An-Najah National University
Civil Engineering Department
Faculty of Engineering
Construction Engineering and Management

Nabil Dmaidi

9/5/2010
Your Expectations of Me

Be prepared
Be on time
Teach for full 50 minute period
Fair grading system
Front load the class work
Do not humiliate students
Practice golden rule
Provide real world examples
Make you think

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9/5/2010
Topics

1) Management Functions and introduction of construction project planning and scheduling
2) Construction scheduling techniques
3) Preparation and usage of bar charts
4) Preparation and usage of the Critical Path Method (CPM)
5) Preparation and usage of Precedence Diagramming Method (PDM)
6) Issues relating to determination of activity duration
7) Contractual provisions relating to project schedules
8) Resource leveling and constraining
9) Time cost tradeoff
10) Schedule monitoring and updating.
11) Communicating schedule
12) Project control and earned value Control
13) claims, Safety and Quality control

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Course Outline

- Introduction and definitions
- Importance of Scheduling
- Networks, Bar Charts, and Time-Scaled Logic Diagrams
- The CPM Calculations
- Float Analysis
- Imposed Finish Date and other CPM Issues
- Precedence Networks
- Updating Schedules
- Brief introduction on:
  - Project Control and Earned Value Analysis
  - Resource Allocation / Leveling
  - Time/Cost Trade-offs

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Management Functions

- Planning
  - Where the organization wants to be in the future and how to get there.
Management Functions

Organizing

- Follows planning and reflects how the organization tries to accomplish the plan.
- Involves the assignment of tasks, grouping of tasks into departments, and allocation of resources.
Management Functions

- **Leading**
  - The use of influence to motivate employees to achieve the organization's goals.
  - Creating a shared culture and values, communicating goals to employees throughout the organization, and infusing employees to perform at a high level.
Management Functions

- Controlling
  - Monitoring employees’ activities, determining if the organization is on target toward its goals, and making corrections as necessary.
Management Skills

- Conceptual Skill—the ability to see the organization as a whole and the relationship between its parts.
- Human Skill—The ability to work with and through people.
- Technical Skill—Mastery of specific functions and specialized knowledge.
Decision Making

- Decision: a choice made from two or more alternatives.
- Part of all four managerial functions
- Decisions are made on the basis of:
  - Rationality
  - Bounded Rationality
  - Intuition
Rationality

- Problem is clear and unambiguous.
- Single goal.
- All alternatives are known.
- Clear and constant preferences.
- Maximum payoff.
- The decision is in the best interest of the organization—not the manager.
Rationality

- Problem is clear and unambiguous.
- Single goal.
- All alternatives are known.
- Clear and constant preferences.
- Maximum payoff.
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Project Life Cycle

Definition
1. Goals
2. Specifications
3. Tasks
4. Responsibilities
5. Teams

Planning
1. Schedules
2. Budgets
3. Resources
4. Risks
5. Staffing

Execution
1. Status reports
2. Changes
3. Quality
4. Forecasts

Delivery
1. Train customer
2. Transfer documents
3. Release resources
4. Reassign staff
5. Lessons learned

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Phase One

Definition Stage

- Defining Specifications
- Establishing objectives
- Determining tasks
- Forming teams
- Assigning responsibilities

Low level of effort
Phase Two

Planning Stage

- Estimating time and cost
- Scheduling activities and resources
- Identifying and determining risks
- Assigning teams

Level of effort increases
Phase Three

Execution Stage

- Producing physical product
- Collecting data
- Monitoring project performance
- Identifying the changes
- Forecasting new measures

Highest level of effort
Phase Four

Delivery Stage

- Training customer
- Transferring documents
- Releasing resources
- Reassigning staff
- Documenting lessons learned

Low level of effort
Definition of a Project

From the Project Management Institute:

“A temporary endeavor undertaken to create a unique product or service”
What is a Project?

- Temporary
- Unique
- There is an end
- Duration is finite
- Characteristics are progressively elaborated
In the construction

Project Management is the sum of all activities such as Planning, organising, implementing and controlling a project in order to meet the client’s expectation from start to finish within the planned period, budget and quality.”
The purpose of Project Management is to foresee or predict as many of the dangers and problems as possible and to:

- Plan
- Organize
- Coordinate
- Control
The components of Project Management

- Scope
- Time
- Cost
- Quality
- Human Resource
- Communications
- Risk
- Procurement
Project Constraints

- Time
- Cost
- Quality

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Control

The heart of the project management system is controlling the execution of the works.

The purpose of this control is to determine and predict deviations in a project so corrective actions can be taken.

The milestones of the control process are as follows:

- To determine the aim
- Determine the control standards
- To determine the strategic points
- To evaluate the actual results and to compare to the planned
Control

It defines the quality of the management
Skills for Project Management

- Good Planning
- Conflict Resolution
- Creativity
- Flexibility
- Negotiation
- Communication
  - Client
  - Subcontractors
  - Team

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Dimensions of Project Management

- Performance
- Money
- Time

Plan should consider all of these before starting.

Manager needs to track them during project.

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Project Management

Project Management is the Science and Art of Enhancing the Probability of Success by Inspired Leadership using Structured Techniques for Planning that Integrate Technical Performance, Scheduling and Budgeting (1).

(1)-Fundamentals of Space Systems - Pisacane and Moore
What Will You Learn

1. How To Plan Projects
2. How To Make A Time Schedule
3. How To Allocate Resources
   (Time, Money, People, others)
4. How To Monitor Progress
5. How To Manage And Control The Project
6. How to plan and schedule Linear projects
Project Management

Guide and Direct the effort

- Science and Art
- Enhancing the Probability of Success
- Leadership (Inspired or not)
- Structured Techniques for Planning
  - Critical Path — the path of a network that requires the longest period of time to complete
  - Integrate Technical Performance, Scheduling and Budgeting
Four Project Goals

Projects Should Be Completed:

1. On Schedule
2. Within Budget
3. Of Acceptable Quality
4. With Zero Accident
Planning and Control

Why We Need a Plan

1. To establish time frame and organize construction activities
2. To provide a communication tool between all parties involved (contractors, subs, A/E, owner)
3. Used as a document for future projects
4. Can refer to for modifications
5. To show the impact of productivity-related problems on project completion.

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General Project Management Functions

Plan
What is to be done? How and in what order?

Schedule
When will plan and resources be committed?

Allocate
Action to commit resources

Work
Work effort consuming resources

Monitor
What is being done by whom?

Record
What has been done?
Project Definition

Project Management Requires:

1. Set project objectives or goals in terms of:
   a. Time
   b. Cost
   c. Logic

2. Produce alternative schedules, and associated time and cost.

3. Select the best schedule.
Project Management Requires: (cont.)

4. Optimize resource allocation for the schedule.
5. Implement the project plan.
6. Monitor progress

Plan, Compare, and Modify
An Introduction to:

Project Scheduling Planning, Scheduling, and Control

August 2010
Planning and Scheduling

Planning and scheduling are two terms that are often thought of as synonymous

- They are not!
- Scheduling is just one part of the planning effort

Project planning serves as a foundation for several related functions such as cost estimating, scheduling, and project control

Project scheduling is the determination of the timing and sequence of operations in the project and their assembly to give the overall completion time
Planning and Scheduling

Planning is the process of determining how a project will be undertaken. It answers the questions:

- “What” is going to be done,
- “how”,
- “where”,
- By “whom”, and
- “when” (in general terms: start and finish).

Scheduling deals with “when” on a detailed level.
Planning and Scheduling

The Plan

when

Schedule
## Why Schedule Projects

### Owners
1. Get an idea on project’s expected finish date
2. Ensure contractor’s proper planning for timely finish
3. Use for cash flow prediction (example 1) (example 2)
4. Use for project control and verification of progress payment requests
5. Use for change orders’ impact (and what-if scenarios)
6. Use to verify contractor’s delay claims

### Contractors
1. Ensure ability to meet owner’s requirements
2. Have an efficient work plan / Coordinate with subcontractors
3. Use for cash flow prediction
4. Use for preparation of progress payment requests / project control
5. Use to assess change orders’ impact
6. Use to prove a delay claim
7. Plan material procurement (order, deliver)

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THE HIERARCHY OF SCHEDULES
PLANNING RESOURCES

1. Materials

Need to determine

- Quantities takeoff
- Availability and probable delivery time
- Type of materials

2. Equipment

- Selection of the type of equipment
- Availability and delivery time
- Decision for purchase or renting
PLANNING RESOURCES (cont.)

3. Manpower
   - Crew size and composition
   - Availability
   - Time required to perform each activity

4. Money
   - Account receivable, account payable

5. Time
   - Beginning
   - End date
   - Milestones
BAR CHARTS

A graphical representation of a project in which activities’ types and duration represented by bars in proportion duration.
NETWORKS

Definition
A network consists of two basic elements: nodes and links between these nodes.

Arrow Diagram
Activities are represented by two nodes and one link.

Precedence Diagram
Activities represented by nodes and links represent the relationship.
Arrow Diagram for a Small Garage

Precedence Diagram for a Small Garage

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Who Else Needs the CPM Schedule?

- The designer A/E
- The PMC / CM
- Lending institutions
- Legal consultants / attorneys
- Other?
The Scheduler.....

The “scheduler”:

- Qualifications needed
- The three types of knowledge
- “I am not the Primavera man!”

The Certification: AACEI, PMI-COS

The Tripod of Good Scheduling System:

- The Human Factor
- The Technology
- The Management
Scheduling as Part of Project Management

Project management in construction includes:

- Scheduling / Time Management,
- Cost / Budget Management,
- Quality management,
- Change / Scope management,
- Risk Management
- Procurement management,
- Project administration,
- Safety management,
- Other

They are all interrelated
Steps to Schedule a Project

1. Break down the project into activities:
   - Reasonable activity size
   - Simple versus complex activities
   - WBS, coding, activity description
   - Activity types: Task, milestone (start or finish), Hammock (level of effort)
Project Breakdown
Construction stages can be broken down into many operations that define the major elements to be performed.

The Single Relationship

- Finish-to-start relationship
- Each activity must be selected so that all the previously required activities must be completed before the chosen one can begin and all the following activities cannot be started until the chosen one is complete.
Activity Definition

- An activity is a unique unit of the project which can be described within prescribed limits of time

Dummy Activities

An activity having a zero duration used:

1. To establish proper logic
2. To maintain the numbering system
3. To mark milestones
The WBS (Work Breakdown Structure)

IT is used to break down the project from one main and relatively big entity into smaller, defined, manageable and controllable units, usually called work groups or tasks, or, at the finest level of detail (which is undesirable) activities.
Take care!!!

- The deeper you go into the lower levels of the WBS, the more detailed knowledge you’ll need to know.
- A good rule of thumb is the rule of 1-5-5-5-5, which entails that each level be broken down into a maximum of five lower levels.
Who develops the WBS?

- A WBS is developed by the A/E at the end of the design phase
- and/or by the bidders during the proposal (procurement phase)
The CWBS (Contract Work breakdown Structure)

- After contract award, the project manager expands the WBS into a contract work breakdown structure (CWBS).
  
- As the initial step in the PLANNING process.
The CWBS

The extended CWBS must include the levels at which required reporting information is summarized for submittal to the Owner
Uses of the WBS

- The WBS is used to report program status externally to the Owner.
- The CWBS is used internally to plan the program in detail and to collect status information on a periodic basis for the lowest level of the CWBS, namely the schedule activities.
- The basis for technical planning and project achievement.
The CWBS

- it is a major task to undo.
- Why???
- Because cost collections begins at a CWBS element,
The individuals assigned the responsibility for WBS/CWBS development should never lose sight of the fact that the WBS is used for technical planning and status achievement.
Conclusion

- The work breakdown structure defines the product elements (work packages).
- And their interrelations to each other and to the product.
- The WBS mostly ends with project tasks.
- Using the tasks you can extract project’s activities.
What is the difference between a schedule and a Plan?

The schedule: putting the plan in time scale.
Most Common Scheduling methods

- common scheduling methodologies:
  - Bar Charts (Gantt Charts)
  - Critical Path Method (CPM)
  - PERT (Project Evaluation & Review Techniques)
  - Linear Scheduling Method (LSM)
Activity sequencing needs to take into account the relationships between activities. There are four types of relationships that need to be taken into account.

Physical

Exists between two (or more) activities when one cannot start until another is partially or totally complete (i.e. cannot pour footings until they have been formed)
DEVELOP ACTIVITY SEQUENCE (cont.)

❖ Safety

Exists when simultaneous performance of two activities can result in a safety hazard (i.e. in multi-story construction it is at times unsafe for crews to be working under one another.)

❖ Resource

Due to limited resource availability, two activities may not be able to use a resource at the same time (i.e. A crane cannot be used for both pouring walls and erecting steel.)

