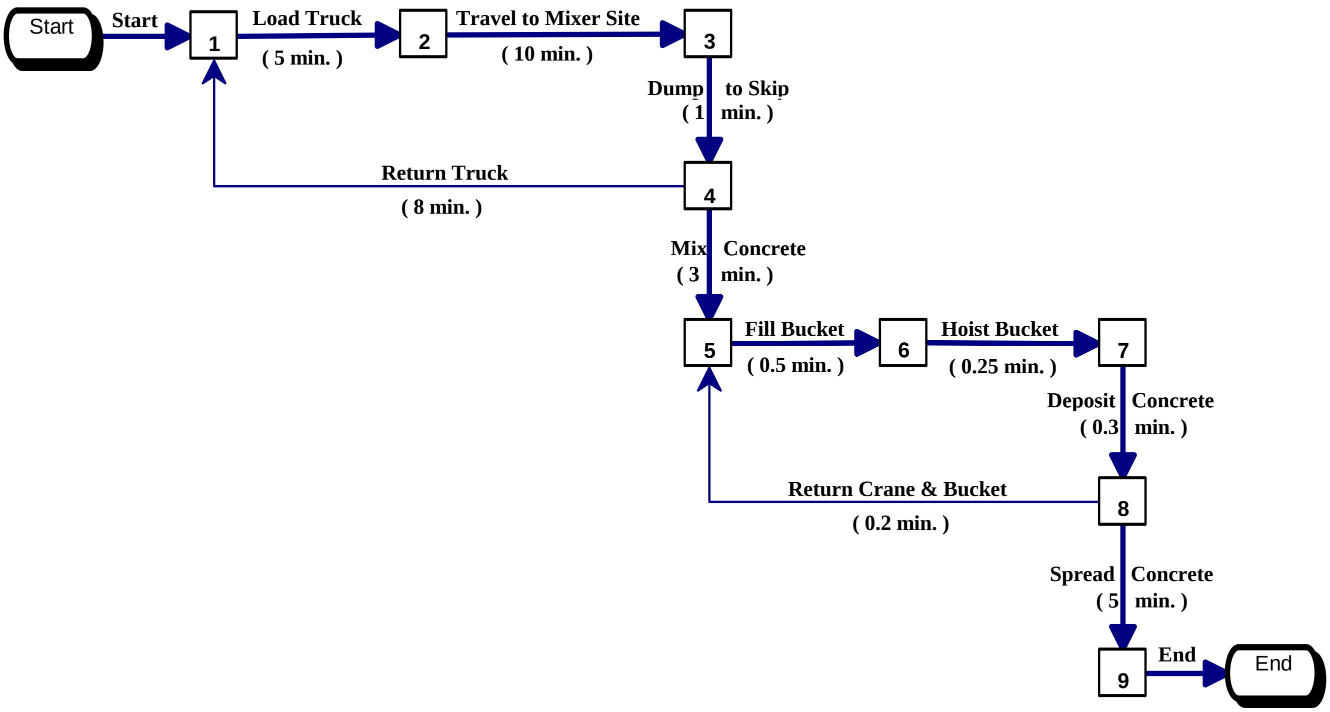


Table 1: Description of a Construction Case study Activities and Work-Paths

Activity (Node)		Work-Path (Arrow)		
No.	**Characteristics**	**Name**	**Required Resources & Objects**	**Generated Objects**
Start	---------	Start	---------	- "Truck-avail." (only 4 objects)
1	- Max. copies = 1 (i.e., one activation at a time) - Priority = 9	1-2 Load Truck	- Truck (resource), 5 minutes - "Truck-avail." (1 object)	- "Truck-avail." (1 object)
2	- Max. copies = unlimited - Priority = 8	2-3 Travel to Mixer Site	- Truck (resource), 10 minutes - "Truck-avail." (1 object)	- "Truck-avail." (1 object)
3	- Max. copies = unlimited - Priority = 7	3-4 Dump to Skip	- Truck (resource), 1 minute - Mixer (resource), 1 minute - "Truck-avail." (1 object)	- "Truck-avail." (1 object) - "Batch" (5 object)
4	- Max. copies = unlimited - Priority = 6	4-1 Return Truck	- Truck (resource), 8 minutes - "Truck-avail." (1 object)	- "Truck-avail." (1 object)
	- Max. copies = unlimited - Priority = 6	4-5 Mix Concrete	- Mixer (resource), 3 minutes - "Batch" (1 object)	- "Batch" (1 object)
5	- Max. copies = unlimited - Priority = 5	5-6 Fill Bucket	- Bucket (resource), 0.5 minute - Mixer (resource), 0.5 minute - "Batch" (1 object)	- "Batch" (1 object)
6	- Max. copies = unlimited - Priority = 4	6-7 Hoist Bucket	- Crane (resource), 0.25 minute - Bucket (resource), 0.25 minute - "Batch" (1 object)	- "Batch" (1 object)
7	- Max. copies = unlimited - Priority = 3	7-8 Deposit Concrete	- Crane (resource), 0.30 minute - Bucket (resource), 0.30 minute - "Batch" (1 object)	- "Batch" (1 object) - "Bucket-empty" (1 object)
8	- Max. copies = unlimited - Priority = 2	8-5 Return Crane & Bucket	- Crane (resource), 0.20 minute - Bucket (resource), 0.20 minute - "Bucket-empty" (1 object)	--------
	- Max. copies = unlimited - Priority = 2	8-9 Spread Concrete	- Crew (resource), 5 minutes - "Batch" (1 object)	- "Batch" (1 object)
9	- Max. copies = unlimited - Priority = 1	End	- "Batch" (1 object)	--------
End	-------	-------	-------	-------

References

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Case Study 2

Another simple concrete-placing operation is presented. The example was described in Paulson et al. (1987) and was modeled using INSIGHT, an advanced variation of the CYCLONE system. The process involved placing a number of concrete columns, 2 yd^3 each, for a new structure. One crane-bucket combination with a capacity of 1 yd^3 and a flexible "elephant-trunk" was assumed for placement. Concrete was delivered by four trucks, each with a capacity of 8 yd^3. Because of site constraints, however, only one truck could be moved into the delivery position at a time. One crew of construction workers was also assumed for the process. If a truck and the crane-bucket are both available, then the crane can load the 1-yd^3 bucket and hoist it to column placement location. The construction crew then uses the bucket to place concrete into a column. The crane and bucket then return for another load. After two buckets are placed, the column is complete and the crew can move to the next column. After the movement, placement in the new column can begin. Finally, after a truck is emptied, the truck departs and a new truck can enter into the delivery stall. How many columns can be constructed in one day?

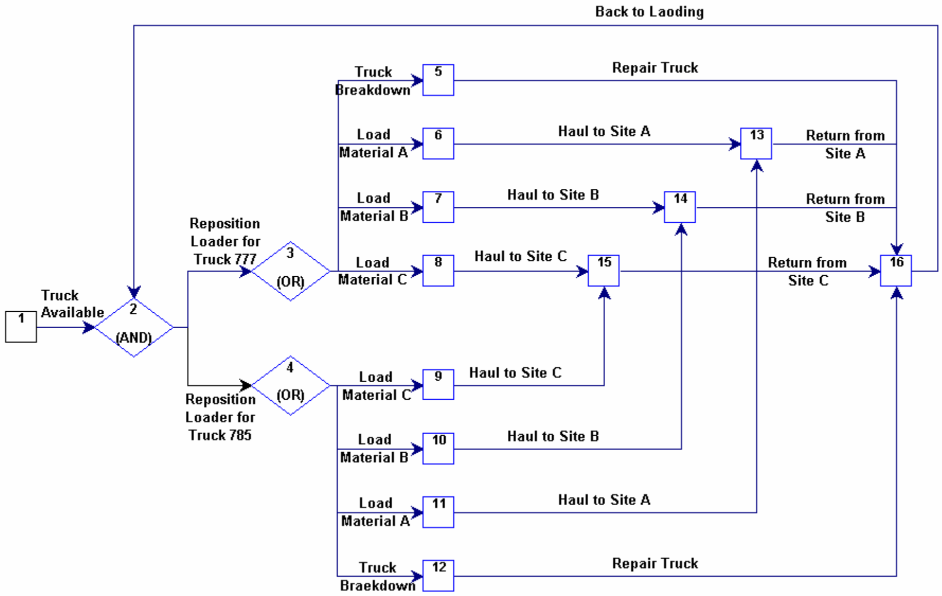
Activity	Resource	Duration
2-3 Loading & Hoisting	- Truck - Crane-Bucket	Normal (1.0, 0.2)***** Normal (1.0, 0.2)
3-4 Placing & Vibrating Concrete	- Crane-Bucket - Work Crew	Normal (2.0, 0.4) Normal (2.0, 0.4)
3-2 Reposition New Truck	- Truck	0.01 minute
4-2 Crane-Bucket Return	- Crane-Bucket	Normal (0.5, 0.1)
4-3 Crew Moves to Next Column	- Work Crew	Normal (3.0, 0.4)

***** Normal Distribution with mean = 1.0 minutes and standard deviation = 0.2 minutes.

Note: Resources are: 4 Trucks (8 cu yd capacity each), 1 Crane-Bucket combination, and 1 Work Crew.

Case Study 3

This example illustrates a complex construction earthmoving operation used at the New Hong Kong International Airport site. It represents a realistic construction operation with unique characteristics involving priorities, probabilities, and queuing systems. The example was previously modeled by Wakefield and Sears (1997) using PETRI Nets.



The earthmoving operation involved loading an excavated material into trucks using a one Demag H285 loader. Based on the quality of the excavated material, it was hauled into one of three fill locations (Site A, Site B, or Site C). Generally, trucks of two capacities were used on site: CAT777 trucks with capacity 30, 33, or 35 m^3 of material type A, B, or C, respectively; and CAT785 trucks with capacity 50, 55, or 60 m^3 of material type A, B, or C, respectively. The probability of a truck breakdown or loading material A, B, & C is shown in the following table.

Trucks are first loaded, one-at-a-time, using the only available Demag H285 loader. During loading, either material type (A, B, or C) may be used according to a known probability. Consequently, truck capacity, hauling time, and destination site were based. For practicality, truck breakdown probabilities were also given to model the situation in which one type of truck is more reliable than another. Once the excavated material is loaded, it is then hauled to, and dumped at, the appropriate fill location (Site A, Site B, or Site C). Finally, the trucks return back into the loading positions. The work was carried out in two 11-hour shifts per day. How much material received at sites A, B, and C in one day using 3 CAT785 Trucks and 4 CAT777 Trucks?.

Activity	Resource	Duration
Reposition Loader for CAT777	CAT777 , H285 Loader	R (0.5, 1.5, 0.5)*
Reposition Loader for CAT785	CAT785 , H285 Loader	R (0.5, 1.5, 0.5)
CAT777 Breakdown (P^{++}=0.001)	CAT777	0.0
Load CAT777 with Mat. A (P=0.449)	CAT777 , H285 Loader	R (1.0, 2.0, 0.5)
Load CAT777 with Mat. B(P=0.300)	CAT777 , H285 Loader	R (1.0, 2.0, 0.5)
Load CAT777 with Mat. C (P=0.250)	CAT777 , H285 Loader	R (1.0, 2.0, 0.5)
Load CAT785 with Mat. C (P=0.250)	CAT785 , H285 Loader	R(2.0, 3.0, 0.5)
Load CAT785 with Mat. B (P=0.300)	CAT785 , H285 Loader	R(2.0, 3.0, 0.5)
Load CAT785 with Mat. A (P=0.449)	CAT785 , H285 Loader	R(2.0, 3.0, 0.5)
CAT785 Breakdown (P=0.001)	CAT785	0.0
Repair CAT777	CAT777 , Workshop	N (240, 60)**
CAT777 Haul to Site A	CAT777	N (4.0, 0.7)
CAT777 Haul to Site B	CAT777	N (3.0, 0.5)
CAT777 Haul to Site C	CAT777	N (5.0, 0.9)
CAT785 Haul to Site C	CAT785	N (5.0, 0.9)
CAT785 Haul to Site B	CAT785	N (3.0, 0.5)
CAT785 Haul to Site A	CAT785	N (4.0, 0.7)
Repair CAT785	CAT785 , Workshop	N (240, 60)
CAT777 Return from Site A	CAT777	N (2.4, 0.4)
CAT785 Return from Site A	CAT785	N (2.4, 0.4)
CAT777 Return from Site B	CAT777	N (1.8, 0.3)
CAT785 Return from Site B	CAT785	N (1.8, 0.3)
CAT777 Return from Site C	CAT777	N (3.0, 0.5)
CAT785 Return from Site C	CAT785	N (3.0, 0.5)
CAT777 Back to Loading	CAT777	--------
CAT785 Back to Loading	CAT785	--------

* Random Distribution with start value = 0.5 min., end value = 1.5 min., and increment of 0.5 min.

** Normal Distribution with mean = 240 min. and standard deviation = 60 min.

+ Mat. Stands for material. ++ P stands for probability.