❖ Preferential

How the contractor wishes certain activities to be sequenced
TYPES OF ACTIVITIES

1. Production Activities
   Those that can be taken directly from plans and specifications

2. Procurement Activities
   Procurement of material and equipment

3. Management Decision Activities
   Activities that can be created by management to avoid certain situations
   - Delay Concrete
   - Company Vacation
   - Deer Hunting

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Factors to Be Considered in Defining Activities

1. Nature of the work / Homogeneity
2. Location / Floor
3. Size / Duration
4. Timing / Chronology
5. Responsibility
6. Phase
Definition

Activity: A basic unit of work as part of the total project that is easily measured and controlled

- It is also called Task
- It is time and resource consuming
- Unit of measure: simple or complex:
  - Formwork + rebar + concrete + finish (4 activities), or
  - FRP Concrete (one activity)
Events and Milestones

- An event: a point in time that is usually the start or finish of a certain activity(s)
  - Duration = 0

- Important events are called milestones
  - start milestones such as NTP and
  - finish milestones such as Substantial Completion

- An activity has a start date and a finish date
- An event / milestone has a start date or a finish date
Level 0

Tampa Office Bldg

100000

Level 1

Foundation/Substructure

110000

Building shell

120000

Exterior closure

130000

Interior finishes

140000

Mechanical/Electrical

150000

Site Work

160000

Level 2

Columns

121000

Shear Walls

122000

Elevated Slabs

123000

Beans/Girders

124000

CIP Stairs

125000

Level 3

Post-tensioned Slabs

123100

Flat Slabs

123200

Waffle Slabs

123300

One-way Slab and beam

123400

Level 4

Falsework

123110

Rebar

123120

Post-tension cable

123130

Concrete

123140

Level 5

Soffit and edges

123111

Scaffold (tables)

123112

Shores

123113

Reshores

123114

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Steps to Schedule a Project

2. Estimate activity durations:
   - Time unit: hour, day, week, month?
   - Duration = Total Quantity/Productivity
   - \( \frac{10,000 \text{ M}^3}{800 \text{ M}^3/\text{day}} \) = 12.5 days \( \approx \) 13 days
   - Multiple crews – multiple shifts
   - Productivity adjustment factors
   - Define calendars
3. Set up the schedule logic:
   - Establish logic relationships
     - Sometimes there is more than one way to depict logic
     - Tendency to overuse Finish-to-Start (FS) relationship
   - Lags & leads
   - External relationships
   - Logic versus resource constraints
   - Imposed constraints
Steps to Schedule a Project

4. Draw network & perform CPM Calculations (or input in the computer and execute):
   - Imposed finish date?
   - Non-work days
   - Check software default rules / settings
   - Make sure any specific requirement is met
Additional Steps for Scheduling a Project

5. Review and analyze the schedule:
   - Check logic back & forth
   - Make sure there are no errors, loops, omissions, or redundancies
   - Check with leaders of teams involved with the project
Additional Steps for Scheduling a Project

6. Implementation of the schedule: Taking the schedule from paper to action
   - Adopt a single pair of dates (start – finish) for each activity
   - Print different reports to different parties
   - The final form is going to be your “baseline schedule”
Additional Steps for Scheduling a Project

7. Monitor and Control:
   - Choose a uniform time interval for periodic updating
   - Define the update procedures
   - Communicate with all parties
   - Reporting / Documentation
   - Implement any changes
Additional Steps for Scheduling a Project

8. Database Revisions and Feedback
   - Project / activity notes
   - Documentation and organization
   - Accessibility and confidentiality
Budgeting and Resource Loading

- Optional steps when scheduling a project:
  - Cost loading
  - Resource loading (allocation)
  - Resource leveling
  - Cash flow analysis / forecast
  - Materials procurement schedule
Project Schedule versus Construction Schedule

- The scheduler may want to include all project-related activities:
  - Design
  - Design review
  - Construction
  - Owner’s activities (review, approval)
  - Vendors (for owner’s purchased equipment)
  - Other agencies’ activities (e.g. government, test labs)

- Subs’ schedules integration in the GC’s
Myths/Misconceptions About Scheduling

- I should get a very accurate schedule... I bought the most expensive software in the market!
- I hired a computer specialist to handle Primavera!
- CPM schedules are bunch of junk. We do it just because the owner required it.
- We don’t need an expensive system... it is all up here
Quiz 1

True or False:

1. There are no two projects that are identical
2. Every construction project needs a CPM schedule
3. Planning and scheduling are two names for the same function
4. The maintenance of a large office building is considered a project
5. The renovation of a large office building is considered a project
6. There is one standard way to break down the project into activities for the purpose of creating a schedule
Bar (Gantt) Charts

- Defined as a graphic representation of project activities shown in a time-scaled bar lines with no links shown between activities.
- Developed in 1917 by Henry Gantt.
- Also known as Gantt charts.

Site Clearing
Excavation
Foundation
S.O.G.
Framing
Roofing
Finish Interior

2 4 6 8 10 12 14 16 18
Time (days)

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Activity

An activity is a task or closely related group of tasks whose performance contributes to the completion of the overall project. “Excavate Foundation”.

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<table>
<thead>
<tr>
<th>Item</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>M10</td>
<td>Mobilization</td>
</tr>
</tbody>
</table>

(Month or Year)

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CONSTRUCTION THE BAR CHART

- When constructing a bar chart, the following questions must be answered:
  1. What time units should be used?
  2. Should work days or calendar days be used?
  3. What about noncontinuous work?

- Additional information may be added to the basic bar chart such as activity value, cost, and resource requirements.
TYPE OF BAR CHART

Type I

Linear time-scaled for planning, Linear progress-scaled for reporting

- Assume the progress of the activity as a direct-linear function of the elapsed time.

- For this example
  - Five months were originally scheduled for this activity.
  - Reporting date at 3rd month, 60% of the elapsed time.
  - Activity behind by 10% “May or may not be true”.

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Type I Bar Charts

(a) Type I Plan Bar

(b) Type I Reporting: Version 1

(c) Type I Reporting: Version 2

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TYPE OF BAR CHART (cont.)

Type II

Time scaled for planning - Time scaled for reporting.

- Planned cumulative progress % are written at the end of each time interval.
- No linearity
- the reporting bar gives no indication of about the actual progress.

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Type II Bar Charts

(a) Type II Plan Bar

(b) Type II Reporting: Case 1

(b) Type II Reporting: Case 2

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Bar (Gantt) Charts

Example 2:

<table>
<thead>
<tr>
<th>Activity Name</th>
<th>Orig Dur</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Development</td>
<td>245.0d</td>
<td>18-Sep-03</td>
<td>19-May-04</td>
</tr>
<tr>
<td>Design Procurement</td>
<td>20.0d</td>
<td>20-May-04</td>
<td>08-Jun-04</td>
</tr>
<tr>
<td>NTP for Design</td>
<td>0.0d</td>
<td>09-Jun-04</td>
<td></td>
</tr>
<tr>
<td>30% Design</td>
<td>30.0d</td>
<td>09-Jun-04</td>
<td>08-Jul-04</td>
</tr>
<tr>
<td>30% Design Review</td>
<td>15.0d</td>
<td>09-Jul-04</td>
<td>23-Jul-04</td>
</tr>
<tr>
<td>60% Design</td>
<td>30.0d</td>
<td>24-Jul-04</td>
<td>22-Aug-04</td>
</tr>
<tr>
<td>60% Design Review</td>
<td>15.0d</td>
<td>23-Aug-04</td>
<td>06-Sep-04</td>
</tr>
<tr>
<td>90% Design</td>
<td>30.0d</td>
<td>07-Sep-04</td>
<td>06-Oct-04</td>
</tr>
<tr>
<td>90% Design Review</td>
<td>15.0d</td>
<td>07-Oct-04</td>
<td>21-Oct-04</td>
</tr>
<tr>
<td>Final Design</td>
<td>30.0d</td>
<td>22-Oct-04</td>
<td>20-Nov-04</td>
</tr>
<tr>
<td>Final Design Review</td>
<td>15.0d</td>
<td>21-Nov-04</td>
<td>05-Dec-04</td>
</tr>
<tr>
<td>Site Selection &amp; Acquisition</td>
<td>180.0d</td>
<td>22-Oct-04</td>
<td>19-Apr-05</td>
</tr>
<tr>
<td>Bid Advertisement (C)</td>
<td>1.0d</td>
<td>20-Apr-05</td>
<td>20-Apr-05</td>
</tr>
<tr>
<td>Bid Opening (C)</td>
<td>10.0d</td>
<td>21-May-05</td>
<td>30-May-05</td>
</tr>
<tr>
<td>BOCC Award (C)</td>
<td>0.0d</td>
<td>01-Jun-05</td>
<td></td>
</tr>
<tr>
<td>NTP for Construction</td>
<td>0.0d</td>
<td>11-Jun-05</td>
<td></td>
</tr>
</tbody>
</table>
Bar Charts with Interrupted Activities

- Excavate
- Form Footings
- Place Rebar
- Place Concrete
- Strip Forms

Days: 2 4 6 8 10 12 14 16 17

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Bar Charts Loaded with More Info

- Foundation: 7,000 manhours
- First Floor: 6,000 manhours
- Second Floor: 5,000 manhours
- Third Floor: 4,000 manhours
- Fourth Floor: 3,000 manhours
- Roof: 2,000 manhours
- Site: 1,000 manhours

Days: 2 4 6 8 10 12 14 16 18 20 22 24 26 28

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Bar Charts Loaded with More Info

- **Remove Old Roof**
  - As Planned
  - As Built

- **Replace rotten rafters**
  - 90%
  - 80%

- **Install Sheathing**
  - 70%
  - 60%

- **Install Felt**
  - 50%
  - 40%

- **Install Shingles**
  - 30%
  - 20%

- **Clean Up**
  - 10%

Data Date:

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Days:

- Percent Complete:
  - 100%
  - 90%
  - 80%
  - 70%
  - 60%
  - 50%
  - 40%
  - 30%
  - 20%
  - 10%

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Bar Charts: Advantages

- Time-scaled
- Simple to prepare
- Simple to read and interpret
- Can be more effective and efficient if CPM based
  - Still the most popular method
- Bars can be dashed to indicate work stoppage
- Can be loaded with other information (budget, man-hours, resources, etc.)
Bar Charts: Disadvantages

Does not show logic

- Some computer programs can show links but it may look so complicated and confusing.

Not practical for projects with too many activities

- As a remedy, we can use bar charts to show:
  1. A small group of the activities (subnet)
  2. Summary schedules
Quiz 2

True or False:

1. The bar representing a 4-day activity is twice as long as a bar representing a 2-day activity in a bar chart
2. Bar chart method lost its applicability with the introduction of the Critical Path Method
3. Bars in a bar chart must be connected with relationship lines
4. A bar representing an activity in a bar chart may not be continuous
5. Bar charts and Gantt charts are two different methods
6. Bar charts can be loaded with information other than the timeline of the project
Class Exercise 1

Choose one of these projects. Write down the activities involved (5-10) and draw a bar chart representing the project:

1. You want to add a 2-car attached garage to your house
2. You like to re-decorate your bedroom
3. You had a flat tire and need to replace it
Logic Networks: A Definition

- A network is a graphical representation of the activities (and events) comprising the project, in a logical and chronological depiction.

- Network diagrams are basically two types:
  - arrow networks and
  - node networks:
    - Basic node networks
    - Precedence networks
Arrow Networks

- Arrow network: A network on which activities are represented by arrows between nodes (events).

- Also called:
  - I-J Method (10-20 for activity A above),
  - Activity on Arrow (AOA) Network,
  - Arrow Diagramming Method (ADM)
Basic Logic Patterns for Arrow Diagrams

(a) Basic Activity
Basic Logic Patterns for Arrow Diagrams (cont.)

(b) Independent Activities

(c) Dependent Activities
(d) A Merge

Activity C depends upon the completion of both Activities A & B

(e) A Burst

Activities B and C both depend upon the completion of Activity A
Activities C and D both depend upon the completion of Activities A and B

(f) A Cross

Basic Logic Patterns for Arrow Diagrams (cont.)
The use of dummy to maintain unique numbering of activities

(a) Incorrect Representation

(b) Correct Representation

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The use of dummy to maintain unique numbering of activities (cont.)

Diagram:

(a) Incorrect Representation

(b) Correct Representation

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Removal of Redundant Dummies

Original Diagram

Diagram after removal of redundant dummies

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Removal of Redundant Dummies (cont.)

Original Diagram

Diagram after removal of redundant dummies

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Combining Beginning and Ending Nodes
Combining Beginning and Ending Nodes (cont.)

(a) Incorrect Representation

(b) Correct Representation
Basic Rules of Network Logic

Rule 1.
Before an activity may begin, all activities preceding it must be completed. (Activities with no predecessors are self-actuating when the project begins.)

Rule 2.
Arrows imply logical precedence only. Neither the length of the arrow nor its “x” direction on the drawing have any significance. (An exception to this rule is discussed under “Time-scaled Networks”.)
Basic Rules of Network Logic (cont.)

Rule 3.
Event numbers must not be duplicated in a network.

Rule 4.
Any two events may be directly connected by more than one activity.

Rule 5.
Networks may have only one initial event (with no predecessor) and only one terminal event (with no successor).

Rule 6.
- Even, odd, in fives or tens
- Smaller numbers to the left
- Each activity has its unique number

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Arrow Networks

- Network schedules were first developed by E. I. Dupont de Nemours Company in conjunction with the UNIVAC Applications Research Center of Remington Rand between 1956 and 1958.
- At the beginning, Arrow Networks were the only way to do CPM schedules.
- In the last three decades, Arrow Networks have become obsolete. They were replaced by Node and Precedence Networks.
**Arrow Networks: Simple Example**

<table>
<thead>
<tr>
<th>Activity</th>
<th>IPA*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>B</td>
</tr>
<tr>
<td>E</td>
<td>C, D</td>
</tr>
</tbody>
</table>

* IPA: Immediately Preceding Activities*
Example Solution

A

B  30  D

C

E  40

10  20

40  50

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### Example 2 for Arrow Network

<table>
<thead>
<tr>
<th>Activity</th>
<th>IPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>-</td>
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<tr>
<td>C</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>A</td>
</tr>
<tr>
<td>E</td>
<td>A,B</td>
</tr>
<tr>
<td>F</td>
<td>A,B,C</td>
</tr>
<tr>
<td>G</td>
<td>E,F</td>
</tr>
<tr>
<td>H</td>
<td>D,G</td>
</tr>
<tr>
<td>I</td>
<td>D,G</td>
</tr>
</tbody>
</table>
Solution
Comments on Arrow Networks

- An arrow represents an activity.
- A node represents an event of starting and/or finishing an activity or activities.
- Arrow networks can only accommodate finish-start relationships.
- Dummy activities are required in Arrow Networks for logic or identity.
- Waiting periods (lags) have to be incorporated in the network as real activities.
Node Networks

- A node network is a network where nodes represent activities and arrows represent logic relationships (dependencies)
  - Also called activity on node (AON)

- Precedence diagrams (or networks) are an advanced form for node networks
  - Also called Precedence Diagramming Method, PDM
Example 1 for Node Network

<table>
<thead>
<tr>
<th>Activity</th>
<th>IPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>B</td>
</tr>
<tr>
<td>E</td>
<td>C, D</td>
</tr>
</tbody>
</table>

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Solution of Example 1
## Example 2 for Node Network

<table>
<thead>
<tr>
<th>Activity</th>
<th>IPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>A</td>
</tr>
<tr>
<td>E</td>
<td>A, B</td>
</tr>
<tr>
<td>F</td>
<td>A, B, C</td>
</tr>
<tr>
<td>G</td>
<td>E, F</td>
</tr>
<tr>
<td>H</td>
<td>D, G</td>
</tr>
<tr>
<td>I</td>
<td>D, G</td>
</tr>
</tbody>
</table>
Solution of Example 2
Retailing wall arrow diagram - start event approach

(a) Wall 1
   Footing 2
   Wall 2

(b) Footing 1
   Wall 1
   Footing 1

(c) Footing 1
   Wall 1
   Footing 1
   Wall 2

(d) Footing 1
   Wall 1
   Footing 1

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## Activity List with Redundant Removed - Remodeling Chemical Laboratory

<table>
<thead>
<tr>
<th>No.</th>
<th>Activity</th>
<th>Depends upon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strip room</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Repair walls and ceiling</td>
<td>1, 5, 7</td>
</tr>
<tr>
<td>3</td>
<td>Repair floor</td>
<td>1, 5</td>
</tr>
<tr>
<td>4</td>
<td>Lay vinyl floor</td>
<td>2, 12, 13, 14</td>
</tr>
<tr>
<td>5</td>
<td>Rough-in plumbing and electrical</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Finish plumbing and electrical</td>
<td>2, 3, 5, 9, 10, 11, 19</td>
</tr>
<tr>
<td>7</td>
<td>Replace existing fume duct</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Install new fume hood</td>
<td>2, 3, 16</td>
</tr>
<tr>
<td>9</td>
<td>Install 1/3 base cabinets</td>
<td>2, 3, 8, 15</td>
</tr>
<tr>
<td>10</td>
<td>Install wall cabinets</td>
<td>2, 3, 7, 15</td>
</tr>
<tr>
<td>11</td>
<td>Install chemical sink</td>
<td>2, 3, 5, 9, 17</td>
</tr>
<tr>
<td>12</td>
<td>Paint cabinets</td>
<td>6, 8, 9, 10, 11, 18</td>
</tr>
<tr>
<td>13</td>
<td>Paint walls and ceiling</td>
<td>2, 3, 6, 8, 9, 10, 18</td>
</tr>
<tr>
<td>14</td>
<td>Obtain vinyl floor covering</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Obtain cabinets</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Obtain fume hood</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Obtain chemical sink</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Painter availability</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Install 2/3 base cabinets</td>
<td>2, 3, 9, 15</td>
</tr>
</tbody>
</table>
Tips for Proper Network Drawing

Improper

Proper

A
5

A
5
Tips for Proper Network Drawing

- Improper
  
  A
  5

  B
  3

- Proper
  
  A
  5

  B
  3

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Tips for Proper Network Drawing

- Improper

- Proper

A 5

B 3
Tips for Proper Network Drawing

- Improper

A

5

B

3

- Proper

A

5

or

B

3

A

5

B

3

or

A

5

B

3

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Tips for Proper Network Drawing

- 5

Improper

Proper

A
5

C
4

B
3

D
7

A
5

C
4

B
3

D
7
Tips for Proper Network Drawing

Starting a network diagram

Improper

Proper
Ending a network diagram

Improper

Proper

X
5

Y
3

Z
4

X
5

Y
3

Z
4

PF

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Time-Scaled Logic Diagrams
Time-Scaled Logic Diagrams

- It was thought of a method that combines the main advantage of bar charts (time-scaled) with the main advantage of networks (show logic) in one method.
- The main problem is the amount of lines and their intersections.
- A partial solution is to show binding (driving) relationships only.
- It is introduced in computer software as an option with bar charts.
Quiz 3

True or False:

1. A node in an arrow diagram represents an event
2. An arrow in an arrow diagram represents an event
3. A node in a node diagram represents an event
4. An arrow in a node diagram represents a logic relationship
5. A milestone is a term used by scheduling software to indicate an important event
6. One of the major advantages of networks over bar charts is ability to depict logic
Class Exercise 2

Do Exercise II a, b, and c.
Precedence Diagram
Advantages of using Precedence Diagram:

1. No dummy activities are required.
2. A single number can be assigned to identify each activity.
3. Analytical solution is simpler.
Redundant Linkages

(a) Incorrect Representation

(b) Correct Representation
Closing the network to give Single Beginning and Ending Nodes

(a) Incorrect Representation

(b) Correct Representation
Retaining Wall Precedence Diagram

Wall 1

Footing 1

Footing 2

Wall 2

Footing 1

Footing 2

Wall 1

Footing 2

Wall 2

Footing 1

20

10

30

40

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Precedence Diagram - Sequence Stepped and Numbered

Start

10 A

15 D

20 C

25 E

30 F

35 Finish

1

2

3

4

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Constructing the Precedence Diagram

1. Create Activity list and eliminate redundancies.

2. Construct precedence diagram
   - Activities with no dependency arranged at the left
   - Create dummy start if you have more than one start “Contract Award”

3. Arrange activities in a sequential order
The Critical Path Method

The Critical Path Method (CPM):

- A scheduling technique using networks for graphic display of the work plan
- Network calculations determine when activities can be performed, the expected completion date of the project, and the critical path of the project

![Graph showing the critical path for the hunting trip example]
CPM Definitions

- Early Start, ES: The earliest date the activity can start within project constraints.
- Early Finish, EF: The earliest date the activity can finish within project constraints.
- Late Start, LS: The latest date the activity can start without delaying the completion of the project.
- Late Finish, LF: The latest date the activity can finish without delaying the completion of the project.
CPM Definitions

The Critical Path: The longest path in a network from start to finish

- The definition “the path with zero float” is inaccurate
- The critical path represents the summation of the durations of activities along that path including lags, and taking constraints in consideration
- For every network, there must be at least one critical path but there might be more than one critical path
- Multiple paths may share one or more activities
More CPM Definitions

- **Forward pass:** The process of going from the start to finish of a network in order to calculate early start and early finish time for each activity, and the expected finish date for the entire project.

- **Backward pass:** The process of going from the finish to start of a network in order to calculate late start and late finish time for each activity.

- Both passes identify the critical path and float times for activities.
More CPM Definitions

- A critical activity: An activity on the critical path that is if delayed, the entire project will get delayed

- Total Float, TF: The maximum amount of time an activity can be delayed from its early start (ES) without delaying the entire project
  - TF = LS – ES = LF – EF = LF – ES - Dur

- Float is one of the most important, interesting, and controversial issues in construction; technically and legally
Calculation
Estimating Activity Duration

Time Interval

- Time Interval is selected according to the nature of the activity (seconds - minutes...)
- It is common practice in construction industry to use calendar day.
- Use one and only one time unit for any schedule.
Estimating Activity Duration

1. From company’s record
2. From standard estimating guide
3. Interviewing field personnel.
Weather and Contingency Allowance

Two approaches for assignment of weather allowance:

1. Add the Weather Allowance at the end of the project as a separate activity.

2. Add Weather Allowance to those affected by the weather.

3. Add weather allowance at the end of each construction segment (site preparation, foundation, ... etc.)
Contingency items

- Other activities can be added to allow for contingency such as strikes

Time Zero

The close of the work period immediately preceding the start of the project.
Scheduling Computation for Arrow Diagram

Four time values associated with each activity:

1. ESD  Early Start Date
2. EFD  Early Finish Date
3. LSD  Late Start Date
4. LFD  Late Finish Date
The Four Activity Times - Arrow Diagram Notation

(a)

(b)
Forward Pass Rules

Rule 1
The initial project event is assumed to occur at time zero.

Rule 2
All activities are assumed to start as soon as possible, that is, as soon as all the predecessor activities are completed.

Rule 3
The early finish time of an activity is merely the sum of its early start date and the estimated activity duration.

\[ EFD_{ij} = ESD_{ij} + T_{ij} \]
Rule 4

The late start date \( \text{LSD}_{ij} \) is found by subtracting the activity duration \( T_{ij} \) from the late finish date \( \text{LFD}_{ij} \)

\[
\text{LSD}_{ij} = \text{LFD}_{ij} - T_{ij}
\]
<table>
<thead>
<tr>
<th>$i$</th>
<th>$j$</th>
<th>Activity Description</th>
<th>$T$ (Days)</th>
<th>ESD</th>
<th>EFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>Strip room</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>Obtain fume hood</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>Obtain cabinet</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>Obtain chemical sink</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>Painter availability</td>
<td>20</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>Obtain vinyl floor covering</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Rough-in plumbing and electrical</td>
<td>5</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>Replace existing fume duct</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
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<td>6</td>
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<td>Dummy</td>
<td>0</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>Repair floor</td>
<td>1</td>
<td>8</td>
<td>9</td>
</tr>
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<td>8</td>
<td>10</td>
<td>Repair walls and ceiling</td>
<td>4</td>
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<td>12</td>
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</tr>
<tr>
<td>12</td>
<td>16</td>
<td>Install new fume hood</td>
<td>1</td>
<td>12</td>
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<tr>
<td>14</td>
<td>16</td>
<td>Dummy</td>
<td>0</td>
<td>12</td>
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</tr>
<tr>
<td>14</td>
<td>22</td>
<td>Install all wall cabinets</td>
<td>5</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>16</td>
<td>18</td>
<td>Install 1/3 base cabinets</td>
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<td>2</td>
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</tr>
<tr>
<td>20</td>
<td>22</td>
<td>Install chemical sink</td>
<td>1</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>22</td>
<td>24</td>
<td>Finish plumbing and electrical</td>
<td>2</td>
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<td>24</td>
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<td>24</td>
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<td>Paint cabinets</td>
<td>6</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>26</td>
<td>28</td>
<td>Paint walls and ceiling</td>
<td>3</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>28</td>
<td>30</td>
<td>Lay vinyl floor</td>
<td>1</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>i</td>
<td>j</td>
<td>Activity Description</td>
<td>T (Days)</td>
<td>ESD</td>
<td>EFD</td>
</tr>
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<td>----</td>
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</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Strip room</td>
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</tr>
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<td>12</td>
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<td>10</td>
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<td>10</td>
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<td>2</td>
<td>14</td>
<td>Obtain cabinet</td>
<td>10</td>
<td>0</td>
<td>10</td>
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<td>2</td>
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<td>5</td>
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</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Rough-in plumbing and electrical</td>
<td>5</td>
<td>3</td>
<td>8</td>
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<tr>
<td>4</td>
<td>8</td>
<td>Replace existing fume duct</td>
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<td>3</td>
<td>6</td>
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</tr>
<tr>
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<td>10</td>
<td>Repair floor</td>
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<td>Repair walls and ceiling</td>
<td>4</td>
<td>8</td>
<td>12</td>
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<tr>
<td>10</td>
<td>12</td>
<td>Dummy</td>
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<td>12</td>
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</tr>
<tr>
<td>10</td>
<td>14</td>
<td>Dummy</td>
<td>0</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>16</td>
<td>Install new fume hood</td>
<td>1</td>
<td>12</td>
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<td>5</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>16</td>
<td>18</td>
<td>Inst all 1/3 base cabinets</td>
<td>1</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>Dummy</td>
<td>0</td>
<td>14</td>
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<td>16</td>
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<tr>
<td>20</td>
<td>22</td>
<td>Inst all chemical sink</td>
<td>1</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>22</td>
<td>24</td>
<td>Finish plumbing and electrical</td>
<td>2</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>24</td>
<td>26</td>
<td>Dummy</td>
<td>0</td>
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</tr>
<tr>
<td>24</td>
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<td>Paint cabinets</td>
<td>6</td>
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<tr>
<td>26</td>
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<td>Paint walls and ceiling</td>
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<td>28</td>
<td>30</td>
<td>Lay vinyl floor</td>
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</tr>
</tbody>
</table>
1. Total Float

Total float may be defined as that time span in which the completion of an activity may occur and not delay the termination of the project.

\[ TF_{ij} = LFD_{ij} - EFD_{ij} = LSD_{ij} - ESD_{ij} \]
2. Free Float

Free float may be defined as the time span in which the completion of an activity may occur and not delay the finish of the project nor delay the start of any following activity.

\[ FF_{ij} = ESD_{jk} - EFD_{ij} \]
Free Float, FF: The maximum amount of time an activity can be delayed without delaying the ES of the succeeding activity(s)

- \( FF_i = \min(ES_{i+1}) - EF_i \)
- \( FF_B = \min(8, 12) - 8 = 0 \)
- \( FF \leq TF \)
3. Interfering Float

That part of the total float which remains after free float has been deducted is the interfering float.

It may be defined as: the time span in which the completion of an activity may occur and not delay the termination of the project but within which completion will delay the start of some other following activity.

$$INTF_{ij} = TF_{ij} - FF_{ij}$$
4. Independent Float

The fourth float, independent float, is the amount of scheduling leeway of an activity that is independent of the early starts and late finishes of any other activity. It may be formally defined as:

The time span in which the completion of an activity may occur and not delay the termination of the project, not delay the start of any following activity, and not be delayed by any preceding activity.
<table>
<thead>
<tr>
<th>j</th>
<th>Activity Description</th>
<th>T (Days)</th>
<th>ESD</th>
<th>EFD</th>
<th>LSD</th>
<th>LFD</th>
<th>TF</th>
<th>FF</th>
<th>INTF</th>
<th>INDF</th>
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<td>4</td>
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<td>0</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
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<td>Obtain fume hood</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>4</td>
<td>14</td>
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<td>Rough-in plumbing and electrical</td>
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<td>Replace existing fume duct</td>
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<td>Repair walls and ceiling</td>
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<td>15</td>
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<td>3</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>Install wall cabinets</td>
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<td>12</td>
<td>17</td>
<td>13</td>
<td>18</td>
<td>1</td>
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</tr>
<tr>
<td>16</td>
<td>Install 1/3 base cabinets</td>
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<td>14</td>
<td>15</td>
<td>16</td>
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<td>14</td>
<td>17</td>
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</tr>
<tr>
<td>18</td>
<td>Install 2/3 base cabinets</td>
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<td>16</td>
<td>16</td>
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<tr>
<td>20</td>
<td>Install all chemical sink</td>
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<td>18</td>
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<tr>
<td>22</td>
<td>Finish plumbing and electrical</td>
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<td>18</td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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Nabil Dmaidi
Critical Path Computations on the Network
The Two Event Approach

Early Start Event

In the forward pass, the maximum of the EFD values for all activities merging at a node is taken as ESD value for all the activities that burst from the same node.

\[ TE_j = \max_{\forall i} (TE_i + T_{ij}) \]
For all activities entering node $j$, $TE_j$ is taken as the greatest sum of all activities merge to the node.
Late Finish Event