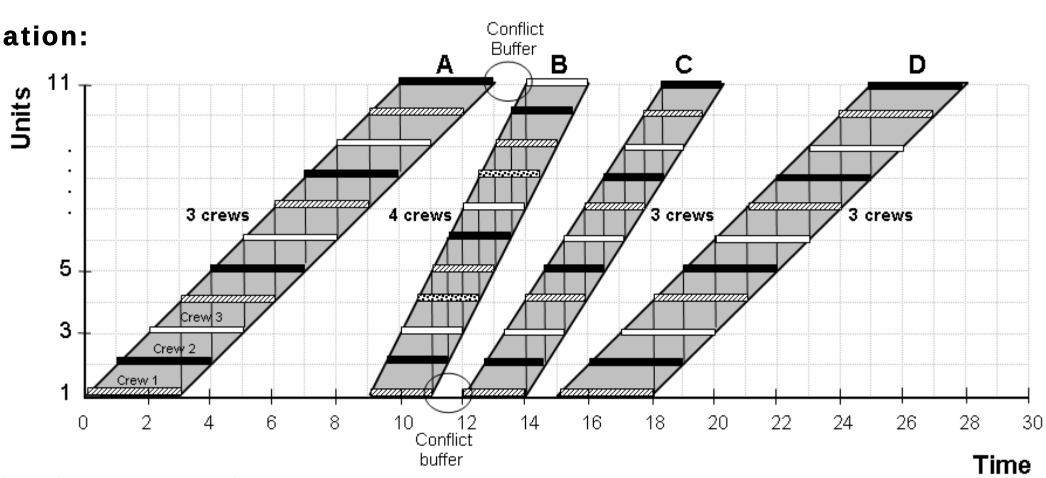
Note: Resources are: 1 H285 Loader, number of CAT777 Trucks, and number of CAT785 Trucks.

Scheduling Repetitive & Linear Projects

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

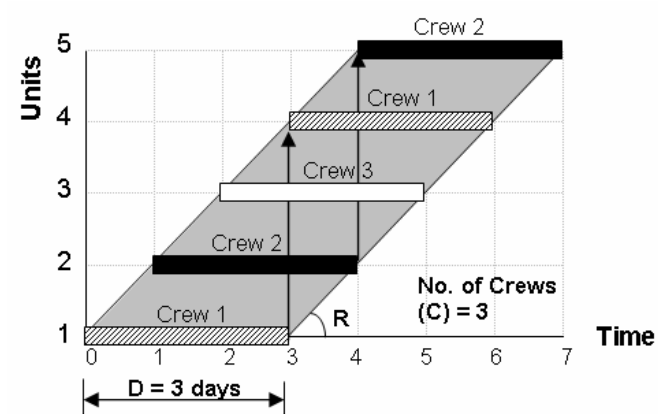
Integrated CPM & LOB Calculations:

New Representation:

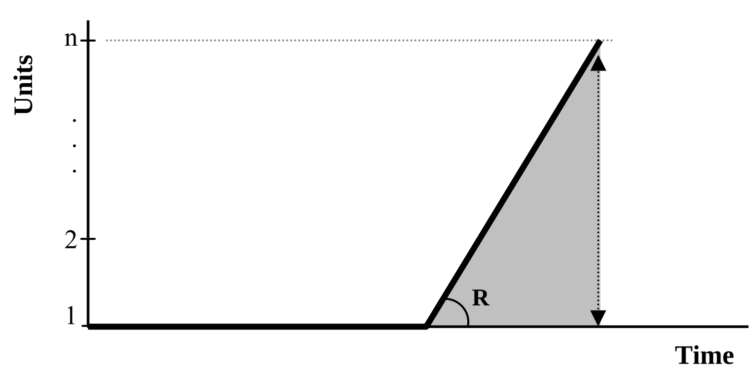


Crew Synchronization Calculations:

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

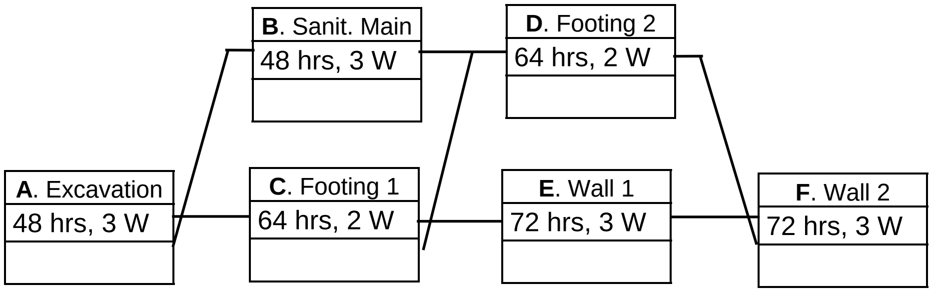


Calculating a Desired Progress Rate (R):



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;

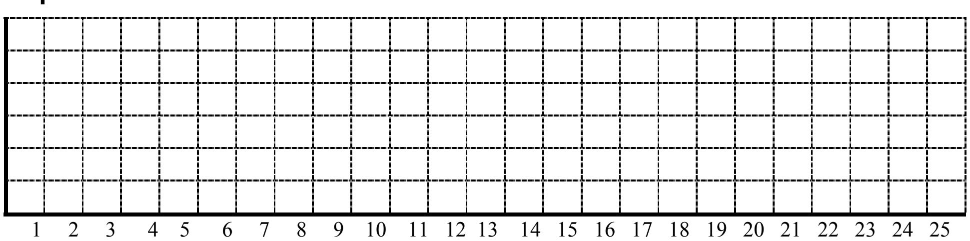


Step 1: CPM Calculation

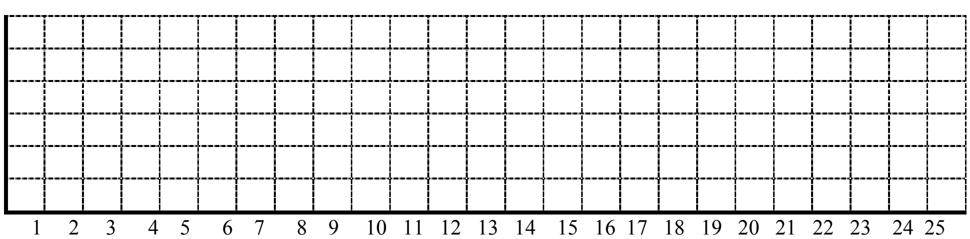
Step 2: LOB Calculations Deadline $T_L = 21$; $T_1 =$ ___ ; n = 5

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



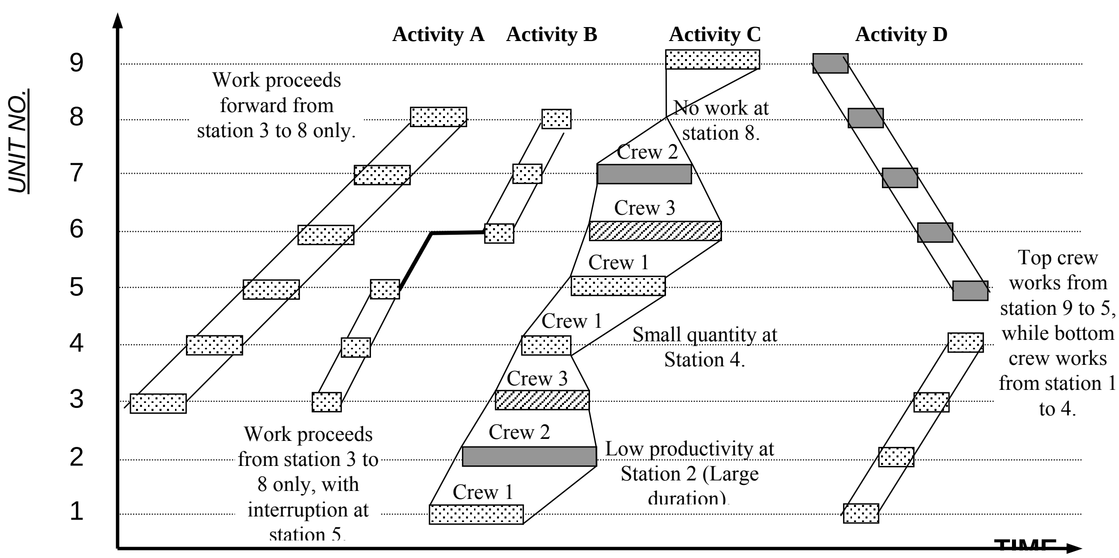
Assume:

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

More Advanced Linear scheduling Model

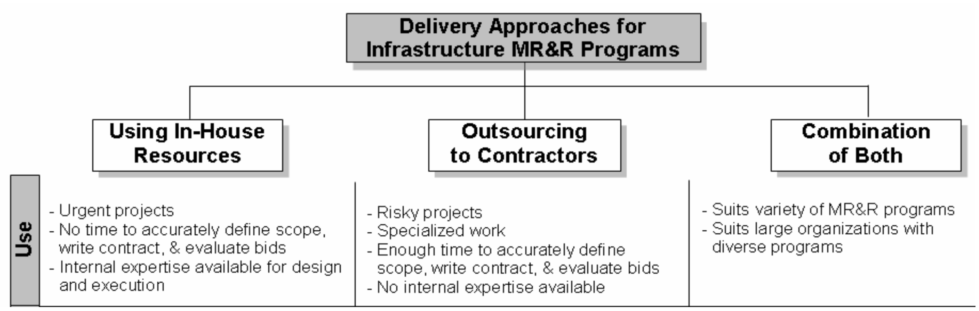
Flexible features for scheduling the activities include: color-coded or pattern-coded crews; varying quantities; productivity impact; crew interruption time; crew staggering; crew work sequence; and activities' progress speeds (slopes of lines). It is noted that the schedule is efficiently arranged with 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.



Infrastructure Networks with Distributed Sites: A Bigger Challenge

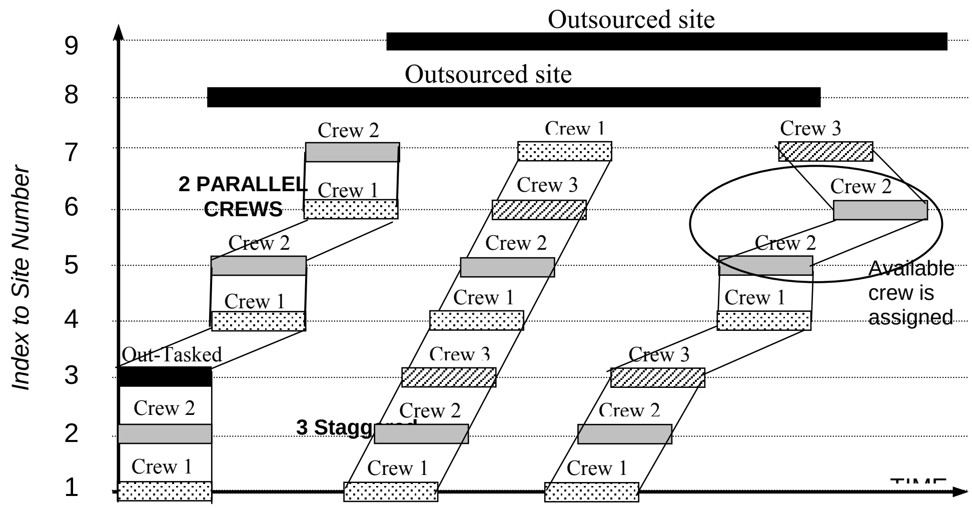
Buildings, Hispitals, Schools, Highway Spots, Bridges



Delivery approaches for MR&R programs

Effect of Site order

Scheduling of crews along multiple sites



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?

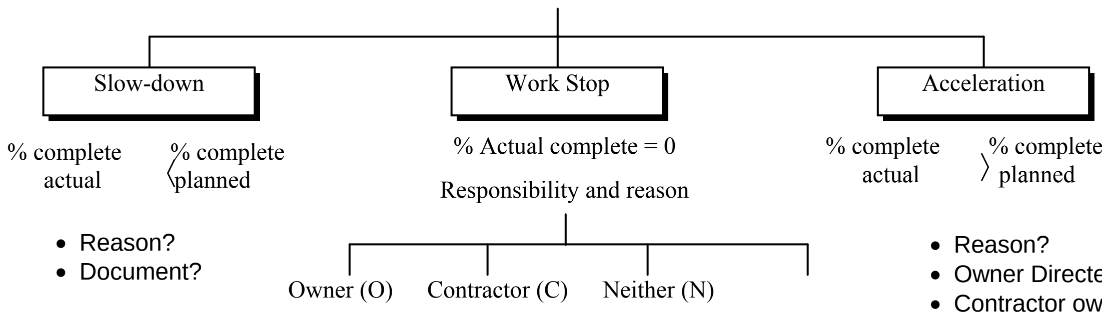
a) **Organized Site** = Safety + Productivity + Good Circulation + Cost & Time Savings

(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



- Reason?
- Document?