- In the backward computations, the minimum of LSD valves is taken as the latest finish time for all activities that enter the node.

\[ \text{TL}_j = \min_{\forall i} (\text{TL}_i + T_{ij}) \]
Start by the last activity, the TL for the next earlier node is taken as the minimum value of the late time event minus activity duration.
Float Calculations From Event Times

**Total Float**

\[ T_{f_{ij}} = TL_j - TE_i - T_{ij} \]

**Example**

\[ TF_{2-20} = TL_{20} - TE_2 - T_{2-20} \]

\[ = 17 - 0 - 10 = 7 \]
Free Float

$$FF_{ij} = TE_j - TE_i - T_{ij}$$

Example

$$FF_{2-20} = TE_{20} - TE_2 - T_{2-20}$$

$$= 14 - 0 - 10 = 4$$
Interfering Float
\[ \text{INTF}_{ij} = \text{TL}_j - \text{TE}_j \]

Example
\[ \text{INTF}_{2-20} = \text{TL}_{20} - \text{TE}_{20} = 17 - 14 = 3 \]

Independent Float
\[ \text{INDF}_{ij} = \text{TE}_j - \text{TL}_i - T_{ij} \]

Example
\[ \text{INDF}_{2-20} = \text{TE}_{20} - \text{TL}_2 - T_{2-20} = 14 - 0 - 10 = 4 \]
Forward Pass Calculations
Early start / Early Finish
EF = ES + D

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Backward Pass Calculations
Late start / Late Finish
LS = LF - D
The Critical activities
Total Float = LF - ES - D
The critical Path
**Exercise**

Draw a network for the following activities.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>IPAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>--</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>A, C</td>
</tr>
<tr>
<td>F</td>
<td>2</td>
<td>B</td>
</tr>
<tr>
<td>G</td>
<td>1</td>
<td>B</td>
</tr>
<tr>
<td>H</td>
<td>4</td>
<td>B, C</td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td>B, E</td>
</tr>
<tr>
<td>J</td>
<td>4</td>
<td>F</td>
</tr>
<tr>
<td>K</td>
<td>4</td>
<td>F, G, H</td>
</tr>
<tr>
<td>L</td>
<td>1</td>
<td>F, I, K</td>
</tr>
</tbody>
</table>

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The Arrow Network will be:
• Forward Pass calculations (ES, EF)
backward Pass calculations (LS, LF)
Specify the Critical Path
# Table of activities

\[ \text{EF} = \text{ES} + \text{D} \]

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>IPAs</th>
<th>ES</th>
<th>EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>--</td>
<td>0</td>
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</tr>
<tr>
<td>B</td>
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<td>G</td>
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<td>D</td>
<td>7</td>
<td>8</td>
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<tr>
<td>H</td>
<td>4</td>
<td>F,E</td>
<td>10</td>
<td>14</td>
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<tr>
<td>I</td>
<td>2</td>
<td>F</td>
<td>6</td>
<td>8</td>
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<tr>
<td>J</td>
<td>4</td>
<td>G,H</td>
<td>14</td>
<td>18</td>
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<td>I,H</td>
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<td>K,J</td>
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<td>19</td>
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</tbody>
</table>

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**Table of activities**

**LS = LF - D**

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<tr>
<th>Activity</th>
<th>Duration</th>
<th>IPAs</th>
<th>ES</th>
<th>EF</th>
<th>LS</th>
<th>LF</th>
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<td>C</td>
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</table>

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Nabil Dmaidi
Total Float (TF): The amount of time an activity can be delayed without delaying the overall project completion.

TF = LF – ES – D
= LF – EF
= LS - ES

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>IPAs</th>
<th>ES</th>
<th>EF</th>
<th>LS</th>
<th>LF</th>
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Nabil Dmaidi
Total Float (TF): The amount of time an activity can be delayed without delaying the overall project completion.

TF = LF – ES – D
    = LF – EF
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<table>
<thead>
<tr>
<th>Activity</th>
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<th>IPAs</th>
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9/5/2010

Nabil Dmaidi
Bar / Gantt chart Early Start / Finish

EF = ES + D

Activity
A
B
C
D
E
F
G
H
I
J
K
L

Time
2 4 6 8 10 12 14 16

9/5/2010
Bar / Gantt Chart Late Start / Finish

LS = LF - D
Bar / Gantt of the previous network

A
B
C
D
E
F
G
H
I
J
K
L

2 4 6 8 10 12 14 16

9/5/2010

Nabil Dmaidi
Bar / Gantt chart Early Start / Finish

EF = ES + D

Activity

A
B
C
D
E
F
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H
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J
K
L

Time

9/5/2010

Nabil Dmaidi
Bar / Gantt Chart Late Start / Finish

$LS = LF - D$

9/5/2010
## CPM Calculations: Example

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CPM Calculations:
Example 2 Tabular Solution

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CPM Calculations: Example 2 Graphic Solution

All dates above represent the end of the day
CPM Calculations: Example 3

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CPM Calculations: Example 3 Graphic Solution
Free Float Calculation in Our Example: Activities C, F, I
## CPM Calculations: Example 3 Tabular Solution

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### CPM Calculations: Example 4

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CPM Calculations: Exercise
CPM Calculations: Exercise
Graphic Solution

A
5
0, 5

B
6
5, 11
0, 5

C
5
6, 11
1

D
3
8, 11
3

E
3
11, 14

F
4
11, 15
1

G
4
8, 12
3

H
7
12, 19
3

I
8
15, 23
5

J
2
15, 17
20, 22

K
3
19, 22
3

L
2
15, 23

P
23, 25

PF
25

Nabil Dmaidi 2089/5/2010
# CPM Calculations: Exercise

## Tabular Solution

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</table>
End-of-Day Convention

- The dates on the activities represent the “end of day”. That’s why we always start with day 0: end of day 0 = start of day 1
- This concept is **not** applied in computer programs. In computer programs start dates (ES, LS) represent the beginning of the day while finish dates (EF, LF) represent the end of the day
Exercise Solution Using The Computer
Near-critical activities may be as important as critical activities.

It is a good practice for the project manager not to give subordinates two sets of dates:

- PM has to choose one set of dates within the range of Early - Late.
- Management may reserve a number of days as “management float” or “time contingency.”
Float Discussion

- Total float—in general—belongs to a path rather than the activity itself
  - If an activity uses “its” float, successors may lose some or all of “their” float
  - Total float versus free float
- Total float is broken down into free float, independent float, and interfering float
  - Researchers have come up with even more types
More Float Discussion

The question is: “who owns the float”?  
- Float distribution attempts
- Review the contract – what if it is *not* mentioned?

Float with resource leveling

Shifting activities within their float may affect:
- Start / finish dates of succeeding activities
- Resource usage: Labor and equipment (crews)
- Materials: delivery, storage
- Cash flow
Class Exercise 3

Do Exercises III a and b.
Lags in Node Networks

- A lag is a minimum compulsory waiting period between the start/finish of an activity and the start/finish of the successor.
  - Actual waiting period may be greater, but never less than the lag.
  - Lags are very common with SS and FF relationships.
  - A lead is a negative lag.

- The lag is added in the CPM’s forward pass calculations and subtracted in the backward pass.
Lags in Node Networks

Examples:

- Concrete curing (before formwork stripping or reshoring)
- Asphalt curing (before striping)
- Waiting for a permit to be issued
- Waiting for the delivery of a custom material or equipment
CPM Calculations with Lags: An Example

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Tabular Solution

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</table>
Constraints and the CPM

A Constraint is an externally imposed restriction affecting when an activity can start and/or finished

- Constraints may conflict with logical relationships
- Constraints are not alternatives for logic
Software Quiz

On a continuous path:

Activities A, B, and C are critical; but D, E, and F not critical.

Why?
Driving Relationships in CPM

- Driving Relationship: A relationship from a predecessor activity that controls the start or finish of a successor activity
  - For any activity with predecessors, there must be at least one driving relationship
- Relationships may change from driving to non-driving (or vice versa) if conditions preceding that activity change:
  - duration(s), logic, constraints, resource leveling
- Removing non-driving relationships is not a good idea
Which Relationships are Driving for Activities E, F, G, H, I?

Diagram showing relationships and dependencies between activities A, B, C, D, E, F, G, H, I, with arrows indicating dependencies and numbers indicating durations or time intervals.
Effect of Imposed Finish Date

- Imposed Finish Date is the project’s completion date, as specified in the contract or stipulated by the owner.

- When compared to the calculated finish date:
  - Calculated finish date < imposed finish date
    - You are in good shape
    - What happens if you enter the imposed date?
  - Calculated finish date > imposed finish date
    - Negative float appears when you enter the imposed date
    - You need to accelerate / crash the schedule
Examples with Imposed Finish Dates

- Repeat Example 3 with imposed finish date of 28 days
- Repeat Example 3 with imposed finish date of 22 days
Imposed Finish Date > Calculated Finish Date
Imposed Finish Date < Calculated Finish Date
Negative Float

Negative float is a situation that occurs when performing an activity even on its early dates, fails to meet the project’s imposed finish date or other constraint.

It may occur in one of two cases:
- Before construction starts
- During construction (after normal start)
Calendars

Each activity has to be assigned a calendar

Different crews working for different activities work on different calendars

- The crew working for the same activity may work 5 days/week at normal times then switch to 6 or 7 days/week

User has to be aware of the impact of such matter on the duration of activities and consequently the project
Calendars (Cont’d.)

- Computer scheduling programs can handle calendars:
  - Global, default, and other calendars
  - Recurring holidays
  - Work hours per day
  - Resource calendars

- Scheduling in other countries
Software Quiz 1

This is a part of a schedule network

Why is the float different?
In the sub-network below:

Which calendar does the lag follow?

Activity on a 5-workday calendar

0, 5
A
5
2, 7

3

8, 16
B
8
10, 18

Activity on a 6-workday calendar

Calendar for scheduling Relationship Lag

Successor Activity Calendar

Predecessor Activity Calendar

Successor Activity Calendar

24 Hour Calendar

Project Default Calendar
Non-Work Days

Schedulers must take in account non-work days. This includes:

- Scheduled non-work days such as:
  - Holidays,
  - Shut-downs

- Unscheduled non-work days such as:
  - Rain days (or severe weather),
  - Other unforeseen interruptions

Distribution of unscheduled non-work days
Quiz 4

True or False:

1. Determining activities durations is primarily the scheduler’s job
2. You can find out the project’s estimated completion date after performing the forward pass only
3. You can find out the project’s critical path after performing the forward pass only
4. “Event” is another name for an activity
5. “Task” is another name for an activity
6. There could be more than one critical path in a CPM network
7. Total float must be equal to or greater than free float
Class Exercise

Do Exercises III c and d
Precedence Diagramming Method, PDM, uses node diagrams with four types of logical relationships:

- Finish-to-Start, F-S,
- Start-to-Start, S-S,
- Finish-to-Finish, F-F,
- Start-to-Finish, S-F.

It was first introduced by professor John Fondahl of Stanford University in 1961.
1) Finish to start – FS Relationship

- The traditional relationship between activities.
- Implies that the preceding activity must finish before the succeeding activities can start.
- Example: the plaster must be finished before the tile can start.
Finish to start with delay relationship

Concrete curing is an activity which consumes no resources other than time.

Pour concrete 1 day → Concrete curing 28 days → Deshuttering 2 days

28 days is delay time or LAG means that: deshuttering can start 28 days after concrete has been poured.

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3) Star to Finish – SF relationship

- Appear illogical or irrational.

- Typically used with delay time OR LAG.

- The following examples proofs that its logical.
2) Star to Finish – SF relationship

Erect formwork → steel reinforcement → Pour concrete

Order concrete

SF5

The concrete supplier stipulates 5 days order before delivery.

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3) Finish to Finish – FF relationship

- Both activities must finish at the same time.
- Can be used where activities can overlap to a certain limit.

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Finish to Finish – FF relationship

Set flagpole in the hole

Position flagpole in the hole

Backfill hole

FF

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Finish to Finish with delay relationship

- Erect scaffolding
- Remove Old paint
- sanding
- painting
- inspect
- Dismantle scaffolding

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4) Start to Start – SS relationship

- Clean surface
- Spread grout
- Set tile
- Clean floor area

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Precedence Networks

- Precedence networks incorporate:
  - Lags and leads
  - Overlapping activities

- CPM calculations are somewhat different and more complicated than in regular networks
  - Float calculations also take a different approach, particularly with interruptible activities
Scheduling Computations for Precedence Networks
Tabular Format (Precedence Diagram)

- Can be carried out on the tabular form without reference to the diagram.
- Advantage: the time required to construct the diagram is eliminated.
Link Lag

A link lag is the difference between the early start date of an activity and the early finish date of the preceding activity.

\[ \text{LAG}_{ij} = \text{ESD}_j - \text{EFD}_i \]
Determining the Free-Float

- Free Float is the minimum of the log of the link that follows an activity.
- Look at the “Pre. column” to find the same number value of EF for terminal activity “not following act.”

\[ FF_i = \text{Min}_{j} \cdot LAG_{ij} \]
Determining the Total Float “Backward”

$$TF_i = \text{Min} \ (\text{lag}_{ij} + TF_j)$$
INTF = TF - FF
If the free float is zero - no INDF

\[ \text{INDF}_j = \text{FF}_j - \text{Max}_I (\text{TF}_I - \text{LAG}_{IJ}) \]
Lag Determination - Sample Precedence Network
Float Determination - Sample Precedence Network
Late Date Determination - Sample Precedence Network
2) PDM Precedence Diagramming Method
Activity On Node (AON) Method

- PDM is the primary method in use today.
- Used by most of the computer software.

- MS Project
- Primavera
PDM Precedence Diagramming Method

- The PDM depicts activities as NODES in the network linked with logic lines.
- The node representing the activity.
- Arrow representing relationship / dependency
- PDM should be red left to right
PDM Precedence Diagramming Method

- PDM looks like the following:

- The shape of the node could be any shape
PDM vs. ADM

ADM

1 → 2 → 3

4 → 5 → 6

PDM

A → C

B → D

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PDM vs. ADM

ADM

1 → 2
A

2 → 3
2 → 4
B
C

2 → 5
D

PDM

A

B

C

D

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Exercise

Draw a PDM for the following activities.