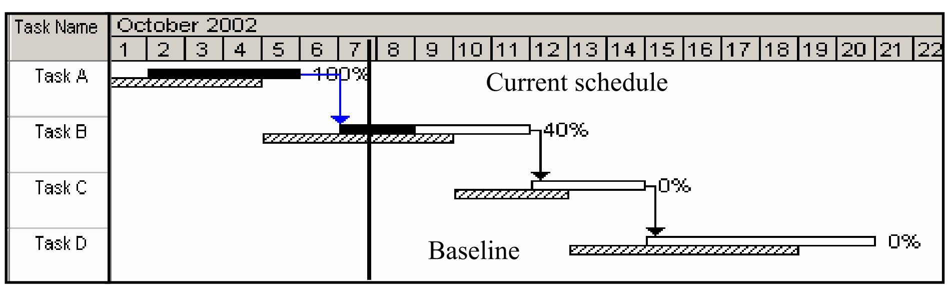
- Reason?
- Owner Directed?
- Contractor own?
- Document?

Calculating activity % complete: pages 291& 292

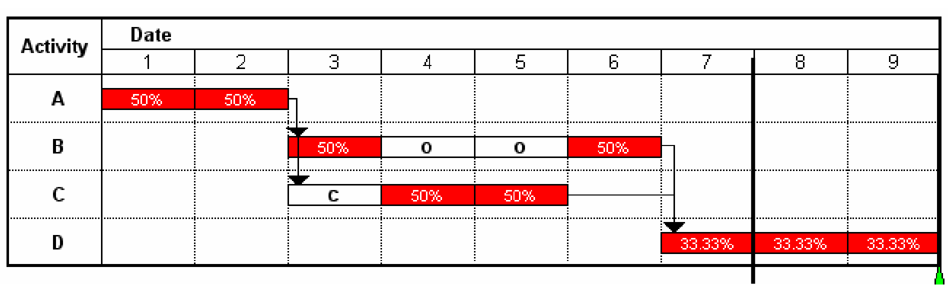
Calculating the overall project % complete: page 293

c) **Using Software**

How to show Delays?
Slow versus Fast?
Reasons for work stops?



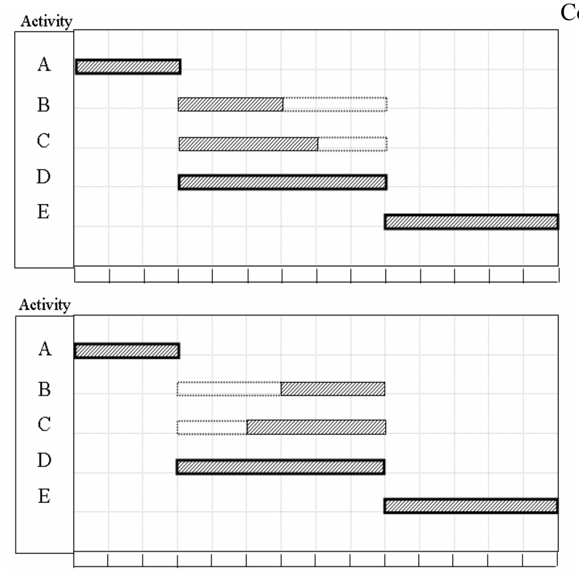
Can we readily decide which party is responsible for the two days delay beyond the deadline?

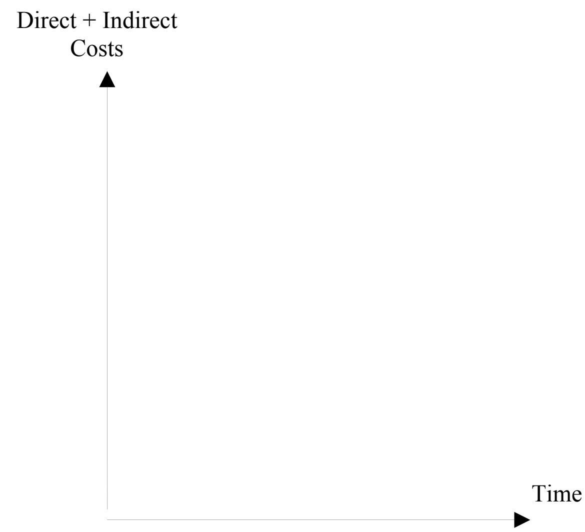


d) **Techniques for Performance Evaluation**

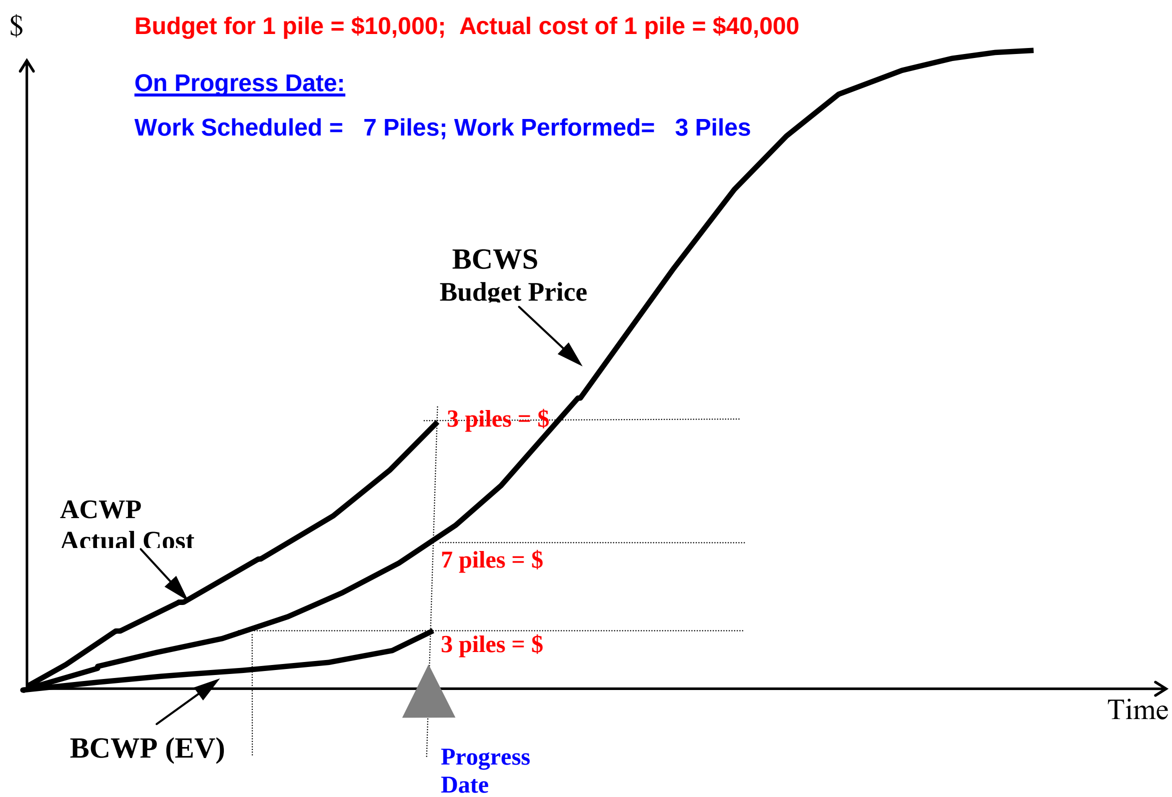
1. S-Curve Envelope:

Contractor's cost Control





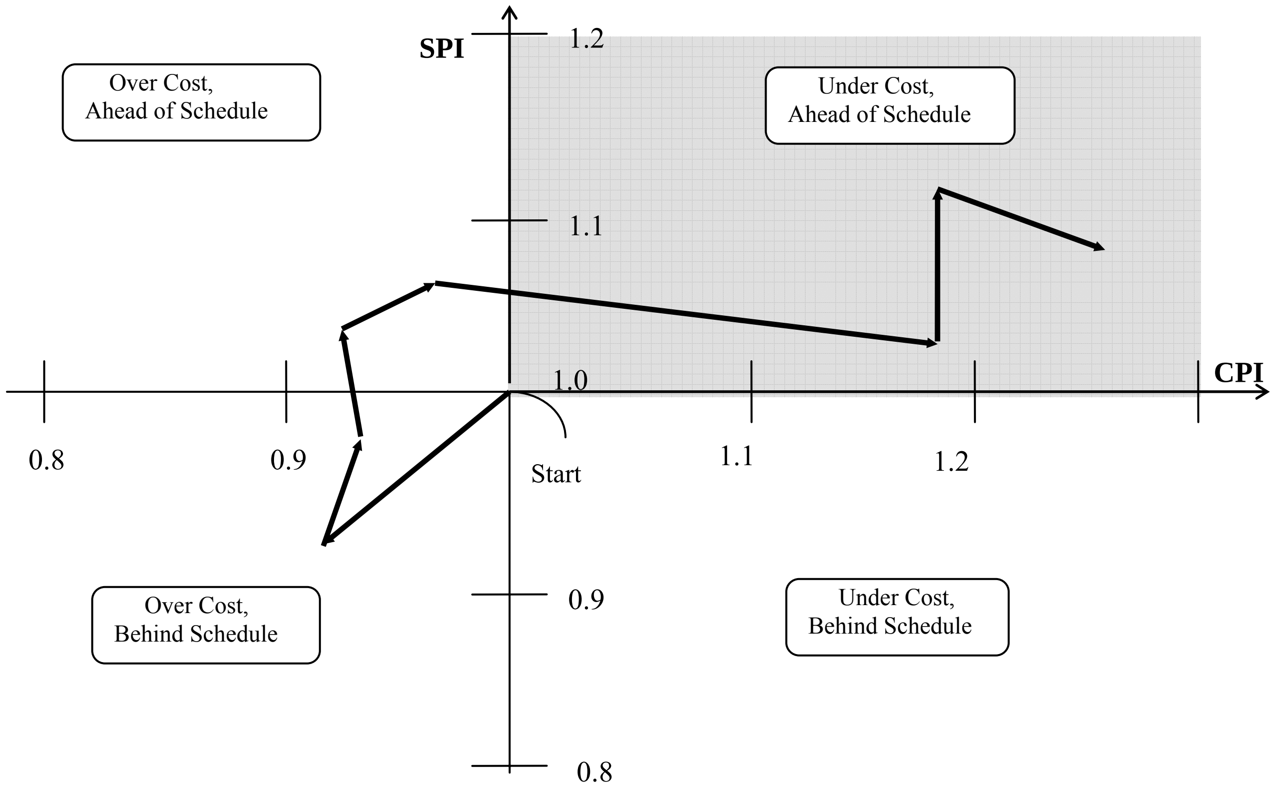
2. Earned-Value Analysis:



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

- Time variance?
- Estimate at completion?

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



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.

f) **New Concept For Project Control (Critical Chain):**

- Estimate with safety removed (50% chance);
- Incentive for early finish;
- Focus on predecessors' finish;
- Project buffer (50%);
- Simple monitoring of buffer penetration;
- Earned-Value for cost analysis.

Updating & Corrective Actions

Forecasting the Remaining Schedule

Using Software

- Open Microsoft Project and add four sequential tasks as shown below. Add the relationships.
- Save the Baseline (Tools – Tracking – Save Baseline).
- Activate the "Tracking Gantt" from the side bar. Notice the two bars per activity.
- Now, Use (View-Table-Tracking) to see the columns related to entering progress details.
- Add the percentage complete shown below for the tasks.

How to show Delays? Which is slow vs Fast? Reasons for work stops?

EasyPlan: PR 7

The activities of a small project are shown in the following table.

Activity	Dependents	Description	Estimate no. 1		Estimate no. 2		Estimate no. 3	
			Dur. (d)	Cost ($)	Dur. (d)	Cost ($)	Dur. (d)	Cost ($)
1	---	Excavation	2	2,000	-----	-----	1	3,000
2	1	Foundation	2	2,000	-----	-----	1	3,000
3	2	Joining Wall	1	1,000	-----	-----	-----	-----
4	3	House Walls	4	4,000	3	3,000	2	5,000
5	4	House Roof	3	3,000	2	5,000	-----	-----
6	---	Select Finishes	1	1,000	-----	-----	-----	-----
7	5, 6	Interior Finishes	3	3,000	2	4,000	-----	-----
8	7, 12	Clean Up	1	1,000	-----	-----	-----	-----
9	---	Fab. Garage Doors	6	6,000	4	10,000	2	12,000
10	3	Garage Walls	3	3,000	2	5,000	-----	-----
11	10	Garage Roof	2	2,000	1	3,000	-----	-----
12	9, 11	Garage Doors	2	2,000	-----	-----	-----	-----

Project Constraints:
- Deadline is 14 days; Indirect cost = $300/day; Penalty = $5,000/day; and Bonus = $1000/day.
- Each activity uses 2 labors (**L5**) daily; and Resource limit is **4 L5** resources per day.
- A reporting period is 3 days; interest rate is 1% / period; Markup is 10%; & owner retention is 5%.

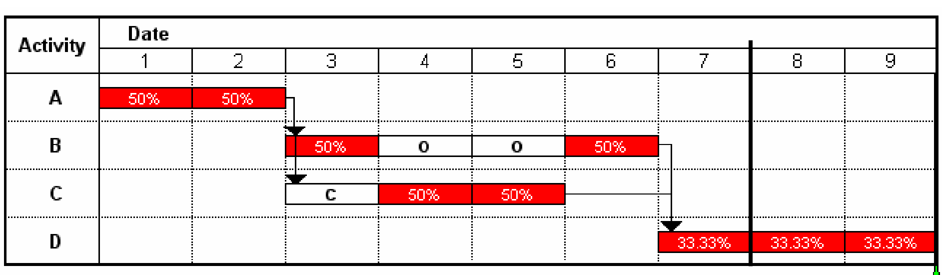
Requirements:
Determine the optimum execution plan. **Check your solution.**
During actual progress, the following events were encountered during **the first 12 days**:

- Day 1: excavation progressed as planned and no other work was done.
- Day 2: the contractor encountered unexpected rock (an owner-related problem). Accordingly, Excavation was stopped until a new machine is procured. No other work was done on day 2.
- Days 3 and 4: the new excavation equipment did not arrive yet. No other work was done.
- Day 5: the new excavation equipment started working and all remaining excavation work was completed that day. No other work done.
- Days 6 and 7: Foundation work was started and completed.
- Day 8: work on the Joining Wall was started and completed.
- On each of days 9 & 10: 25% of the House Walls and 25% of the Garage Walls were completed.
- Day 11: both the owner and contractor caused the House Walls activity to stop. Also, the contractor did not have resources to work on the Garage Walls.
- Day 12: the problem due to both the owner and the contractor still caused the House Walls activity to stop. The contractor also still had a resource problem and could not proceed on the Garage Walls. On the same day, the owner wanted to take some time to change his selection of the interior finishes. In addition, the Fabrication of the Garage Doors activity is 17% done.
- Actual costs to day 12 are assumed to be $5,000 for each of the started activities.

a) What is your optimum corrective action plan? Plot the project S-Curve and Earned-Value curve.
b) Print the payment schedule, Cash Flow chart, resource histograms, & the as-built schedule.

Delay Analysis

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



MBF: MODIFIED BUT-FOR METHOD FOR DELAY ANALYSIS

By Anania Mbabazi; Tarek Hegazy, Member, ASCE; and Frank Saccomanno

“But-For” is a widely used method for analyzing and apportioning project delays among the responsible parties. Despite its acceptability, the traditional But-For method suffers from serious drawbacks; namely its narrow focus on the point of view of a single party and its inability to accurately consider concurrent delays. In this paper, several improvements have been made to the But-For method to produce repeatable results and to account for concurrent delays. Details of the Modified But-For (MBF) method are provided along with an example to demonstrate its advantages. The method is simple and can help practitioners in apportioning project delays in an accurate and equitable manner.

INTRODUCTION

Among the various delay analysis techniques proposed by various researchers, the But-For method has been one of the most widely used (Stumpf 2000). Yet, given an accurate as-built schedule, the implications of each party’s delays are not easily analysed since it is difficult to distinguish each party’s critical delays (affecting project duration) from its non-critical ones. As such, a simple approach is followed in But-For analysis to remove the delays caused by one of the parties from the as-built schedule to determine when the project would have been completed except for (but-for) the actions of that party.

A simple project of four activities (Fig. 1) is shown. The as-planned duration is 8 days but the as-built schedule experienced a number of delays (shown by the fill patterns) that caused the project to be completed only in 11 days. When considering the owner’s perspective in But-For analysis, all the owner’s daily delays are removed from the as-built schedule and project duration became 10 days. Accordingly, the owner is made responsible for one day of critical delay and the balance of 2 critical delay days is apportioned to the contractor. The comparative results are shown in Table 1. As expected, the different methods, and also the owner’s versus contractor’s points of views, give different results.

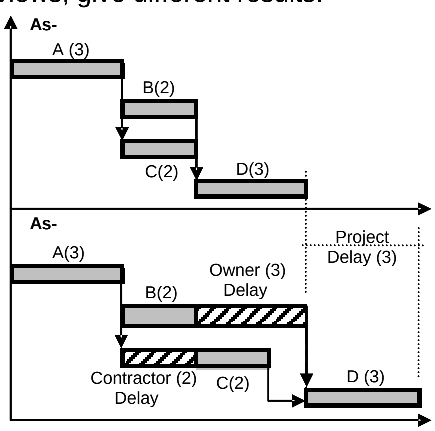


Fig. 1. Project Information for a Small Example

Table 1. Summary of Delay Analysis Results

But-For Methods	Owner Delays (days)	Contractor Delays (days)
As-Built Owner’s View	1	2
As-Built Contractor’s View	3	--

PROPOSED IMPROVEMENTS

Three improvements are proposed to address the identified shortfalls of existing But-For delay analysis methods. These include: new representation of activity disruption; a new representation of possible interactions among the concurrent critical delays of various parties; and a new delay analysis method that considers and reconciles the points of views of all the parties. Each of these is discussed next.

Representation of Activity Disruption

Existing project management software systems do not allow the representation of a work interruption (delay) by any party (o, c, or n) to any activity at a given day. This necessitated a new representation of execution details by manipulating the features of existing software (Microsoft Project Software is used in this study). A delay event (activity disruption) is proposed to be recorded as “o”, “c”, or “n” to represent the party causing the delay, i.e., owner, contractor, and neither party, respectively. It is noted that lower case letters are used to indicate any case of critical or non-critical delay. Additional comments like related correspondence about the site event, site minutes where this event occurred may also be included. To implement the proposed delay representation for the simple example in Fig. 1, an activity is split into two activities at the delay date, and then a new activity is inserted between the two parts to represent the delay. The inserted delay activity is then given an identifier for the responsible party (highlighted column in Fig. 2, with a value of c, o, or n). As such, a delay converts an activity (or a part of an activity) into three activities with logical relationships properly introduced among them.

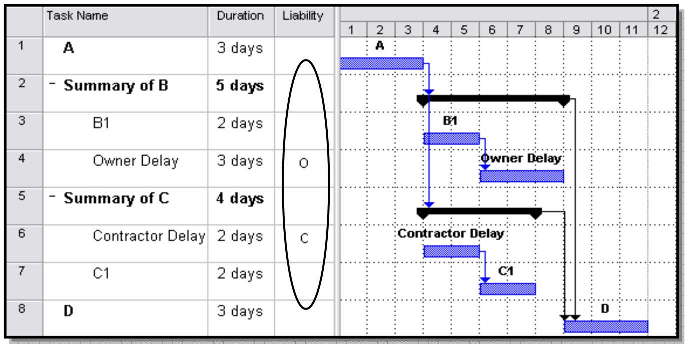


Fig. 2. As-Built Schedule for the Example Showing Delay Representation

Representation of Concurrent Critical Delays

Due to the various delay events that occurred to various activities at various times (3o + 2c = 5), the net project delay experienced in this simple example was 3 days. This indicates that some of these daily events did not affect the project critical path. The delays that occur concurrently on different critical paths and affect project duration are called concurrent critical delays. Fig. 3 shows six concurrent delay situations (occurred on different days) involving one, two, or three parties.

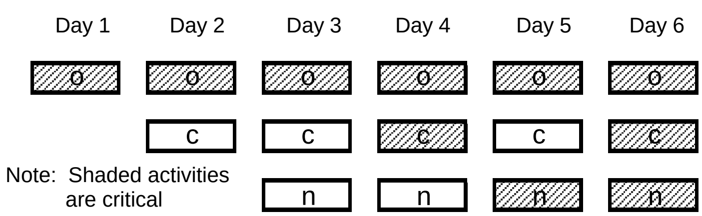
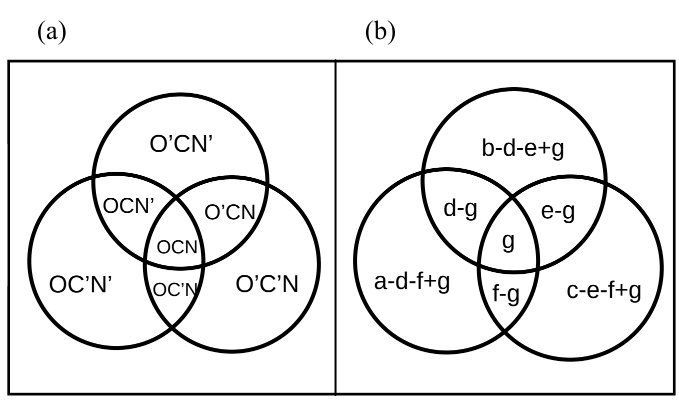


Fig. 3. Interactions among Three-Party Concurrent Delays

A Venn diagram of possible critical delay interactions among three parties is shown in **Error! Reference source not found.**a. The Venn diagram indicates three intersecting sets (C, O, and N), with a naming notation for each segment. It is noted that upper-case letters are used for the set representation to indicate that all delays are critical delays. An example of a one-party delay is OC’N’, i.e., owner but not contractor or third-party delays. Similarly, an example of a two-party concurrent delay is OCN’, i.e., delays involving only the owner and the contractor. In this Venn representation, the values within each segment represent the number of occurrences of each critical delay case (all must sum up to the net project delay). Using set theorems, a mathematical representation of the values represented by each segment can be made using seven variables a, b, c, d, e, f, and g, is shown in **Error! Reference source not found.**b. As shown, all the segments within the (O) set (the union of all occurrences involving the owner) add up to a value of (a), i.e., OC’N’ + OCN’ + OCN + OC’N = = a. Also, all the segments inside the (C) set (the union of all occurrences involving the contractor) add up to a value of (b) and all the segments inside the N set add up to (c).

Fig. 4. Concurrent Delay Representation: (a) Venn Diagram Representation; and (b) Venn Diagram Variables



This Venn representation and the set theory to represent concurrent delays is a new concept that is very useful in apportioning project delays. The Venn diagram shows a representation of all types of critical delay combinations (determined using the modified but-for method in the next section). Based on these critical delay types, accurate time and cost compensation can be decided for each of the seven segments in Fig. 4. A number of equitable compensation rules have been discussed in the literature (Baram 2000; Arditi and Robinson 1995; Kraiem and Diekman 1987). The most equitable rules selected for this study are shown in Table 2.

Table 2. Compensation Rules for Concurrent Delays

Delay Party (ies)	Concurrent Delay Type	Decision Rule		
		Time Ext. to Contractor	Payment to Contractor	Payment to Owner
C only delays	O'CN'*	No	No	Yes
N only delays	O'C'N	Yes	No	No
O only delays	OC'N'	Yes	Yes	No
O and N delays	OC'N = O'C'N	Yes	No	No
C and N delays	O'CN = O'C'N	Yes	No	No
O and C delays	OCN' = O'C'N	Yes	No	No
O,C, and N delays	OCN = O'C'N	Yes	No	No
Two O delays	O+O = OC'N'	Yes	Yes	No
Two C delays	C+C = O'CN'	No	No	Yes
Two N delays	N+N = O'C'N	Yes	No	No

* O' = complement of O.

MODIFIED BUT-FOR (MBF) METHOD

The MBF method is designed to produce repeatable and accurate results by reconciling all the parties' points of views. It uses the Venn diagram representation for three-party critical delays and the selected set of compensation rules. To automate the calculations, a macro program was written on Microsoft Project software. The process starts by identifying all the daily delay events (o, c, and n) on the as-built schedule. Since three parties are involved (contractor, owner, and third-party), there can be seven mathematical combinations of these events, as follows: o, c, n, o+c, o+n, c+n, and o+c+n. The MBF method then removes these seven combinations, one at a time, from the as-built schedule, and the resulting project duration is used to calculate the values in the Venn diagram of Fig. 4. The calculation is in Table 3.

Table 3. MBF Calculations

Analysis Cycle	Daily Delays Removed	Resulting Duration	Venn Diagram Calculations
1	o + c + n	$T_1 = 8$	$T^*_0 – T_1 = 3$ = OUCUN = a+b+c–d–e–f+g
2	o	$T_2 = 10$	$T_0 – T_2 = 1$ = OC'N' = a–d–f+g
3	c	$T_3 = 11$	$T_0 – T_3 = 0$ = O'CN' = b–d–e+g = 0
4	n	$T_4 = 11$	$T_0 – T_4 = 0$ = O'C'N = c–e–f+g = 0
5	o + c	$T_5 = 8$	$T_0 – T_5 = 3$ = (OUC)N' = a+b–d–e–f+g
6	o + n	$T_6 = 10$	$T_0 – T_6 = 1$ = (OUN)C' = a+c–d–e–f+g
7	c + n	$T_7 = 11$	$T_0 – T_7 = 0$ = (CUN)O' = b+c–d–e–f+g

$^*T_0$ = As-built duration = 11 days

The as-built duration T_0 is first determined, considering all delays. Then, in the first analysis cycle (Table 3), all o+c+n delays are removed (simply by setting the durations for these delay activities in the schedule of Fig. 2 to zeroes), resulting in a project duration of $T_1 = 8$ days. As such, the impact of all delays is directly calculated as (T_0 - T_1), which represents the union area (OUCUN) in the Venn diagram of Fig. 4. This gives one equation of the associated variables (i.e., OUCUN = $T_0 - T_1 = 3 = a + b + c – d – e – f + g$), as shown in Table **3**. In the second cycle, all the (o) delays alone are removed from the restored as-built schedule, thus producing a project duration of $T_2 = 10$ days. As such, the net delays caused by only (o), i.e., OC'N' = $T_0 – T_2 = 1 = a – d – f + g$. The process is then continued to remove all the seven combinations in Table 3, resulting in seven simultaneous equations that are solved to determine the following values for the variables: a = 3; b = 2; c = 0; d = 2; e = 0; f = 0; and g = 0. Based on these values, each segment in the Venn diagram is calculated. The final result of the MBF analysis is to apportion the 3-day total project delay as: 1 OC'N' (owner-only delay) + 2 OCN' (concurrent C+O delays). This result of the MBF is different from all other But-For methods presented earlier in Table 1 due to its ability to correctly identify concurrent delays (not apparent in the as-built schedule of Fig. 1). The result of the MBF analysis also proves to be logical and equitable. Simply, the as-built schedule has two paths: 11 days (critical), and 10 days. For the project to have 3 days of total delay, then, the critical path (delayed by the owner) uniquely delayed the project the 11th day. In addition, the delays of days 9 and 10 occurred on both paths (concurrently by the owner and the contractor). As such, only the MBF method could identify the hidden concurrent delays. MBF results are also repeatable.