<table>
<thead>
<tr>
<th>Activity Label</th>
<th>Activity Description</th>
<th>IPAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Lay out</td>
<td>--</td>
</tr>
<tr>
<td>B</td>
<td>Excavation</td>
<td>A</td>
</tr>
<tr>
<td>C</td>
<td>place formwork</td>
<td>B</td>
</tr>
<tr>
<td>E</td>
<td>purchase steel</td>
<td>--</td>
</tr>
<tr>
<td>F</td>
<td>bend steel</td>
<td>E</td>
</tr>
<tr>
<td>G</td>
<td>place steel</td>
<td>C,F</td>
</tr>
<tr>
<td>H</td>
<td>order concrete</td>
<td>--</td>
</tr>
<tr>
<td>D</td>
<td>place concrete</td>
<td>G,H</td>
</tr>
</tbody>
</table>

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The PDM will be:
Clean surface → Spread grout → Set tile → Clean floor area

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Precedence Network Calculations

The basic information that should be calculated in the precedence network are:

1) Early activity start (ES)
2) Early activity finish (EF)
3) Late activity start (LS)
4) Late activity finish (LF)
5) Free Float (FF)
6) Total Float (TF)
Precedence Network Calculations

The previously mentioned information can be illustrated in the activity nod in the network:

<table>
<thead>
<tr>
<th>Activity description</th>
<th>ES</th>
<th>Duration</th>
<th>LS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FF</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TF</td>
<td></td>
</tr>
</tbody>
</table>

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Precedence Network Calculations

- **ES**: the earliest time that an activity can start as determined by the latest of the early finish times of all immediately preceding activities.
- **EF**: the earliest time that an activity can finish, determined by $EF = ES + D$
- **LS**: the latest time that an activity can start without delaying the project completion. $LS = LF - D$.
- **LF**: the latest time that an activity can be finished without delaying the project completion, as determined by the earliest of the late starts of the immediately succeeding activities.
Precedence Network Calculations

- **FF:** the amount of time that an activity can be delayed before it impacts the start of any succeeding activities.

- **TF:** the amount of time that an activity can be delayed before it impacts the project completion.

- **Lag:** the amount of time that exists between the **EF** of an activity and the **ES** of a specified succeeding activity.

\[
\text{LAG}_{AB} = \text{ES}_B - \text{EF}_A
\]
Reminder: The manual calculations assumes that the relationships between activities are Finish to Start (FS) Type.
Precedence Network Calculations

1) Forward pass calculations

4) Backward pass calculations

5) Calculate total Float (TF = LS – ES OR LF – EF)

2) Calculate the Lag (LAG_{AB} = ES_B - EF_A)

3) Calculate the Free Float (FF) FF = \min \_LAG

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6) Determine the Critical Path

The critical path passes through the critical activities where TF = 0

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EF = ES + D

Activity

Bar / Gantt chart

Early Start / Finish

A
B
C
D
E
F
G
H

2 4 6 8 10 12 14 16 18 20

Time

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Activity

Bar / Gantt chart

Late Start / Finish

LS = LF - D

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2 4 6 8 10 12 14 16 18 20

Time

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Activity

Bar / Gantt chart

A
B
C
D
E
F
G
H

2 4 6 8 10 12 14 16 18 20

Time

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Exercise

1) Forward pass calculations

4) Backward pass calculations

2) Calculate the Lag (LAG\textsubscript{AB} = ES\textsubscript{B} - EF\textsubscript{A})

3) Calculate the Free Float (FF) \( FF = \min \text{LAG} \)
5) Calculate total Float (TF = LS – ES OR LF – EF)

6) Determine the Critical Path

<table>
<thead>
<tr>
<th>Task</th>
<th>ES</th>
<th>Dur.</th>
<th>LS</th>
<th>EF</th>
<th>FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block work</td>
<td>1</td>
<td>6</td>
<td>7</td>
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<td>7</td>
<td>4</td>
<td>11</td>
<td>11</td>
<td>11</td>
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<tr>
<td>Inspection</td>
<td>11</td>
<td>6</td>
<td>17</td>
<td>17</td>
<td>17</td>
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<tr>
<td>plaster</td>
<td>17</td>
<td>8</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Floor tile</td>
<td>28</td>
<td>1</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>

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Overlapping Activities: Interruptible

- Excavate
- Form Footings
- Place Rebar
- Place Concrete
- Strip Forms

2 4 6 8 10 12 14 16 17 Days

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Overlapping Activities: Contiguous

- Excavate
- Form Footings
- Place Rebar
- Place Concrete
- Strip Forms

Days: 2 4 6 8 10 12 14 16 17

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Overlapping Activities: Ladder-Type
Learning Precedence Networks thru Simple Examples

The SS Relationship

No lags
Learning Precedence Networks thru Simple Examples

The SS Relationship

With lags

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Precedence Networks: The FF Relationship

No lags

A
0, 10
10
2, 12

B
0, 12
12
0, 12

C
9, 12
3
9, 12

A

B

C
Precedence Networks: The FF Relationship

With lags

A 0, 10
B 1, 13
C 11, 14

A 0, 10
B 1, 13
C 11, 14

A
B
C

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With Combination relationships, the Forward Pass yields two different finish dates:

- One resulting from the SS relationship and one resulting from the FF relationship
- One of the two dates is accepted. The other one is rejected

The same argument applies to the Backward Pass (in reverse)
Example 1
Example 2
Different Ways to Skin the Cat?

Are the 3 situations below equivalent?

A: SS relationship
B: FS relationship
C: FF relationship
Quiz 5.1

True or False:

1. Precedence Networks are another type of Arrow Networks
2. Precedence Networks allow for overlapping activities
3. The Stair-type relationship results in less number of activities than in Precedence Networks
4. Fast-tracking a project can be shown better in precedence networks
Quiz 5.2

1. If A, B, and C are three activities connected with SS and FF (combination) relationships with no lags. Their durations are 5, 10, and 3; respectively. What is the duration of the project:
   a. 5 days      b. 10 days
   c. 3 days      d. 18 days

2. If A, B, and C are three activities connected with SS and FF (combination) relationships with 2-day lag on each relationship. Their durations are 5, 10, and 3; respectively. What is the duration of the project:
   a. 10 days     b. 12 days
   c. 14 days     d. 22 days
3. If A, B, and C are three activities connected with SS and FF (combination) relationships with 2-day lag on the SS relationships only. Their durations are 5, 10, and 3; respectively. What is the duration of the project:
   a. 10 days  
   b. 12 days  
   c. 14 days  
   d. 22 days
Quiz 5.4

Does the following relationship mean:

A. Activity B has to start exactly 3 days after the start of A
B. Activity B can start at least 3 days after the start of A
C. Activity B can start at most 3 days after the start of A
D. None of the above
Quiz 5.5

Does the following relationship mean:

A. Activity B has to finish exactly 3 days after the finish of A
B. Activity B can finish at least 3 days after the finish of A
C. Activity B can finish at most 3 days after the finish of A
D. None of the above
Does the following relationship mean:

A. Activities A and B must start simultaneously, but B has to finish exactly 2 days after the finish of A
B. Activity B can start after the start of A but has to finish at least 2 days before the finish of A
C. Activity B can start before the start of A but has to finish at most 2 days after the finish of A
D. Activity B can start after the start of A but has to finish at least 2 days after the finish of A
Quiz 5.7

Does the following relationship mean:

A. Activity A can start 2 days before the start of activity B
B. Activity B can start 2 days after the completion of activity A
C. Activity B can start no more 2 days before the completion of activity A
D. Activity B has to start at least 2 days before the completion of activity A
Activities Duration

- **Activity duration**: is the estimated time required to complete an activity.

- Activity duration mainly calculated based on the quantities take off.

- And labor or machines productivity rates.

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Activities Duration

- Durations could be estimated by experience. (previous similar jobs)

- If experience not available, others experience could be utilized.

- If not, handbooks of productivity rates are available provide the required information.
Activities Duration

Activity duration can be calculated as follows:

\[
\frac{\text{quantity of the work}}{\text{qty} / \text{crew hour}} = \text{crew hours}
\]

\* \text{qty} / \text{crew hour} \text{ is the productivity rate.}
\* \text{Time unit is hours could be changed to working days.}

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Example: assume that you have a floor tile area of 600 $M^2$, and the productivity rate of a tile mason and one helper is 1.5 $M^2$/hour.

By applying the previous equation:

\[
\frac{600 \, M^2}{1.5 \, M^2/h} = 400 \, \text{hours}
\]

If the time unit is working day (8 hours):

\[
\frac{400 \, \text{hours}}{8 \, \text{hours}} = 50 \, \text{days}
\]
Time & Cost Theoretical Relationship

![Diagram](image)

Minimum Duration

Cost

Duration

A

B

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Some Factors that affects Duration

1) Weather.
2) Availability, quality, and training of operatives.
3) Familiarity with the work.
4) Quality of workmanship specified.
5) Quality of management/supervision.
6) Size and completion date of project.
7) Length and incidence of holidays.
8) Repetitiveness of the work.
9) Physical constraints of the site. Such as access, size, storage space and etc.
1) Weather

- Allowance for weather is important for activities duration.

- It's particularly critical for excavation and earth moving activities.

- Tow approaches to tackle delay due to weather conditions:
1) Weather Cont.

1) First approach: each activity has an added allowance of possible delays due to weather. Fixed percentage is added to each activity for this purpose.

But, it produces difficulties for activities with long duration, if these activities are not sensitive to weather.
1) Weather Cont.

2) Second approach: adding a single allowance at the end of the project.

This method works best if the work activities have more or less the same sensitivity to weather. And the weather does not vary significantly from period to period.
1) Weather Cont.

A delay activity could be added separately to the network represents the weather delay.
Resource Management

- In the context of construction scheduling, resources include labor, materials, and equipment.
- Resource allocation is assigning the required resources for each activity, in the required amount and timing.
- In most project management software, there are two ways of assigning budget:
  - Lump-sum
  - Assign the required resources for the activity. The budget of the activity will be automatically calculated by the program.
Resources Allocation & Leveling

- A time only network assumes that any other needed resources are available at any time.

- E.g. if the excavation activity requires three large mechanical excavators, A time only network assumes that these excavators are available on site at the required time. This seems to be uneconomic situation.
Sort: the process of arranging activities in a list to certain specific order.
Priorities & Sorts

- The activities making up the network must be listed in order of their priority of resources allocation.
- The network shows the logical sequence of activities. (predecessor and successor).
- The listing of activities must therefore reflects the dependency of some activities.
## Activities Sort

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>ES</th>
<th>TF</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>8 H</td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>9 H</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>7 H</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>11</td>
<td>0</td>
<td>5 H</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>4 H</td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>16</td>
<td>0</td>
<td>8 H</td>
</tr>
<tr>
<td>G</td>
<td>6</td>
<td>11</td>
<td>3</td>
<td>2 H</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>20</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Activity sort reflects the logic sequence of the network.

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Major Sort

<table>
<thead>
<tr>
<th>Activity unit</th>
<th>Duration</th>
<th>ES</th>
<th>TF</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>8 H</td>
</tr>
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<td>2</td>
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</tr>
<tr>
<td>E</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>4 H</td>
</tr>
<tr>
<td>G</td>
<td>6</td>
<td>11</td>
<td>3</td>
<td>2 H</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
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<td>5 H</td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>16</td>
<td>0</td>
<td>8 H</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>20</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Activity sort with ES time as Major sort

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## Major & Minor Sorts

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>ES</th>
<th>TF</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>8 H</td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>2</td>
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<td>9 H</td>
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<tr>
<td>C</td>
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<td>7 H</td>
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<td>E</td>
<td>4</td>
<td>7</td>
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<td>D</td>
<td>5</td>
<td>11</td>
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<td>5 H</td>
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<td>G</td>
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<td>3</td>
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<td>16</td>
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<tr>
<td>H</td>
<td>1</td>
<td>20</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Activity sort with ES time as Major sort & TF as Minor Sort

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Resource Aggregation

- Resources aggregation: is a summation of the resources that are used to carry out the program on a time period basis. For example, day to day, or week to week.
Early start resources aggregation diagram (Histogram)

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Late start

Another histogram can be obtained if Late start considered. Shows different resources demand.

And many histograms can be obtained considering a different time in the network.

Each histogram shows different resources demand.
# Late start Sorts

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>LS</th>
<th>TF</th>
<th>Resource</th>
</tr>
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<tbody>
<tr>
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<td>1</td>
<td>0</td>
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<td>20</td>
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<td></td>
</tr>
</tbody>
</table>

Activity sort with LS time as Major sort & TF as Minor Sort

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| Total Labor | 8  | 9  | 9  | 16 | 16 | 16 | 16 | 13 | 9  | 9  | 9  | 7  | 7  | 10 | 10 | 10 | 10 | 4  |

Late start resources aggregation diagram (Histogram)
Early start vs Late start resources aggregation diagram (Histogram)
Early start vs Late start resources aggregation diagram (Histogram)
Activities Sort

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>ES</th>
<th>TF</th>
<th>Resource unit</th>
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</tbody>
</table>

Activity sort with ES time as Major sort & TF and duration as Minor Sorts

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## Activities Sort

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>LS</th>
<th>TF</th>
<th>Resource unit</th>
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<tr>
<td>K</td>
<td>2</td>
<td>22</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Activity sort with LS time as Major sort & TF and duration as Minor Sorts

9/5/2010  
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Late start resources aggregation

9/5/2010

Total Labor

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
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<td>8</td>
<td>8</td>
<td>8</td>
<td>2</td>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>8H</td>
</tr>
<tr>
<td>9H</td>
<td>9H</td>
<td>9H</td>
<td>9H</td>
<td>5H</td>
<td>5H</td>
<td>5H</td>
<td>5H</td>
<td>5H</td>
<td>5H</td>
<td>8H</td>
</tr>
<tr>
<td>5H</td>
<td>5H</td>
<td>5H</td>
<td>5H</td>
<td>5H</td>
<td>5H</td>
<td>8H</td>
<td>5H</td>
<td>5H</td>
<td>5H</td>
<td>5H</td>
</tr>
<tr>
<td>4H</td>
<td>4H</td>
<td>2H</td>
<td>2H</td>
<td>2H</td>
<td>2H</td>
<td>2H</td>
<td>2H</td>
<td>2H</td>
<td>2H</td>
<td>2H</td>
</tr>
</tbody>
</table>

Created with nitroPDF professional
Smoothing/Leveling

- Let us program activity F to start by its late start day which is day 17.