CONCLUSION

A Modified But-For (MBF) method is presented in this paper. The MBF method uses a venn-diagram to represent the different sets of one-party, two-party, and three-party concurrent critical delays. As such, the MBF method presented a mathematical basis for reconciling the varying results associated with the individual parties' points of views. The method is simple to use by practitioners and is unique in its consideration of concurrent delays to produce equitable and repeatable delay analysis results.

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APPORTIONING CONCURRENT DELAYS AND ACCELERATIONS USING DAILY WINDOWS

Kehui Zhang and Tarek Hegazy

Project as-built duration is the resultant of all day-to-day events and actions, including slowdowns, work stops, and accelerations, made by all project parties. In current practice, however, a systematic procedure for recording and analyzing daily actions is lacking, thus making the quantification and analysis of time-related and cost-related claims a complex task that is highly controversial. In this paper, a practical model is presented, with an analytical framework, for analyzing project as-built schedules, considering slowdowns, work stops, and accelerations. The model differentiates between owner-directed and contractor-voluntary accelerations and deals with acceleration as a negative delay attributable to the party that creates it. To provide accurate and repeatable results, the model uses a daily windows analysis technique for apportioning concurrent delays and accelerations. Details of the proposed model are provided along with an example application. The model is readily usable by professionals and researchers to dynamically analyze the impact of all events along project duration.

INTRODUCTION

Dynamic analysis of progress events and their net impact on time and cost is essential for deciding correcting actions and also for apportioning net project delay among project parties (contractor, owner, or neither). To date, the Windows Analysis technique is the preferred delay analysis technique (Zack 2000; Finke 1999) can evaluate the impact of work stops that occur on critical paths. Although work stop (delay) has been studied extensively in the literature, the impact of accelerations and decelerations on schedules has not been adequately studied. Since the project as-built duration is the resultant of all day-to-day progress variations (slowdowns, work stops, and accelerations), recording and analyzing these progress details becomes essential for accurate schedule analysis.

In general, work stops can be caused by either the contractor (c), the owner (o), or neither (n, e.g., weather, etc.), while slowdown is mainly attributable to the contractor. Acceleration, on the other hand, can be of three types: (1) Owner-directed through a verbal or a written change order that the contractor executed at additional costs; (2) Owner constructive, where the contractor accelerates the work so as to compensate for excusable delays (due to owner or unforeseeable reasons); and (3) Contractor voluntary, when the contractor escalates the rate of construction for his/her own benefit or convenience, or in an attempt to correct a contractor-caused (non-excusable) delay in an effort to timely complete the work.

REPRESENTATION OF DAILY AS-BUILT EVENTS

A simplified representation of site events on a bar chart has been introduced by Hegazy et al. (2003). The bar chart (Figure 1) is made of adjacent spreadsheet cells. This representation is useful for both site-data recording and also for delay analysis. It records the daily percentage completes of activities along their durations; and any work stops and their responsible parties (using small letters c, o, n). Accelerations and slowdowns are indicated by comparing the planned versus actual progress rates.

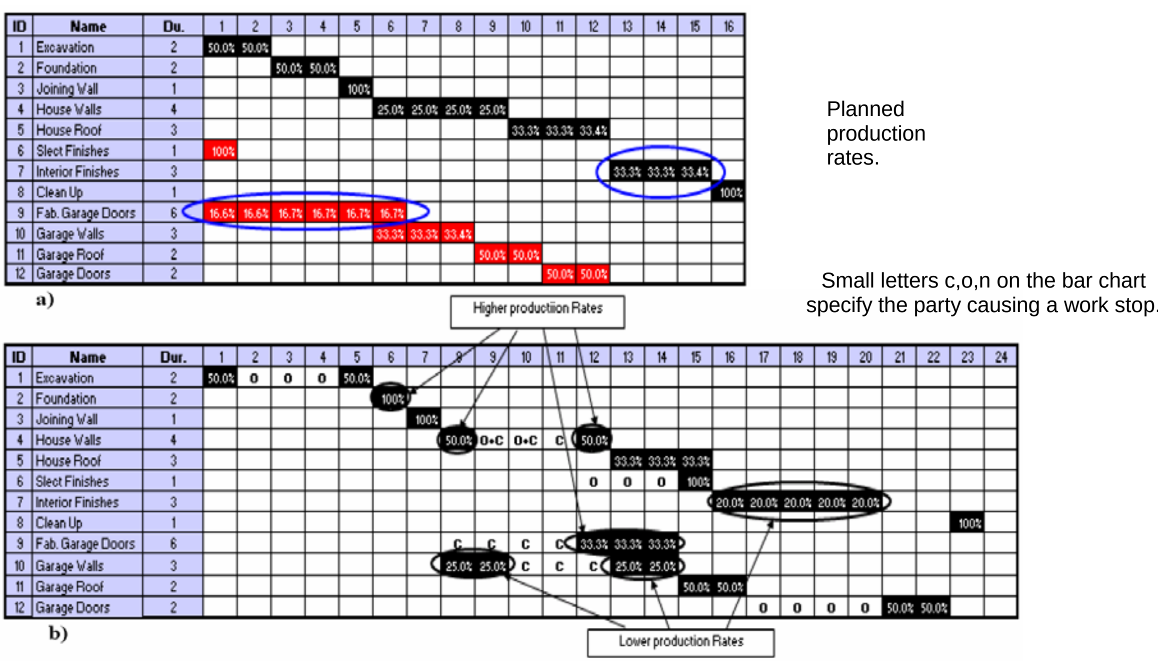

Figure 1. Representation of delays and accelerations: a) As-Planned; b) As-Built.

In the representation of Figure 1, all work stops, slowdowns, and accelerations are recorded on the bar chart on the day(s) they occur. If an activity is stopped due to owner-related reasons, an "o" letter is shown on that day. In the same manner, if the work stop is contractor-related, a "c" letter is shown. In case of work stops that are not liable to owner or contractor (e.g., acts of God), an "n" letter is shown. Also, if both parties cause an activity work stop, a combination of any of these three letters is shown (e.g., "o+c"). The reasons for delays are also recorded as comments on appropriate cells.

The as-built bar chart of Figure 1 can be generated as the project evolves, or alternatively, after the end of construction. In the latter case, the chart is generated from activities' actual start and finish times, in addition to any manually recorded work stops and their reasons. Daily percentage completes can be distributed equally along the activities' actual durations.

ANALYSIS OF DELAYS AND ACCELERATIONS

TRADITIONAL WINDOWS ANALYSIS

Traditional windows analysis looks at several project intervals (windows or snapshots) and assesses how the critical path varies from each window to the other (but not within each window). When acceleration is not considered, the analysis may produce different results depending on the window size. This is illustrated in the small 2-activity example of Figure 2. The two activities of this example are both critical. During execution, the first task (A) was completed in one day instead of two. At this stage, it can be perceived that the acceleration of activity A introduces a float (called acceleration float) with respect to the original deadline. After the completion of A, activity B started on day 2 where progress was a little slower than planned (20% as opposed to 33%). Afterwards, the owner caused a work stop on the third day, while the contractor caused a work stop on the fifth day. The net project delay is one day, as shown in Figure 2 (6 days as-built versus 5 days as-planned).

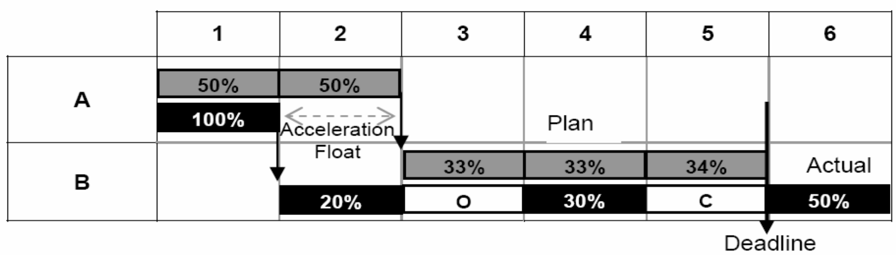

Figure 2. Bar charts of a simple example.

Using the traditional windows approach and assuming only one window ending at day 6, the two days of delay (one o and one c) both occurred on the critical path. As such, the net one-day project delay is apportioned equally to both. In this case, the acceleration to activity A is not considered in the analysis. Alternatively, when the well accepted concept of "Float belongs to the party who uses it first" is used, the analysis produces a different result. In this case, the acceleration float is consumed by the owner at day 3 (first to use it). Accordingly, the contractor's delay at day 5 is responsible for project's net delay. The different conclusion reached in this case demonstrates the conflicting nature of traditional windows analysis.

DAILY WINDOWS ANALYSIS

A Daily Windows technique for delay analysis (Zhang 2003) is extended in this research to the general case of delay and acceleration. The daily windows approach uses a window size of one day to account for all the fluctuations that occur in the project's critical path(s). Using this approach on the same example is illustrated in Figure 3, with 6 daily windows. For each window, the left side is actual progress until the window date, while the right side is the anticipated remaining project duration, calculated based on planned schedule. In each window, the actual daily events are entered successively, and the fluctuation of the net project duration reflects the incremental impact of these daily events.

In the first window of day 1, activity A is accelerated, leading to 4-day project duration. Accordingly, a one-day acceleration (A = 1) is decided (right side of Figure 3). In the window of day 2, an actual progress of 20% is entered and remaining duration of activity B is calculated as 2 working days. Accordingly, the project duration remains 4 days. Continuing the daily analysis process, in the window of day 3, an owner work stop was experienced. Accordingly, project duration becomes 5 days (one-day project delay from the duration of previous window). Accordingly, one-day (O = 1) delay is decided. It is noted that the analysis result is indicated by capital C, O, and N letters. In the window of day 4, the project duration is not changed (5 days). The analysis continues to the window of day 5, which experienced contractor work stop, thus bringing the project duration to 6 days (one day delay from previous window). As such, one contractor delay (C = 1) is decided. At the final window of day 6, the project duration remains 6 days. Therefore, the conclusion of the analysis is one day of acceleration (A =

1), one-day contractor delay (C = 1); and one-day owner delay (O = 1). This result is certainly different from that of the traditional windows approach and critical accelerations become readily identifiable.

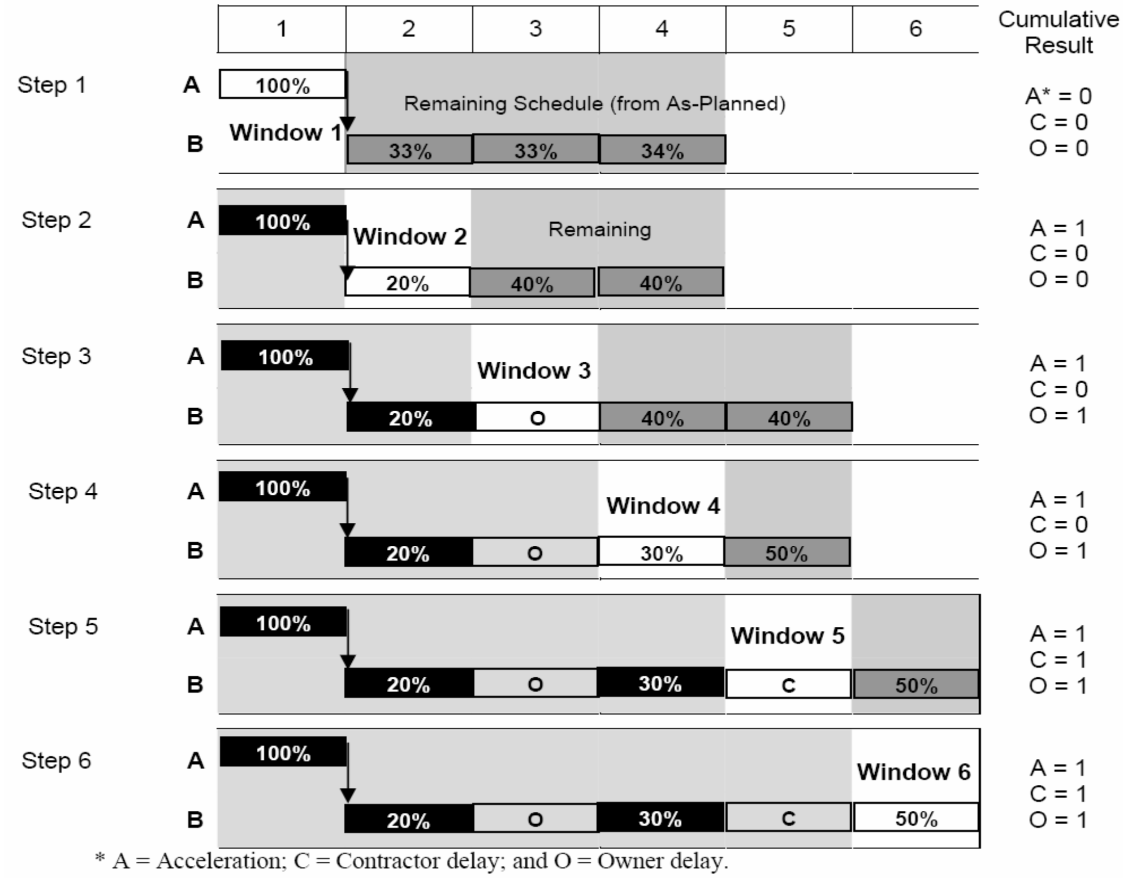

Figure 3. Daily windows delay analysis.

ACCELERATION AS A NEGATIVE DELAY

Since acceleration can be attributed to either the contractor or the owner, it is reasonable to consider that each party's acceleration(s) can be used to offset its own delay(s). This is to say that acceleration can be dealt with as negative delay attributable to the party that causes it. This is also reasonable and fair to all parties. In many contracts, the owner has the right to demand the contractor to accelerate operations and pay the additional costs, given the demand is reasonable. In effect, when the owner pays for the acceleration, it is reasonable that only the owner, not the contractor, has the right to consume any consequent float. On the other hand, the contractor has the right to accelerate or decelerate parts of his/her work to suit his/her convenience, as long as his/her action does not extend the project duration. As indicated in most contracts, the contractor has the right to finish the project early. As such, the owner is not entitled to consume the float generated by the contractor's own acceleration because this deprives the contractor of the right to finish early.

To continue the analysis of the small example's acceleration, the first option is to consider acceleration based on the common rule that any float will be used by the party that uses it first. Accordingly, the one-day acceleration achieved at window 1 will be used to offset the owner's delay, which is the first delay to be encountered. The second option is to use the "acceleration as negative delay" rule. Then, assuming that the one-day acceleration is voluntary by the contractor, the daily analysis of day 1 should indicate a (-C) delay, continuing the daily approach, at day 3, a one-day (O) delay is defined. Then, at day 5, another (C) delay is accumulated. The net result is a zero delay for the contractor and one-day delay for the owner. If, on the other hand, the acceleration at activity A was owner-directed, then the daily windows analysis determines a (-O). Then, at day 3, another (O) delay is accumulated. Then at day 5, a (C) delay is defined. The net result is zero delay for the owner and one-day delay for the contractor. Summary of results is shown in Table 1.

Table 1. Delay analysis results of various approaches.

Approach	Owner Delay (O)	Contractor Delay (C)
Traditional: One window ending at day 6	0.5	0.5
Daily Windows: Acceleration Float consumed by first party to use it	0	1
Daily Windows: Acceleration = - Delay (Contractor Voluntary)	1	0
Daily Windows: Acceleration = - Delay (Owner-Directed)	0	1

ANALYSIS OF CONCURRENT DELAYS AND ACCELERATIONS

As shown in the previous simple example, daily windows calculations apportion the net delay caused by the events of each day among the activities that lie on concurrent critical paths. As such, regardless of how many parallel paths exhibit delay events, concurrent delays in the analysis refer only to the delays that occur concurrently on critical paths.

The general case of dealing with delays and accelerations, however, is not as simple as presented in the previous example, particularly when daily site events cause extensive project delay or acceleration (greater than one day). Examples of this situation include when a work stop brings an activity to a different period of time with lower productivity. To deal with the general case, a systematic approach has been developed for the two cases that represent the possible consequences of the events of a single day: net acceleration (Figure 4b); and net delay (Figure 4c).

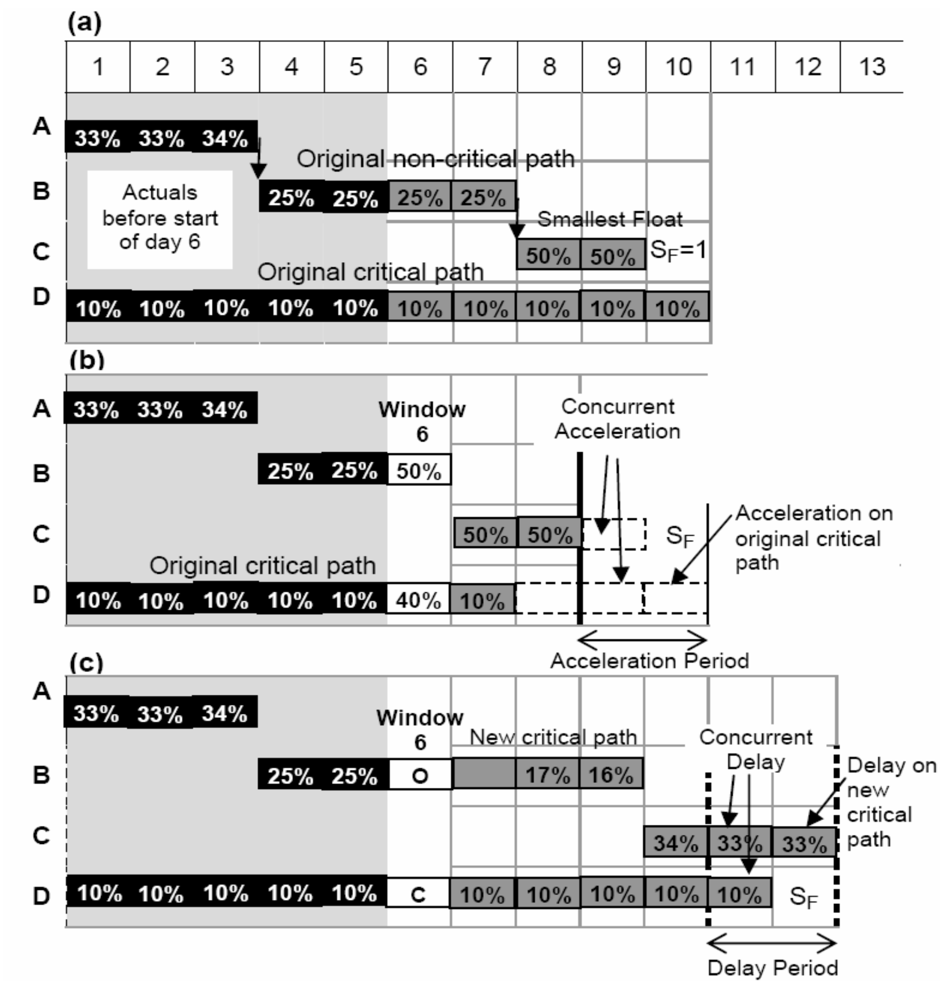

Figure 4. General effect of delay and acceleration:
a) Window of day 5;
b) Window of day 6 with accelerations; and
c) Window of day 6 with delays

The example of Figure 4 has an as-planned duration of 10 days (Figure 4a). Construction ran according to plan for the first five days and as such, daily windows analysis for the first five days shows no delays or accelerations by any party. The critical path before the start of day 6 is the bottom path (Activity D). The top path, on the other hand, is the nearest-to-critical path (i.e., having the smallest float S_F = 1 day among all other paths). Figure 4b shows the application of daily windows analysis at day 6. The progress events of day 6, which involved high progress values on activities B and D, were entered. Accordingly, the project duration became 8 days, with project acceleration period of 2 days (i.e., A = 2) as shown on the figure. This acceleration period is then studied and appropriately apportioned among the parties who caused the acceleration.

Examining the acceleration period in Figure 4, it is clear that the original critical path (activity D) was shortened by the amount S_F (one day) before two **concurrent** critical paths were formed. The rest of the acceleration period (A - S_F = 1 day) is then attributed to the two concurrent critical paths (the original critical path and the original nearest-to-critical path, each 0.5 days). As such, the result of analyzing the acceleration period is as follows:

- Original critical path contributing 1.5 days.

- Original nearest-to-critical path contributing 0.5 days.

It is important to note here that since the analysis is currently on day 6, the 1.5 days of acceleration that are attributable to the original critical path can then be apportioned to activity D. Similarly, the 0.5 days of acceleration that are attributable to original nearest-to-critical path can be apportioned to activity B. Accordingly, considering the causation of accelerations on activities B and D, the two-day project acceleration can be further allocated to the owner and/or the contractor. It is noted that even though activity D was shortened 3 days, only 2 days had actual impact on project duration, as shown in Figure 4b. Another observation is that the presented analysis investigates the composition of the acceleration period and its contributing paths to apportion it appropriately. A special case of this analysis is when the acceleration period is only one day, as presented in the simple example of the previous section.

Similar analysis can be made in the general case of delay, as shown in Figure 4c. The progress events of day 6 were assumed to involve work stops caused by the owner on activities B and by the contractor on activity D. Accordingly, the project duration became 12 days (i.e., project delay period is 2 days), as shown in Figure 4c. This delay period is then studied and appropriately apportioned among the parties. It is noted that the new critical path becomes the top path, while the new nearest-to-critical path with smallest float (S_F = 1 day) becomes the bottom path.

Examining the delay period in Figure 4c, it is clear that the new critical path is solely responsible for a portion of the delay period that equals the S_F (one day). The rest of the delay period (2 - S_F = 1 day) is then attributed to the two concurrent critical paths (the new critical path and the new nearest-to-critical path). As such, the result of analyzing the delays that occurred on day 6 by the owner and contractor, and the consequent delay period is:

- Owner delay on activity B, causing one day of project delay.

- Concurrent (owner + contractor) delays on activities B and D, causing one delay project delay, which may be dealt with in various ways (e.g., divided equally as half day due to each of the owner and contractor, or as one day due to neither).

The presented analysis, as such, investigates the composition of the delay period and its contributing paths to apportion it appropriately. A special case of this analysis is when the delay period is only one day.

One important note in the general delay analysis is its dependence on the manner by which the remaining part of the schedule is calculated (right side of each window). As shown in Figure 4c, for example, an assumption is made that the delay by owner in day 6 will increase the duration of activity B due to a low productivity period. Instead of completing the remaining 50% in two days as shown in the as-planned chart of Figure 4a, activity B will require 3 days to be completed (Figure 4c). The calculation of the remaining schedule, therefore, is necessary to be carried out in an accurate and agreed upon manner. Hegazy and Petzold (2003) proposed various ways, the one used in this example is as follows:

Activity Remaining Duration = (1 – P) * Planned Duration / f .... (1)

Where, P is the activity percentage complete to date, and f is the seasonal productivity factor associated with the construction season (month and day of the year) or project specific conditions. For example, in activity B, activity planned duration is 4 days (Figure 4a). On day 6, activity B is 50% complete, and assuming that the productivity factor starting day 7 (f = 0.67), then the remaining duration of activity B becomes: (1 - 0.5) * 4 / 0.67 = 3 days (from Eq. 1). Accordingly, the remaining 50% progress of activity B is divided among its 3 days, as shown in Figure 4c. It is noted that if all productivity factors are assumed to be 1.0s (i.e., productivity factors are ignored), then the remaining duration becomes equal to the as-planned remaining duration. Even if productivity factors are ignored, activity duration may be extended if the owner's delay in day 6 will result in a need for extra day of work preparation that can be justified by the contractor.

Similar to its use in the delay case, Eq. 1 can be used to determine the remaining duration in the case of acceleration. In Figure 4b, for example, activity D is 90% complete in day 6. The remaining duration is then calculated as (1 - 0.9) * 10 / 1 = 1 day, as shown in the figure.

GENERAL ANALYSIS PROCEDURE

To facilitate computer implementation of daily windows analysis considering both delays and accelerations, a systematic procedure is set up as follows:

1. Save a copy of the As-Built schedule, then clear all actual progress to get the As-Planned schedule;
2. In each day (*i*), starting from day 1 to project duration (n), the following steps are performed:
    a. If current day (*i*) corresponds with a baseline update, activity durations are set to the durations of the updated baseline;
    b. Identify critical path(s) and near-critical path(s), and find the Smallest Float S_F (*i*) among all non-critical paths;
    c. From the saved as-built copy, the site events (progress percentage, work stops, etc.) of current day (*i*) are add to the schedule and activities' remaining durations calculated and used to adjust the schedule. Accordingly, any resulting change in project duration is analyzed and apportioned among parties, as follows:
        - If the project exercises acceleration from its preceding day's analysis, the acceleration period is analyzed similar to the analysis made for Figure 4b.