- And activity I to start by day 14.

- The resulting resources aggregation histogram will be as follows:
Early start resources aggregation

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Let us program activity H to start by its late start time.

So its resources demand starts with its Late start date.

The resulting resource aggregation and histogram will be as follows:
Smoothing/Leveling

- In case activity D is splitable activity. It could be interrupted to be carried out in tow parts.

- Let us program activity B to start by 7th day.

- And activity H to starts by its Late start date.

- And activity E to start by day 14.

- The resulting resource aggregation and histogram will be as follows:
Early Start or Early Finish

- There are many solutions between the limits of Early Start and Early Finish.

- The optimal solution is zero fluctuation histogram. Which is hard to be achieved.

- It is preferred to solve the problem toward the Early start resources aggregation diagram.
Early Start or Early Finish

Because if there are labor availability problems to be overcome, they will occur in the early beginning of the project.

By other words, if the program based on the Late Start date, it means that all the activities are Critical, and any labor problem will affect the project completion.
When Resources are Limited

Resources Allocation

The previous method of resources aggregation has been carried out within a fixed project duration.

The basic objective was to optimize the use of the resources and to know the mount of resources needed to carry out the job on time period basis.

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Allocation within resources restraints

- Another situation which you may face in practice is the restricted resources availability.

- Where you have to carry out the job with the available resources only.

- In this case the project duration may be prolonged to suit the availability of the restricted resources.
## Activity list

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>LS</th>
<th>TF</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>8 H</td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>9 H</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>7 H</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>10</td>
<td>3</td>
<td>4 H</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>11</td>
<td>0</td>
<td>5 H</td>
</tr>
<tr>
<td>G</td>
<td>6</td>
<td>14</td>
<td>3</td>
<td>2 H</td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>16</td>
<td>0</td>
<td>8 H</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>20</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Activity sort with LS time as Major sort & TF as Minor Sort

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Solve the schedule

Assume that the available labors in the company restricted to 10 helpers, and the company decided to carry out the job without resorting to hire more labor.

The resulting program will exceed the Early finish date based on the network.
<table>
<thead>
<tr>
<th>Labor</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Labor</td>
<td>8</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>13</td>
<td>13</td>
<td>7</td>
</tr>
</tbody>
</table>

Early start resources aggregation diagram (Histogram)

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Rules for scheduling activities with limited resources

1) schedule activities to start as soon as their predecessors have been completed.
2) if more than one activity using a specific limited resources can be scheduled, priority is given to the activity with early Late Start. (LS as Major Sort)
3) if tow or more activities have the same Late start, give priority to the activity with least Total Float. (TF as Minor Sort)
4) if the activities have the same Total Float in the minor sort, give the priority to the activity with the Largest Number of Resources.
5) If the activities are tied in the number of resources, give priority to the activity that has already
Resources aggregation diagram

Activity

Time

Total Labor

Labor Limit

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Resource Leveling

- Resource leveling is minimizing the fluctuation in day-to-day resource usage throughout the project.
- It is usually done by shifting non-critical activities within their available float.
- In general, it applies to labor and equipment only.
- The “typical” project resource profile.
- Resource leveling may be done at a single or multiple project level.
- Resource leveling: GC versus subs.
Money and network schedules

Reminder, cost was one of the elements of project constraints triangle (COST, TIME & QUALITY)

An effective management tries to minimize and integrate the above mentioned elements.
Money and network schedules

❖ CPM provides a mean for relating time and money.

❖ The application of resources to a project (materials, manpower and machinery) related to another resource which is MONEY.

❖ The value of the resources for each activity represents a component of project cost.
Hint

Construction costs includes:

1) Materials costs.
2) labor costs.
3) plant and equipment costs
4) overhead costs and profit.
## Activities cost

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>ES</th>
<th>TF</th>
<th>cost ( $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>650</td>
</tr>
<tr>
<td>C</td>
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<td>0</td>
<td>1300</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>400</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>1450</td>
</tr>
<tr>
<td>H</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>500</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>1100</td>
</tr>
<tr>
<td>G</td>
<td>3</td>
<td>11</td>
<td>0</td>
<td>600</td>
</tr>
<tr>
<td>F</td>
<td>2</td>
<td>11</td>
<td>6</td>
<td>350</td>
</tr>
<tr>
<td>I</td>
<td>3</td>
<td>13</td>
<td>6</td>
<td>1000</td>
</tr>
<tr>
<td>J</td>
<td>8</td>
<td>14</td>
<td>0</td>
<td>1300</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>22</td>
<td>0</td>
<td>200</td>
</tr>
</tbody>
</table>

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Cash Flow

It is quite significant to the contractor to know the amount of money that would be spent in each stage of the project. (Expenditures)

And compare it to the amount of money that would be received. (income)
Overtrading

Overtrading: arises when the current liabilities of a company exceed the current assets, even though the business is solvent.
Cumulative Expenditures & Revenues

Expenditures

Revenues

Retainage Release

Amount of Negative Cash Flow

Time (Months)

Cash Flow Curve for revenue and expenditures

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Cash Flow Example
Cash Flow Analysis

- Cash flow analysis consists of a detailed examination of funds disbursement (expenditures) and the receipt of revenue.

- Cash flow shows if surplus fund available during project, or if negative cash position will occur during construction.

- The cash position of contractor during project whether positive or negative is important.
Negative cash position

- Negative cash position means that the revenues obtained from a project insufficient to meet the financial obligations (expenditures) of the project.

- In this case other fund from the company or from outside sources must be used.
Positive cash position

- Positive cash position means that the revenues obtained from a project exceed the financial obligations (expenditures) of the project.

- In this case surplus (extra) fund available with the contractor.

- And the contractor may invest this surplus.
Time-Cost Trade-Off

Some amount of knowledge brings more......
Time/Cost Trade-offs

Introduction

The Northridge Quack case

Why Accelerate a Schedule?

1. To make sure expected finish date meets owner’s (contract’s) stipulated date
2. To avoid liquidated damages (and tarnished reputation) and/or get early finish bonus
3. To start other projects
4. Simply to reduce cost / increase profit
Time/Cost Trade-offs

Schedule acceleration may be:
- planned before construction starts, or
- decided in the middle of the project

Determine the project’s priority: money or time

The principle of schedule compression: Shorten the longest (critical) path in the project

This compression is achieved by cutting the duration of one or more activities along the critical path

As we continue compressing, the process becomes more difficult and more expensive
Schedule Compression: Multiple Paths
Cost Changing with Schedule Acceleration

Direct Cost

Indirect Cost

Total Cost

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Time-Cost Trade-Off

For the following discussions it is important to remember:

Direct costs: Related to putting the facility components in place. They represent the resources used by an activity. (material, labor and equipment).
Time-Cost Trade-Off

Indirect job costs (job overhead): costs that could not be attributed to a specific work item. (such as, site offices, superintendents, security fence & etc)

These costs are generally incurred whether or not productive work achieved.

Longer project duration will result in higher indirect costs.
Time-Cost Trade-Off

- Operating Overhead costs (company overhead): If the cost cannot be attributed to any specific job, they are operating overhead costs, costs of running business. (head office costs, communications & etc).

- These costs continue as long as the company exists even one project is running.
Logic of Time-Cost Trade-Off

Assumption: *increasing or decreasing an activity’s duration will lead to increased direct costs for that activity.*
Direct Costs

Project duration

General relation of direct costs to project duration

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Logic of Time-Cost Trade-Off

Assumption: decreasing a project’s duration will lead to lower indirect costs.
Indirect Costs

General relation of indirect costs to project duration

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Logic of Time-Cost Trade-Off

Assumption: A project’s duration can be decreased by decreasing the duration of one or more critical activities on the critical path.
Logic of Time-Cost Trade-Off

Assumption: Decreasing a project’s duration may increase or decrease the total cost of a project depending upon whether the additional direct costs required to decrease the activity duration are greater or less than indirect costs savings of decreasing the project’s duration.
Project Costs

Total project costs

Direct costs

Indirect costs

Project duration

General relation of project costs to project duration

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Graph analysis

A project’s total costs combines direct costs and indirect costs. Therefore, the curve of total costs versus duration involves adding the cost amounts of direct and indirect costs curves.

Remember, the direct costs curve has a negative slope (direct costs increase as duration decrease) and indirect costs curve has a positive slope (indirect costs decrease as duration decreases).

So, the slope of the total costs curves at any point depends whether the slope of direct costs curve less than that of indirect cost curve.
## Activities Sort

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>LS</th>
<th>TF</th>
<th>Resource unit</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>8 H</td>
<td>200</td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>9 H</td>
<td>450</td>
</tr>
<tr>
<td>D</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>9 H</td>
<td>900</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>10</td>
<td>8</td>
<td>7 H</td>
<td>500</td>
</tr>
<tr>
<td>G</td>
<td>5</td>
<td>11</td>
<td>0</td>
<td>5 H</td>
<td>250</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>15</td>
<td>8</td>
<td>4 H</td>
<td>400</td>
</tr>
<tr>
<td>I</td>
<td>9</td>
<td>16</td>
<td>0</td>
<td>8 H</td>
<td>450</td>
</tr>
<tr>
<td>F</td>
<td>8</td>
<td>17</td>
<td>6</td>
<td>5 H</td>
<td>1200</td>
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<tr>
<td>H</td>
<td>6</td>
<td>19</td>
<td>8</td>
<td>2 H</td>
<td>900</td>
</tr>
<tr>
<td>J</td>
<td>1</td>
<td>25</td>
<td>0</td>
<td>4 H</td>
<td>1500</td>
</tr>
</tbody>
</table>

Activity sort with LS time as Major sort & TF and duration as Minor Sorts

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The previous analysis suggests that in performing Time-Cost Trade-off analysis, it is necessary to determine the cost of decreasing the critical path by one time unit (day, month & etc).

The cost will vary depending upon which activity duration decreased.

Usually, select the activity with least shortening costs. (lowest additional cost per day of shortening) to minimize the additional costs of shortening.
Reducing Project Duration

As the critical path of the network decreased, some non-critical activities lose some amount of their total float.
Reducing Project Duration

Thus, the extent to which an activity can be shortened and still has the effect of shortening the project is limited by the amount of total float exists in the parallel activities.
Reducing Project Duration

As the projects duration decreases, the number of critical paths through the network increases.
Reducing Project Duration

- If more than one critical path exist, it is necessary to reduce all critical paths in the network simultaneously, which becomes expensive.
Four Different Solutions for Each Network

The schedule can be viewed in several different ways in order to satisfy the client. A client may wish to perform the project in the lease cost, or in the least time. Or in any manner satisfies him.

1) **All Normal**: the original network and activity duration result in all normal solution, based on each activity being performed in its “NORMAL” least cost manner.

Remember, it is not necessarily the least cost or least time solution to schedule a project.
Four Different Solutions for Each Network

2) **Least Cost:** considering both direct and indirect costs, it may be possible to find a project duration that minimizes these total costs. By paying more to decrease one or more critical activity (direct cost) and save greater indirect costs. (Means that the result will be total cost saving.)
General relation of project costs to project duration
Four Different Solutions for Each Network

3) **Least Time:** A project can be shortened beyond its least cost duration. Until a point reached where no activities in the critical path can be physically shortened regardless of how many resources are applied. (results in higher costs)
Four Different Solutions for Each Network

4) **All crash**: in this solution, every activity has been shortened as much as physically possible. Its duration the same as the least time solution, but its costs greater. Because the direct cost increases without further reductions in the indirect costs.

A fully crashed schedule occurs when all activities shortened to their shortest possible duration.
Four Different Solutions for Each Network

**All crash**

- It is not an efficient approach since some non-critical activities will be shortened without having any shortening influence on the project duration.
Logically reducing Project Duration

- The logical approach is to shorten those activities that contribute to reduce the project duration.

- To begin the time-cost trade-off in a rational manner, basic calculations needed.

- First compute the early start and early finish times for each activity.
Reducing Project Duration to shortest possible duration
Logically reducing Project Duration

By computing the link lag values between activities. \( \text{Lag} = \text{ES}_B - \text{EF}_A \). It is logical that there is at least one path between the first activity and last activity where lag values are 0.

These activities forming the critical path. (other solution can be derived by computing TF).

In the previous network. Activity A, L forming the critical path.
Logically reducing Project Duration

✧ To shorten the project’s duration it is essential to shorten on of the critical activities. A or B or F or H or L.

✧ Without shortening the project will end after 28 days with a cost of 5300 $.

✧ This is the normal duration cost. And any decrease in duration will increase the direct cost.

✧ The following table shows information about activities.

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<table>
<thead>
<tr>
<th>Activity</th>
<th>Normal Cost per</th>
<th>Normal Shorten</th>
<th>Crash Duration</th>
<th>Normal Days</th>
<th>Crash Days</th>
<th>Cost</th>
<th>Normal Days</th>
<th>Crash Cost</th>
<th>Days to Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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<td>1</td>
<td>1</td>
<td>800</td>
<td>800</td>
<td>0</td>
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</tr>
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<td>B</td>
<td>1600</td>
<td>7</td>
<td>4</td>
<td>1000</td>
<td>1600</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>300</td>
<td>6</td>
<td>4</td>
<td>300</td>
<td>500</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
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<td>2</td>
<td>400</td>
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<tr>
<td>F</td>
<td>50</td>
<td>7</td>
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<td>350</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Identifying activities for 1st compression cycle

Activity | A | B | F | H
---|---|---|---|---
Cost/day | $∞$ | $200$ | $150$ | $250$

Cannot be shortened
At any cost

Least cost activity to shorten

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Logically reducing Project Duration

From the previous table, it can be noticed that activity F has the least incremental shortening cost. (150 $ per day).

E.g. Shortening F for 2 days costs $150 \times 2 = 300$.

Bear in mind, activities for shortening selected based on cost per day. Not cycle cost basis.
Logically reducing Project Duration

❖ How many days activity F could be shortened?

❖ The answer in computing the Network Interaction Limit (NIL).

❖ So, reducing activity F by 2 days will affect the link lag values of the succeeding activities and TF of parallel activities.