- If the project exercises delay from its preceding day's analysis, the project delay period is analyzed similar to the analysis made for Figure 4c.

d. The counter is incremented to the next day.

3. At the end of the process, the total accumulated (O), (C), (N) delays and contractor-acceleration (CA), owner-acceleration (OA) are presented as the final conclusion of the analysis. Based on these values, decisions related to time and cost compensation can be made.

COMPUTER IMPLEMENTATION AND EXAMPLE

Building upon the developed step-by-step procedure, Excel macros were written to implement the proposed approach. As such, the only manual work needed is to enter progress data, as discussed earlier, directly on the progress bar chart. All other aspects of daily analysis of delays/ accelerations were fully automated.

To demonstrate the proposed model, a case study for the construction of a house and garage (Figure 5). The as-planned and as-built bar charts are those of Figure 1. Three accelerations are assumed during the project: contractor voluntary acceleration to activity "Foundation" on day 6 with; contractor voluntary acceleration to activity "House Walls" on days 8 and 12; and owner directed acceleration to activity "Fab. Garage Doors" on days 12 to 14. The as-built project duration is 23 days (Figure 1b), with 7 days of net delay from the 16-day as-planned duration.

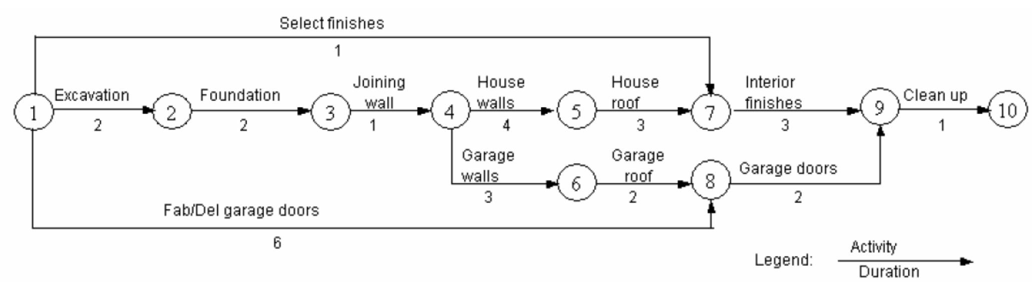

Figure 5. CPM for the house-garage case study.

The analysis proceeds as follows: At days 6 and 8, the contractor and owner each solely caused one-day acceleration, respectively, thus one-day voluntary acceleration and one-day owner-caused acceleration were accumulated. At day 12, both the contractor and owner concurrently caused acceleration of one day. Since the two activities are on concurrent critical paths, the one-day acceleration was equally divided between the contractor and owner (each 0.5 day). Each party uses their own acceleration to offset his/her delays, the conclusion becomes 5.5 days of owner caused delay (O) and 2 days of shared delay (C+O) and 0.5 days of voluntary acceleration (5.5 "O" + 2 "C+O" + 0.5 "AC").

SUMMARY AND CONCLUDING REMARKS

This paper presented a method for representing and analyzing schedules that involve delays and accelerations. The proposed approach identifies slowdowns, work stops, and accelerations and presents them legibly on as-built bar charts. The proposed approach then uses a daily windows analysis to consider the day-by-day fluctuation in critical path(s) along the project duration. It also uses a simple rule "acceleration = negative delay" to efficiently analyze both delays and accelerations. The highly automated and computerized nature of the proposed approach makes it simple and repeatable. With the proposed site data recording approach, the user becomes more concerned about the accuracy of the as-built model, rather than on computational aspects.

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Practice Questions

INSTRUCTIONS: Note the most suitable answer for each multiple-choice question in the appropriate space on the answer sheet.

Use the following information to answer questions 1 through 4:

BCWS = \$2,200
BCWP = \$2,000
ACWP = \$2,500
BAC = \$10,000

1. According to earned value analysis, the SV and status of the project described above is—

   a. –\$300, and the project is ahead of schedule
   b. +\$8,000, and the project is on schedule
   c. +\$200, and the project is ahead of schedule
   d. –\$200, and the project is behind schedule

2. What is the CPI for this project, and what does it tell us about cost performance thus far?

   a. 0.20; actual costs are exactly as planned
   b. 0.80; actual costs have exceeded planned costs
   c. 0.80; actual costs are less than planned costs
   d. 1.25; actual costs have exceeded planned costs

3. The CV is—

   a. +\$300
   b. –\$300
   c. +\$500
   d. –\$500

4. What is the EAC for this project, and what does it represent?

   a. \$12,500; the revised estimate for total project cost (based on performance thus far)
   b. \$10,000; the revised estimate for total project cost (based on performance thus far)
   c. \$12,500; the original project budget
   d. \$10,000; the original project budget

5. All the following statements about analogous estimating are true *except* that it—

   a. Supports top-down estimating
   b. Is a form of expert judgment
   c. Has an accuracy rate of ±10% of actual costs
   d. Involves using the cost of a previous, similar project as the basis for estimating the cost of the current project

6. The purpose of the cost change control system is to—

   a. Define when to add contingency funds to the project
   b. Define the procedures by which the cost baseline may be changed
   c. Determine why a cost variance has occurred
   d. Determine whether a budget update is required

7. Which of the following is *not* an example of a direct cost?

   a. Salary of the project manager
   b. Subcontractor expenses
   c. Materials used by the project
   d. Electricity

8. If the cost variance is the same as the schedule variance, then—

   a. The cost variance is due to the schedule variance
   b. The variance is favorable to the project
   c. The schedule variance can be easily corrected
   d. Labor rates have escalated since the project began

9. In bottom-up cost estimating, accuracy is enhanced—

   a. If previous projects are similar in fact, not just in appearance
   b. By using accurate historical information
   c. With smaller work items
   d. If the individuals or groups preparing the estimates are fully qualified

10. Cost control is concerned with—

    a. Influencing the factors that create change to the cost baseline to ensure that the change is beneficial
    b. Developing an approximation of the costs of the resources needed to complete the project
    c. Allocating the overall cost estimate to individual work items
    d. Establishing a cost baseline

11. The to complete performance index (TCPI) is used to—

    a. Determine the schedule and cost performance needed to complete the remaining work within management's financial goal for the project
    b. Determine the cost performance needed to complete the remaining work within management's financial goal for the project
    c. Predict final project costs
    d. Predict final project schedule and costs

12. The cost management plan—

    a. Describes how CVs will be managed
    b. Establishes the cost baseline
    c. Measures and monitors cost performance on the project
    d. Establishes the performance measurement baseline

13. If operations on a work package were estimated to cost $1,500 and finish today but, instead, have cost $1,350 and are only two thirds complete, the cost variance is—

    a. +$150
    b. -$150
    c. -$350
    d. -$500

14. Considering the project schedule during the cost budgeting process—

    a. Identifies the project elements so that costs can be allocated
    b. Allows costs to be allocated to the time period when they will be incurred
    c. Provides another way to help measure and monitor cost performance
    d. Provides another way to help measure and monitor schedule performance

15. As of the fourth month on the Acme project, cumulative planned expenditures were $100,000. Actual expenditures totaled $120,000. How is the Acme project doing?

    a. It is ahead of schedule.
    b. It is in trouble because of a cost overrun.
    c. It will finish within the original budget.
    d. The information is insufficient to make an assessment.

16. As an input to cost control, performance reports provide information on—

    a. Which budgets have and have not been met
    b. Projected costs for the resources required on the project
    c. Anticipated productivity levels for the personnel working on the project
    d. Specific change requests

17. Which of the following estimates would most closely predict the actual cost of a project?

    a. Order-of-magnitude
    b. Budget
    c. Definitive
    d. Detailed

18. Managing overhead costs is difficult because they—

    a. Are handled on a project-by-project basis
    b. Represent only direct labor costs
    c. Represent only equipment and materials needed for the project
    d. Are usually beyond the project manager's control

19. The purpose of resource planning is to—

    a. Determine the physical resources needed to perform project activities
    b. Approximate the costs of resources needed to complete project activities
    c. Determine the resources that are potentially available
    d. Assess the organizational policies concerning resources for use on the project

20. Budget updates generally are made when—

    a. The project manager knows that without revision a cost overrun will result
    b. A scope change is approved
    c. Any aspect of the project is rebaselined
    d. Contingency or management reserve is used

21. Which of the following is a tool for analyzing a design, determining its functions, and assessing how to provide those functions cost effectively?

    a. Pareto diagram
    b. Kanban
    c. Configuration management
    d. Value engineering

22. Which of the following techniques for cost estimating is considered the least accurate?

    a. Analogous estimating
    b. Parametric modeling
    c. Bottom-up estimating
    d. Computerized tools

23. The cumulative CPI has been shown to be relatively stable after what percentage of project completion?

    a. 5% to 10%
    b. 15% to 20%
    c. 25% to 35%
    d. 50% to 75%

24. Supporting detail for cost estimates should include all the following *except*—

    a. A description of the scope of work
    b. Documentation of the basis of the estimate and any assumptions made
    c. An indication of the range of results
    d. The number of people who participated in preparing the estimate

25. The undistributed budget is part of the—

    a. Management reserve
    b. Performance measurement baseline
    c. Level-of-effort cost accounts
    d. General and administrative accounts

26. The purpose of cost budgeting is to—

    a. Determine the cost of the resources needed to complete project activities and allocate them to the proper chart of accounts for the organization
    b. Monitor cost performance to detect variances from the plan
    c. Allocate cost estimates to individual work items to establish a cost baseline against which project performance can be measured
    d. Expend the minimum amount of funds possible

27. Which of the following is an input to cost control?

    a. Lessons learned
    b. The WBS
    c. Computerized tools
    d. Change requests

Project Time Management

Practice Questions

INSTRUCTIONS: Note the most suitable answer for each multiple-choice question in the appropriate space on the answer sheet.

1. The most important element necessary for project control is—
   a. Upper management commitment
   b. Responsibility over resources
   c. Clear requirements
   d. Sufficient management reserve

2. A precedence diagram and an arrow diagram are both examples of networks. Which statement describes the primary difference between them?
   a. The arrow diagram incorporates PERT in the activity duration.
   b. The precedence diagram represents activities as nodes.
   c. The arrow diagram does not indicate critical path.
   d. The precedence diagram uses float as part of the activity duration.

3. Which term describes a modification of a logical relationship that delays a successor task?
   a. Lag
   b. Lead
   c. Float
   d. Slack

4. Which of the following parameters are affected by scheduling and allocating resources to multiple projects?
   a. Resource use and resource leveling
   b. Duration compression and simulation
   c. Activity lists and the WBS
   d. Schedule slippage and in-process inventory

5. Milestones are *not*—
   a. Activities of zero duration
   b. Significant events in the project life cycle
   c. Measures of achievement for expenditures of money or time
   d. Best utilized when denoting start and finish of all activities

6. An important part of schedule control is to—
   a. Determine whether schedule variations require corrective action
   b. Define the activities needed to produce the project's deliverables
   c. Assess whether scope definition is adequate to support the schedule
   d. Ensure that project team morale is high so that team members can work at their full potential

7. If a project is to employ two people each for 40 hours at a labor rate of $30 per hour with overhead included and a third person for 30 hours during the same period but at a loaded labor rate of $50 per hour, the BCWS for the week is—
   a. $2,400
   b. $3,600
   c. $3,660
   d. $3,900

8. Your lead engineer estimates that a work package will most likely require 50 weeks to complete. It could be completed in 40 weeks if all goes well, but it could take 180 weeks in the worst case. What is the PERT estimate for the expected duration of the work package?
   a. 45 weeks
   b. 70 weeks
   c. 90 weeks
   d. 140 weeks

9. The practice of overlapping project activities is known as—
   a. Concurrent engineering
   b. Fast-tracking
   c. Leveling
   d. Crashing

10. Activity A has a duration of 3 days and begins on the morning of Monday the 4th. The successor activity, B, has a finish-to-start relationship with A. The finish-to-start relationship has 3 days of lag, and activity B has a duration of 4 days. Sunday is a nonworkday. What can be determined from these data?
    a. The total duration of both activities is 8 days.
    b. Calendar time between the start of A to the finish of B is 11 days.
    c. The finish date of B is Wednesday the 13th.
    d. Calendar time between the start of A to the finish of B is 14 days.