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# Summary of the first compression cycle

<table>
<thead>
<tr>
<th>Cycle #</th>
<th>Activity to shorten</th>
<th>Can be shortened</th>
<th>NIL</th>
<th>Days shortened</th>
<th>Cost per day</th>
<th>Cost per cycle</th>
<th>Total cost</th>
<th>Project duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>5300</td>
<td>28</td>
</tr>
<tr>
<td>1</td>
<td>F</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>150 $</td>
<td>300 $</td>
<td>5600</td>
<td>26</td>
</tr>
</tbody>
</table>

9/5/2010

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Identifying activities for 2\textsuperscript{nd} compression cycle

<table>
<thead>
<tr>
<th>Activity</th>
<th>A</th>
<th>B</th>
<th>F</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>$\infty$</td>
<td>200$</td>
<td>$\infty$</td>
<td>250$</td>
</tr>
<tr>
<td>Cost/day</td>
<td>350$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9/5/2010
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## Summary of the 2\textsuperscript{nd} compression cycle

<table>
<thead>
<tr>
<th>Cycle #</th>
<th>Activity to shorten</th>
<th>Can be shortened</th>
<th>NIL</th>
<th>Days shortened</th>
<th>Cost per day</th>
<th>Cost per cycle</th>
<th>Total cost</th>
<th>Project duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>5300</td>
<td>28</td>
</tr>
<tr>
<td>1</td>
<td>F</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>150 $</td>
<td>300 $</td>
<td>5600</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>200</td>
<td>200</td>
<td>5800</td>
<td>25</td>
</tr>
</tbody>
</table>

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Nabil Dmaidi
Identifying activities for 3rd compression cycle

<table>
<thead>
<tr>
<th>Activity</th>
<th>A</th>
<th>B,C</th>
<th>F</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>∞</td>
<td>300</td>
<td>∞</td>
<td>250$</td>
</tr>
</tbody>
</table>

Cost/day

350$

9/5/2010

Nabil Dmaidi
Summary of the 3rd compression cycle

<table>
<thead>
<tr>
<th>Cycle #</th>
<th>Activity to shorten</th>
<th>Can be shortened</th>
<th>NIL</th>
<th>Days shortened</th>
<th>Cost per day</th>
<th>Cost per cycle</th>
<th>Total cost</th>
<th>Project duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>F</td>
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<td>3</td>
<td>2</td>
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<td>300 $</td>
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<td>B</td>
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</table>

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Nabil Dmaidi
Identifying activities for 4th compression cycle

<table>
<thead>
<tr>
<th>Activity</th>
<th>A</th>
<th>B,C</th>
<th>F</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>∞</td>
<td>300</td>
<td>∞</td>
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</tbody>
</table>

Cost/day 350$

9/5/2010

Nabil Dmaidi
## Summary of the 4th compression cycle

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<th>Cycle #</th>
<th>Activity to shorten</th>
<th>Can be shortened</th>
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<th>Days shortened</th>
<th>Cost per day</th>
<th>Cost per cycle</th>
<th>Total cost</th>
<th>Project duration</th>
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</thead>
<tbody>
<tr>
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<td>300 $</td>
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<td>3</td>
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<td>600</td>
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<td>24</td>
</tr>
</tbody>
</table>

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Identifying activities for 5th compression cycle

Activity | A | B,C | F | H
--- | --- | --- | --- | ---
L
Cost/day | $350 | $\infty$ | $\infty$ | $\infty$

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## Summary of the 5th compression cycle

<table>
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<tr>
<th>Cycle #</th>
<th>Activity to shorten</th>
<th>Can be shortened</th>
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<th>Cost per day</th>
<th>Cost per cycle</th>
<th>Total cost</th>
<th>Project duration</th>
</tr>
</thead>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost/day</td>
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<td>(\infty)</td>
<td>(\infty)</td>
<td>(\infty)</td>
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</table>

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Exercise

Reduce the following project to its shortest duration.
## Duration-Cost Data

<table>
<thead>
<tr>
<th>Activity</th>
<th>Normal Duration</th>
<th>Crash Duration</th>
<th>Normal Duration</th>
<th>days to Cost</th>
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<tr>
<td>A</td>
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<td>0</td>
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<td>500</td>
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<td>20</td>
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<tr>
<td>C</td>
<td>6</td>
<td>300</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>400</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>E</td>
<td>9</td>
<td>200</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>100</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>G</td>
<td>9</td>
<td>320</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>H</td>
<td>5</td>
<td>410</td>
<td>1</td>
<td>90</td>
</tr>
</tbody>
</table>
A 16
B 6 16
   10
   25
C 6 16
   12
D 6 14
   8
   14
E 16 10
   9
   25
F 14 20
   6
G 14 23
   9
H 25 30
   5
   0

ES  Dur.  LS
EF  FF  TF  LF
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Identifying activities for 1\textsuperscript{st} compression cycle

<table>
<thead>
<tr>
<th>Activity</th>
<th>A</th>
<th>B</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost/day</td>
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<td>30</td>
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9/5/2010

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## Summary of the 1st compression cycle

<table>
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<tr>
<th>Cycle #</th>
<th>Activity to shorten</th>
<th>Can be shortened</th>
<th>NIL</th>
<th>Days shortened</th>
<th>Cost per day</th>
<th>Cost per cycle</th>
<th>Total cost</th>
<th>Project duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>--</td>
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<td>--</td>
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<tr>
<td>1</td>
<td>B</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>20</td>
<td>40</td>
<td>2370</td>
<td>28</td>
</tr>
</tbody>
</table>

9/5/2010

Nabil Dmaidi
Identifying activities for 2\textsuperscript{nd} compression cycle

<table>
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<tr>
<th>Activity</th>
<th>A</th>
<th>B,D</th>
<th>E,G</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>∞</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Cost/day</td>
<td>70</td>
<td>90</td>
<td></td>
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9/5/2010

Nabil Dmaidi
## Summary of the 2\textsuperscript{nd} compression cycle

<table>
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<th>Cycle #</th>
<th>Activity to shorten</th>
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<th>NIL</th>
<th>Days shortened</th>
<th>Cost per day</th>
<th>Cost per cycle</th>
<th>Total cost</th>
<th>Project duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>2330</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>20</td>
<td>40</td>
<td>2370</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>E,G</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>70</td>
<td>140</td>
<td>2510</td>
<td>26</td>
</tr>
</tbody>
</table>
## Identifying activities for 3\textsuperscript{rd} compression cycle

<table>
<thead>
<tr>
<th>Activity</th>
<th>A</th>
<th>B,D</th>
<th>E,G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/day</td>
<td>∞</td>
<td>120</td>
<td>∞</td>
</tr>
<tr>
<td></td>
<td>90</td>
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</table>

9/5/2010

Nabil Dmaid
Summary of the 3\textsuperscript{rd} compression cycle

<table>
<thead>
<tr>
<th>Cycle #</th>
<th>Activity to shorten</th>
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<th>Days shortened</th>
<th>Cost per day</th>
<th>Cost per cycle</th>
<th>Total cost</th>
<th>Project duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>--</td>
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<td>--</td>
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<td>--</td>
<td>2330</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>20</td>
<td>40</td>
<td>2370</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>E,G</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>70</td>
<td>140</td>
<td>2510</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>H</td>
<td>1</td>
<td>∞</td>
<td>1</td>
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<td>90</td>
<td>2600</td>
<td>25</td>
</tr>
</tbody>
</table>

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\[\text{Cost per day:} \frac{\text{Total cost}}{\text{Project duration}}\]
Identifying activities for 3\textsuperscript{rd} compression cycle

<table>
<thead>
<tr>
<th>Activity</th>
<th>A</th>
<th>B,D</th>
<th>E,G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/day</td>
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Nabil Dmaidi
Summary of the 4th compression cycle

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<th>Cost per day</th>
<th>Cost per cycle</th>
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<th>Project duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>--</td>
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<td>--</td>
<td>2330</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
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<td>40</td>
<td>2370</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>E,G</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>70</td>
<td>140</td>
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<td>26</td>
</tr>
<tr>
<td>3</td>
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<td>1</td>
<td>120</td>
<td>120</td>
<td>2720</td>
<td>24</td>
</tr>
</tbody>
</table>

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Communicating the Schedule
Communicating the Schedule

**Anticipated User**
- Top management - No need for great details
- Middle Management - looking for detailed breakdown covering long time span.
- Low-level Management - Superintendents, foreman - detail information, cover short period of time.

**Communicating Devices**
- Verbal and written instructions and reports
- Tabular format
- Graphical representation
  - bar chart
  - time scaled
Time-Scaled Arrow Diagram
Remodeling Chemical Laboratory
Schedule Updating & Project Control

 Updating Schedules:

- Why update projects
- Definitions: Project control, Baseline schedules, Data Date
- Steps for project updating
- Hints for Creating and Storing Updates
- Example for updating a schedule

 Project Control and Earned Value Analysis

- Percent complete
- Measuring Work Progress
- Earned Value Analysis
Why Update Schedules?

- Schedules (like cost estimates) are always prepared before the project begins. However, updates must take place routinely for the following two reasons:
  - Unintentional events
  - Intentional changes

- Schedules without updating, monitoring, controlling, and corrective action are useless
Schedule Updating: Definitions

- An updated schedule is “A revised schedule reflecting project information at a given data date regarding completed activities, in-progress activities, and changes in the logic, cost, and resources required and allocated at any activity level.”

- Data Date: The date as of which all progress on a project is reported
  - It is also called as-of-date or status date
  - It is NOT current date or time now
Schedule Updating: Info Needed

- When updating, the following information must be reported. This include two main categories:

- Past: What has happened since last update such as:
  - Activities that have started, their actual start date, percent complete and/or remaining duration
  - Activities that are completed and their actual completion date
  - Actual budget spending or resource consumption for each activity
Schedule Updating: Info Needed-2

Future: Any changes to the schedule or to schedule-related items such as:

- Activities that have been added, along with their information (duration, logic, budget, resources, constraints, etc.)
- Any activities that have been deleted
  - Be careful!
- Activities that have changed in duration, logic, budget, resources, constraints, codes, or any other change
Schedule Updating: Info Needed-3

Future (continued):

- Any change to the “imposed finish date” for the entire schedule or the constraint date for certain milestones
- Any schedule-related, but not activity-specific change such as:
  - cost and availability of resources,
  - change in calendar work days,
  - change in responsibility
Updating Schedule: The Interval

Current Data Date:
- Anything left to this line is past.
- Anything right to this line is future.
Steps for Updating a Schedule

1. The Schedule activity list
   - Filter out completed activities
   - Eliminating activities in the far future?
   - Scheduler sends it to the project PM / superintendent
   - Possibility that PM/superintendent wants to change past events
### Example 1: No Cost

<table>
<thead>
<tr>
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<th>Activity Description</th>
<th>Orig Dur</th>
<th>Rem Dur</th>
<th>% Comp</th>
<th>Early Start</th>
<th>Actual Start</th>
<th>Early Finish</th>
<th>Actual Finish</th>
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9/5/2010

Nabil Dmaidi
### Traffic Control

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### Northbound Outer Lane

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<th>Actual Start</th>
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<th>Cost to Date</th>
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</table>
Steps for Updating a Schedule-2

2. The PM (or superintendent) fills up the form, signs and dates it; and submits it back to the scheduler
   ✓ It is a good idea for the PM to keep a copy for his/her records
   ✓ It is a good idea to assign “ink colors” to different parties

3. The scheduler enters the info in the computer and updates the project, signs and dates the forms
Steps for Updating a Schedule-3

4. The scheduler prints a preliminary report and discusses it with the PM

✓ It is a good idea to produce a summary report (what happened between last update and this update)

✓ Based on this discussion, the scheduler makes any necessary adjustments to the schedule or reports

✓ Any changes to the schedule requested by the PM have to be documented by the scheduler
Steps for Updating a Schedule-4

5. The scheduler produces new (final) reports
   - different reports for different parties
   - If the scheduler receives info on changes in between two updates:
     - Waits till the next update, or
     - Makes a special update
Myths/Misconceptions About Schedule Updating

- We always produce a complete schedule before the commencement of construction. We just don’t update it, We trust our field staff and subcontractors to follow it
- We update projects only when there is a “need” for the update
- Everything is going well. There is no need for an update
True or False:

1. Updating is needed for projects that have duration of at least one year or a minimum budget of QAR 10 million
2. Data date is the date all information was entered in the computer
3. In updating schedules, we must enter not only actual work progress but also any future changes
4. Negative float is an indication that the schedule is not meeting its expected completion date or an interim imposed date
Project Control
What is Project Control?

- Project control is the continuous practice of:
  1. monitoring work progress,
  2. comparing it to baseline budget and schedule,
  3. detecting any deviations and their causes, and
  4. taking a corrective action wherever and whenever necessary.

- The ability to determine a project status as it relates to the time and schedule selected.

- Also called project tracking:
  - Project monitoring?
Why Project Control?

- Project control is needed because projects never run exactly as planned.
- Project control is a cyclical iterative task: do small part of the work and compare to baseline, do corrective measure, adjust plan (if needed), do another part of the work, and so on.
- Project control requires measuring work progress and calculating activities percent complete.
Baseline Schedule

Baselines: The original approved plan for a project including approved changes. It usually includes Baseline Budget and Baseline Schedule. It is used as a benchmark for comparison with actual performance.

Baseline Budget: The project’s original approved budget including any approved changes.

Baseline Schedule: A schedule prepared by the contractor before the start of the project – and usually approved by the owner – typically used for performance comparison.
Percent Complete

- Percent Complete (PC or PCT): is an estimate, expressed as a percent, of the amount of work that has been completed on an activity or a work breakdown structure component. (PMBOK 2008)

- Percent complete may be used to estimate:
  - Activity
  - Groups of activities / assembly / work package
  - Project
Types of Percent Complete

Depending on the type and nature of the activity, percent complete may be calculated using one of several methods that may yield different results:

- Some methods are more subjective than others.
- None of these methods is wrong. None of them is uniquely considered the right method.

Most importantly:

- Know exactly what each percent complete means.
- Pick one or two parameters to use and then be consistent.
Project Control

Major objectives for a good control plan:

1. Should accurately represent the work.
2. Permit deviations to be detected, evaluated and forecasted.
3. Should make provision for periodic corrective actions.
Level of Control

- Small projects - low cost - short duration
  - Detailed network
  - Reporting mechanism

- Middle-sized projects (300 activities)
  - Detailed network
  - Summary network
  - Area and craft network
Target Activities Properties

The scheduler has to choose between early start schedule or target schedule.