31. Several types of float are found in project networks. Float that is used by a particular activity and does not affect the float in later activities is called—

a. Extra float
b. Free float
c. Total float
d. Expected float

32. Rebaselining may be needed to—

a. Show that the project is not behind schedule
b. Provide realistic data to measure performance
c. Report schedule updates
d. Show special forms of corrective actions taken

33. Which of the following should be a consideration when developing activity time estimates?

a. Resource capabilities
b. Expert judgment
c. Simulation
d. Monte Carlo analysis

34. The major difference between PERT and CPM is that PERT—

a. Uses the distribution's mean (expected value) in computing the schedule
b. Uses the most likely estimate to compute float
c. Focuses on calculating float to determine which activities have the least scheduling flexibility
d. Includes nonsequential activities such as loops or conditional branches as part of the diagram

35. Corrective action in project time management primarily concerns—

a. Analyzing reasons behind variances
b. Expediting to ensure that activities remain on schedule
c. Assessing the project management software used
d. Determining the magnitude of any variances

36. Activity A has a pessimistic *(P)* estimate of 36 days, a most likely *(ML)* estimate of 21 days, and an optimistic *(O)* estimate of 6 days. What is the probability that activity A will be completed in 16 to 26 days?

a. 55.70%
b. 68.26%
c. 95.46%
d. 99.73%

Project Time Management

37. A milestone is best described as—

a. A combination of related activities and events
b. An intersection of two or more lines or arrows commonly used for depicting an event or activity
c. An identifiable point in a project that denotes a reporting requirement or completion of an important activity
d. A specific project task that requires resources and time to complete

38. The schedule control system should be integrated with the—

a. Schedule management plan
b. Overall change control system
c. Project plan
d. Execution of the project plan

39. In project time management, crashing means—

a. Reducing project duration by redefining logical relationships
b. Reducing computer network downtime for schedule risk modeling
c. Applying additional resources to all project activities
d. Applying additional resources to critical path activities by priority

40. All the following are characteristics of a dummy activity *except* that it—

a. Is used only in activity-on-arrow networks
b. Has zero duration
c. Requires resources
d. Indicates a precedence relationship

11. Schedule control is concerned with all the following *except*—

   a. Influencing the factors that create schedule changes to ensure that the changes are beneficial
   b. Determining that the schedule has changed
   c. Managing the actual changes when and as they occur
   d. Changing the schedule based on customer demands

12. The schedule development technique that provides early and late start and finish dates for each activity is—

   a. SPC analysis
   b. GERT
   c. CPM
   d. Monte Carlo analysis

13. "I cannot test the software until I code the software." This expression describes which of the following dependencies?

   a. Discretionary
   b. Soft
   c. Preferential
   d. Mandatory or hard

14. In determining the effect of prospective schedule changes, all the following may be required *except*—

   a. New or revised activity duration estimates
   b. Modified activity sequences
   c. Analysis of alternative schedules
   d. Schedule updates

15. Fast-tracking means—

   a. Reducing the duration of critical path activities to shorten project duration
   b. Reducing project duration by redefining logical relationships
   c. Using only the best resources to accomplish work as quickly as possible
   d. Coordinating efforts with other projects to reduce administrative friction

16. A revision is a—

   a. Performance measurement technique for schedule control
   b. Change to the scheduled start or finish dates in the approved project schedule
   c. Corrective action taken to bring expected future schedule performance in line with the project plan
   d. Lesson learned as a result of a schedule change

17. Which of the following should *not* be considered when developing activity duration estimates?

   a. Resource capabilities
   b. The number of resources assigned to a task
   c. Historical data if available
   d. Overhead rates

18. Decomposition is a technique used for both scope and activity definition. Which statement best describes the role decomposition plays in activity definition as compared to scope definition?

   a. Final output is described in terms of work packages in the WBS.
   b. Final output is described as deliverables or tangible items.
   c. Final output is described as activities or action steps.
   d. Decomposition is used the same way in scope definition and activity definition.

19. Which of the following formulas provides the most accurate result for computing activity duration?

   a. $$AD = \frac{\text{Work quantity}}{\text{Production rate}}$$
   b. $$AD = \frac{\text{Work quantity}}{\text{Number of resources}}$$
   c. $$AD = \frac{\text{Production rate}}{\text{Work quantity}}$$
   d. $$AD = \frac{\text{(Production rate) (Work quantity)}}{\text{Number of resources}}$$

20. Which of the following is *not* an input to schedule control?

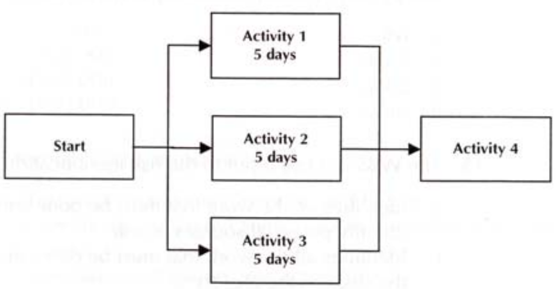
   a. The schedule change control system
   b. Change requests
   c. The schedule management plan
   d. Performance reports

7. The Delphi method is a particularly useful risk quantification technique to—
   a. Present a sequence of decision choices graphically to decision makers
   b. Define the probability of occurrence of specific variables
   c. Determine probability assessments relating to future events
   d. Help take into account the attitude toward risk of the decision maker

8. A workaround is—
   a. An unplanned response to negative risk events
   b. A plan of action to follow when something unexpected occurs
   c. A specific response to certain types of risk as described in the risk management plan
   d. A proactive, planned method of responding to risks

9. Most statistical simulations of budgets, schedule, and resource allocations use which of the following approaches?
   a. PERT
   b. Decision-tree analysis
   c. Present value analysis
   d. Monte Carlo analysis

10. In the path convergence example below, if the odds of completing activities 1, 2, and 3 are 50%, 50%, and 50%, respectively, what are the chances of starting activity 4 on day 6?



   a. 10%
   b. 13%
   c. 40%
   d. 50%

11. All the following criteria are considered essential to the assessment of technical risk *except*—
   a. Planned procedures for completing project activities
   b. Explicit attention to technical risk, not just to schedule or cost risk with consideration of technical risk implied
   c. Critical path analysis
   d. Reassessment to detect changes in risk during a system's development

12. Range estimating identifies all the following *except*—
   a. Mathematical probability that a cost overrun will occur
   b. Risks and opportunities ranked in order of bottom-line importance
   c. The contingency required for a given level of confidence
   d. The specific risk event impacting the estimate

13. Each of the following statements about risk avoidance is true *except* that it—
   a. Focuses on eliminating the elements that are creating the risk
   b. Includes making the decision not to bid on a project in which the risk exposure is believed to be too high
   c. Accepts the consequences of the risk event should it occur
   d. Includes leaving the risk with the customer when the customer is in the best position to mitigate the risk

14. If the probability of event 1 is 80% and of event 2 is 70% and they are independent events, how likely is it that both events will occur?
   a. 6%
   b. 15%
   c. 24%
   d. 56%

15. The WBS is a key input to the risk identification process because it—
   a. Identifies all the work that must be done and, therefore, helps identify potential sources of risk
   b. Identifies all the work that must be done and, therefore, includes all the risks on the project
   c. Helps organize all the work that must be done on the project
   d. Identifies work packages, which enables specific responsibility to be assigned

16. To be effective, the risk management process should—
    a. Be applied primarily during the concept and closeout phases and to some extent during the implementation and planning phases
    b. Be applied throughout the project and at all levels of system decomposition and project organization
    c. Include assembly of certain stakeholders to identify risks and develop mitigation strategies
    d. Focus on those risks that senior management finds most critical

17. Management reserve is used for—
    a. Risks that are identified at the outset of the project
    b. Risks that are not identified at the outset of the project but are known before they occur
    c. Risks that cannot be known before they occur because they are external risks
    d. Any risks that cannot be known before they occur

18. The simplest form of risk analysis is—
    a. Probability analysis
    b. Sensitivity analysis
    c. The Delphi method
    d. Utility theory

19. If a business venture has a 60% chance to earn $2 million and a 20% chance to lose $1.5 million, what is the expected monetary value of the venture?
    a. ($50,000)
    b. $300,000
    c. $500,000
    d. $900,000

20. Categories of risk response are—
    a. Technical, marketing, financial, and human
    b. Identification, quantification, response development, and response control
    c. Avoidance, mitigation, and acceptance
    d. Avoidance, retention, control, and deflection

38. Which of the following tools is the most appropriate for measuring schedule risk?
    a. CPM
    b. WBS
    c. PERT
    d. PDM

39. The ultimate responsibility for identifying and managing project risks rests with the project—
    a. Sponsor
    b. Manager
    c. Team
    d. Manager and project sponsor

40. The primary objective of risk quantification is to—
    a. Improve the accuracy of risk assessment
    b. Take the guesswork out of the risk management process
    c. Compare the cost of risk response development to the risk's expected monetary value
    d. Determine which risk events warrant responses

Practice Questions

INSTRUCTIONS: Note the most suitable answer for each multiple-choice question in the appropriate space on the answer sheet.

1. The purpose of project plan development is to—
   a. Create a document to guide project execution and control
   b. Document project assumptions and constraints
   c. Promote communication among stakeholders
   d. Define key project reports

2. Overall change control is primarily concerned with—
   a. Influencing factors that cause change, determining that change has occurred, and managing actual changes as they occur
   b. Maintaining integrity of baselines, integrating product and project scope, and coordinating change across knowledge areas
   c. Integrating deliverables from different functional specialties on the project
   d. Establishing a change control board that oversees the overall changes on the project

3. The principal objective of project stakeholder management is to—
   a. Identify all potential users of the project to ensure complete requirements analysis
   b. Thwart criticism of the project by developing a list of responses to known stakeholder concerns
   c. Be proactive in curtailing stakeholder activities that might adversely affect the project
   d. Build goodwill in the case of schedule and cost overruns

4. Most of the project's budget is expended during—
   a. Project plan development
   b. Project plan execution
   c. Overall change control
   d. Project initiation

5. Assumptions generally involve some risk because—
   a. Assumptions are based on lessons learned
   b. Historical information may not be available
   c. Assumptions are based on constraints
   d. Assumptions involve factors that are considered true, real, or certain

6. All approved changes should be reflected in the—
   a. Performance measurement baseline
   b. Change management plan
   c. Quality assurance plan
   d. Project plan

7. In project plan development, which of the following is *not* an organizational policy whose effects on the project must be considered?
   a. Continuous improvement targets
   b. Status meetings
   c. Employee performance reviews
   d. Time reporting

8. The output of project plan execution consists of—
   a. Work results and change requests
   b. Project plan updates and corrective action
   c. Baseline changes and work authorization
   d. Additional planning and deliverables

9. The primary purpose of benchmarking is to—
   a. Perform marketing research to forecast how well a particular product will sell
   b. Measure products, services, and processes against those of other organizations
   c. Understand and collect data on customer requirements to focus attention on meeting customer needs
   d. Determine performance targets

10. Change requests occur in all the following forms *except*—
    a. Oral or written
    b. Legally mandated or optional
    c. Formal or informal
    d. Externally or internally initiated

11. According to McGregor, a manager who uses Theory X sees workers as—
    a. Highly motivated, willing to take responsibility, and reliable
    b. Highly untrustworthy, needing to be watched and closely managed at all times
    c. Very productive when first given an assignment
    d. Unproductive at first, followed by periods of high productivity

22. Configuration management describes procedures to apply technical and administrative direction. Which of the following tasks is *not* performed in configuration management?

   a. Identifying functional and physical characteristics of an item or system
   b. Controlling changes to characteristics
   c. Performing an audit to verify conformance to requirements
   d. Allowing automatic approval of changes

23. As applied to projects, *temporary* means that—

   a. Projects are short in duration
   b. Every project has a definite beginning and end
   c. The undertaking will end at an undetermined time in the future
   d. Projects can be canceled at any time

24. All the following are examples of tools and techniques used in integration management *except*—

   a. The work authorization system
   b. Organizational procedures
   c. Product skills and knowledge
   d. Organizational policies

25. Which of the following is an example of a constraint in project plan development?

   a. Records of past performance
   b. Financial reports from similar projects
   c. A predefined budget
   d. Lessons learned from prior projects

26. Performance measurement techniques are useful in overall change control because they—

   a. Help show the status of the project
   b. Measure overall project progress
   c. Summarize information on the project for reporting to stakeholders
   d. Help assess whether variances from the plan require corrective action

27. The management-by-objectives technique addresses all the following *except*—

   a. Establishing unambiguous and realistic objectives
   b. Periodically evaluating whether project objectives have been achieved
   c. Promoting participation, team building, and commitment to the project
   d. Establishing a specific career path for a project team member

28. A work authorization system is a—

   a. Work breakdown structure showing individual work elements
   b. Formal procedure for sanctioning work so that it is done at the right time and in the proper sequence
   c. Method to ensure that each person on the project team knows the work elements that are his or her responsibility
   d. System to help measure performance in terms of work completed versus work planned

29. The purpose of a project planning methodology is to—

   a. Provide a structured approach to guide the project team in project plan development
   b. Ensure that all required forms are completed
   c. Ensure that organizational policies and procedures are followed during the development and execution of the project plan
   d. Serve as a repository of lessons learned that can be applied to the current project

30. Lessons learned from projects are significant because they—

   a. Must be collected to meet requirements of organizational policies and procedures
   b. Show the causes of variances and the reasons certain corrective actions were selected
   c. Show why certain projects were selected by the organization over others
   d. Show why certain people were selected as project manager and team members over others