Two Major Considerations:

1. The way in which the resources are applied to the activity.
2. The manner in which the activity is to be measured.

In all the previous work we assumed that each activity has a constant rate of utilization.
We will keep this assumption knowing that the most probable one is

- **If an activity has expended a third of its cost, the activity is said to be one-third finished.**

- **The most important consideration in measuring the completion of activities is that the measure should be consistent throughout the project.**
Target Activity Durations

(a) As assumed

(b) Probably as practiced

(c) Decreasing resource rates

(d) Increasing resource rates

(e) Variable resource rates
Monitoring the Project

1. Feedback from direct contact
   ■ Efficient but requires close cooperation between the manager and field personnel.
2. Feedback from photography

- Record progress and provide permanent documentation of the work.
- Tell nothing about the time taken to perform the work.
Monitoring the Project (cont.)

3. Feedback from check-off list

- Planner prepares a check-off list that is started, to be continued, or to be finished in the next time interval.
- Effective if the reporting periods are short “Daily, Weekly” and small number of activities involved.
- Disadvantage: false reporting
Monitoring the Project (cont.)

4. Feedback from bar chart

5. Feedback from networks

**Advantage:**

Superintendent has complete information about the status of the project.

**Disadvantage:**

Diagram may appear confusing to field personnel.

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Setting the Target Schedule

Early Start Schedule: As Target for Control

- Problem:
  Required high effort to keep the plan working

Late Start Schedule As Target for Control

- Problem:
  Because every activity is timed to start as its latest, project overruns are sure to follow.
Target Schedule

- Activities may be positioned early or late start or somewhat in between.
- Non-critical activities allow intermediate start.
Anticipated target S-Curve
The S-Curve field
Sample Project Cost Data

<table>
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<td>1,000</td>
<td>1,100</td>
</tr>
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</table>

4909/5/2010

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Early Start Tree

A 2
B 17
C 3
D 5
E 6
F 2
G 1

FF = 0
TF = 0
FF = 0
TF = 0
FF = 2
TF = 8
FF = 0
TF = 6
FF = 0
TF = 6
FF = 10
TF = 10

2
2
5
2
7
2
7
9

20
19
13
6
19
2

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Late Start Tree

TF = 0

TF = 0

TF = 0

TF = 0

TF = 0

TF = 0

TF = 0
Target Network
Actual Versus Target S-Curves
Earned Value Analysis
Earned Value Analysis

- Earned Value (EV) Analysis: Earned Value analysis is an integrated cost-schedule approach to monitor and analyze the progress in a project.

- Earned Value Management (EVM), started in the 1960’s as a method for integrated project cost and schedule control, was designed by the U.S. Air Force and named the Cost/Schedule Planning and Control System.

- In 1967, it became U.S. DOD policy and was renamed Cost/ Schedule Control Systems Criteria, or C/SCSC.
The Concept of EVM

The concept of Earned Value is simple; at any given point find out:

1) The cost of work you have actually done (ACWP),
2) The cost of work you planned to do by this date (BCWS),
3) The amount earned for work performed (BCWP),
4) Calculate schedule and budget variances (SV, CV)
5) Analyze causes for major variances and suggest remedies,
6) Extrapolate these variances to the end of the project (FSV, FCV)
Earned Value Analysis (EVA)

Foundations of modern cost control

What’s more important?

- Knowing where you are on **schedule**?
- Knowing where you are on **budget**?
- Knowing where you are on **work accomplished**?

Earned Value Analysis (EVA) addresses all three:

- It compares the PLANNED amount of work with what has actually been COMPLETED to determine if COST, SCHEDULE, and WORK ACCOMPLISHED are progressing as planned.
EVA Terminology

◆ **BCWS – Budgeted Cost of Work Scheduled**
  - Planned cost of the total amount of work scheduled to be performed by the milestone date. (a.k.a. your original plan)

◆ **BCWP – Budgeted Cost of Work Performed**
  - The planned (not actual) cost to complete the work that has been done.
  - Also known as “Earned Value”

◆ **ACWP – Actual Cost of Work Performed**
  - Cost incurred to accomplish the work that has been done to date.

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Input data for EVA

- Activity schedule, usually in the form of a bar chart.
- Budgeted cost for each activity.
- Percent complete for each activity.
- Cost to date for each activity.
Information Needed to Compute

- **Budgeted Cost of Work Scheduled (BCWS)**
  - Activity budget at completion (BAC)
  - Activity schedule
  - Data date

- **Budgeted Cost of Work Performed (BCWP)**
  - Activity budget at completion (BAC)
  - Physical activity progress as a percentage of its total work

- **Actual Cost of Work Performed (ACWP)**
  - Each activity’s cost to date from the job costing system

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Earned Value Reporting - Costs

- **Budgeted Cost of Work Performed (BCWP)** = earned value of project
- **Actual Cost of Work Performed (ACWP)**
- **Cost Variance (CV)**
  - Difference between earned and actual costs for the completed work
- **Cost Performance Index (CPI or CI)**

\[ CV = BCWP - ACWP \]

\[ CPI = \frac{BCWP}{ACWP} \]

- CPI = 1, on budget
- CPI < 1, over budget
- CPI > 1, under budget

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Earned Value Reporting - Schedule

- **Budgeted Cost of Work Performed (BCWP)**
- **Budgeted Cost of Work Scheduled (BCWS)**
- **Schedule Variance (SV)**
  
  Difference between the value of work that was planned for completion and the value of the work that was actually completed

- **Schedule Performance Index (SPI) or SI**
  
  \[ SV = BCWP - BCWS \]

\[ SPI = \frac{BCWP}{BCWS} \]

- SPI = 1, on schedule
- SPI < 1, behind schedule
- SPI > 1, ahead of schedule
Earned Value Reporting

Cost

Time

Current date

BCWS (budgeted)

Schedule variance

Cost variance

(earned)

BCWP

ACWP (actual)
Example:
A simple problem will help to illustrate the application of the principles of earned value. A project has been defined that consist of 12 activities for which the estimated cost and duration have been defined see figure. After three and a half month, the activates 1,2,4,5,7 are completed and (6) is one half complete and (8) is three – fourth complete and (3) is half complete. The incurred cost to date are 152000$. What is the status of this project in terms of the schedule and the budget?
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</table>
Solution:
ACWP = 152000$

BCWS = 22000 + 30000 + 50000 + 10000 + 18000 + 0.5(40000 + 6000 + 16000) = 161000$

BCWP = 22000 + 30000 + 50000 + 10000 + 6000 + 0.5(40000) + 0.75(16000) + 0.5(18000) = 159000$

SV = BCWP - BCWS = -2000$ its behind schedule

CV = BCWP - ACWP = 7000$ below the budget

EAC = ACWP + (BAC - BCWP) = 152000 + (257000 - 159000) = 250000$

9/5/2010 Nabil Dmaidi
# Earned Value Reporting – Activity A Example

<table>
<thead>
<tr>
<th>Week</th>
<th>BCWS</th>
<th>BCWP</th>
<th>ACWP</th>
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<tbody>
<tr>
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<td>500</td>
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<tr>
<td>2</td>
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</table>

9/5/2010

Nabil Dmaidi
**Earned Value Reporting – Activity B Example**

<table>
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<th>BCWP</th>
<th>ACWP</th>
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<tbody>
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<td>4</td>
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9/5/2010

Nabil Dmaidi
## Earned Value Reporting – Activity C Example

<table>
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<th>BCWP</th>
<th>ACWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>2</td>
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<tr>
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</table>

![Graph showing BCWS, BCWP, and ACWP for Activity C Example]
### Earned Value Reporting – Project (Activities A, B, C)

**Example**

<table>
<thead>
<tr>
<th>Week</th>
<th>BCWS</th>
<th>BCWP</th>
<th>ACWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2114</td>
<td>1800</td>
<td>2314</td>
</tr>
<tr>
<td>2</td>
<td>2114</td>
<td>1900</td>
<td>2186</td>
</tr>
<tr>
<td>3</td>
<td>2114</td>
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<td>1800</td>
</tr>
<tr>
<td>4</td>
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</table>

**Graph**

![Graph showing BCWS, ACWP, and BCWP lines over weeks.](image-url)
Earned Value Reporting – Project (Activities A, B, C) Example

<table>
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<th>Week</th>
<th>BCWS</th>
<th>BCWP</th>
<th>ACWP</th>
<th>CI</th>
<th>SI</th>
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<tr>
<td>1</td>
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Schedule index, SI

Cost index, CI
Graph shows trend of cost and schedule indices.
## Class Exercise: BCWS

### Schedule and Estimated Costs

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<tr>
<th>Task</th>
<th>Est. Cost</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
<th>Week 9</th>
<th>Week 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization</td>
<td>2,000</td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Grubbing</td>
<td>5,000</td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridge Excavation</td>
<td>2,000</td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Install Prefabricated</td>
<td>47,000</td>
<td></td>
<td>25%</td>
<td>25%</td>
<td>25%</td>
<td>25%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Bridge</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back Fill Bridge</td>
<td>2,000</td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install Culverts</td>
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<td></td>
<td></td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Rough Excavate Roadway</td>
<td>112,000</td>
<td>25%</td>
<td>25%</td>
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<td>25%</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Install Sanitary Sewer</td>
<td>57,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50%</td>
<td>50%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install Water Lines</td>
<td>69,000</td>
<td></td>
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<td></td>
<td></td>
<td>50%</td>
<td>50%</td>
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<td></td>
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</tr>
<tr>
<td>Install Storm Drains</td>
<td>15,000</td>
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<tr>
<td>Grade and Roll Sub Grade</td>
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<td>50%</td>
<td>50%</td>
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<tr>
<td>Place and Compact Road</td>
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<tr>
<td>Place and Compact Asphalt</td>
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<tr>
<td>Grade Shoulders</td>
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<tr>
<td>Demobilize</td>
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</tbody>
</table>

**Cost wk using estimate & schedule:**

- 9/5/2010: 429,000
- 7/00: 51,000
- 5/8000

**Budgeted Cost of Work (BCWS):**

- 9/5/2010: 55,500
- 9/6,000
- 9/000

Example:

\[
10,000 \times 100\% + 112,000 \times 25\% = 38,000
\]
# Class Exercise: BCWP

## Actual Percent Performed per Week

<table>
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<tr>
<th>Task</th>
<th>Est. Cost</th>
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<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
<th>Week 9</th>
<th>Week 10</th>
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<td>90%</td>
<td>10%</td>
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<td></td>
</tr>
<tr>
<td>Grubbing</td>
<td>5,000</td>
<td>100%</td>
<td></td>
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<tr>
<td>Bridge Excavitation</td>
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<td>100%</td>
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<tr>
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<td>47,000</td>
<td>90%</td>
<td>10%</td>
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<td></td>
</tr>
<tr>
<td>Back Fill Bridge</td>
<td>2,000</td>
<td>90%</td>
<td>5%</td>
<td>5%</td>
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<td></td>
<td></td>
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<tr>
<td>Install Culverts</td>
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<td>30%</td>
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<td>Install Sanitary Sewer</td>
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<td>20% 50%</td>
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<tr>
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<tr>
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<tr>
<td>Place and Compact Road Base</td>
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</table>

Data Date: 9/5/2010

Nabil Dmaidi
# Class Exercise: ACWP

## Actual Costs

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<tr>
<th>Task</th>
<th>Actual Cost</th>
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<th>Week 3</th>
<th>Week 4</th>
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<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
<th>Week 9</th>
<th>Week 10</th>
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<td>32,033</td>
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<tr>
<td>Grade and Roll Sub Grade</td>
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<tr>
<td>Place and Compact Road Base</td>
<td>40,298</td>
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<tr>
<td>Place and Compact Asphalt</td>
<td>48,835</td>
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**Data Date:** 9/5/2010

Nabil Dmaidi
## Class Exercise: SPI and CPI

### Performance Indexes

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<th>Week 1</th>
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<td>110.43%</td>
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9/5/2010

Nabil Dmaidi
Rolling Up EVA Measures

[Diagram showing a hierarchical structure with Top Project Summary at the top, Intermediate Summary Levels, and Management Control Cells, with WBS Elements and Functions at different levels, and Cost Accounts at the bottom.]
EVA: The Curve

Budget ($ or MH) vs. Date

- BCWS
- SV ($)
- CV
- ACWP
- BCWP
- SV days

Data Date


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Quiz 7

True or false:

1. Project control is to be practiced by both contractor and owner
2. Project monitoring is part of project control
3. For assistance in calculating progress payments, percent complete for the project is more important than percent complete of individual activities
4. It is possible that different parties compute the “project percent complete” and come up with different estimates, yet none of them is wrong!
5. It is possible to have the scheduler report saying the project is behind schedule while the earned value analysis is showing a positive schedule variance.
Construction Delay Claims
Major Topics

- Introduction and Definition.
- Delay Claims and Change Order.
- Reasons for Delay Claims
- Types of Delays Resulting in Claims.
- Delay-Claims Prevention.
- Project Schedule Documentation.
- Delay-Claims Resolution.
- The Importance of CPM Schedule in Delay Claims.
- Methods of Schedule Analysis.
- Float Ownership.
INTRODUCTION AND DEFINITION

- **A DELAY** is an event or a condition that results in finishing the project later than stipulated in the contract.

- **A CLAIM** is a request from one contracting party (contractor) to another party for additional compensation, a time extension, or both.

- If we put the two terms together, a delay claim simply means a claim related to delay.
Claims may be initiated by any project participant against any other participant. An architect may file a claim against an owner or vice versa. A supplier may file a claim against a contractor or the owner and so on.

A claim is not always a negative action, nor does it automatically indicate a confrontation. Many claims are legitimate and are routinely resolved to the satisfaction of both parties.
A delay claim may ask for a time extension, monetary compensation, or both. Delays that result in claims are classified as excusable, non excusable and concurrent.
A claim for only monetary compensation often forms the basis for a change order (CO). A CO may be initiated at the request of the owner, contractor, sub contractor and so on. For example, an owner may want to change the color of the walls, the type of floor tile, or the type of light fixtures from that specified in the contract. In this case owner should submitting a request for quotation (RFQ).
To minimize the number of COs, owners should do a thorough job of defining the scope of the project and selecting a competent designer. Many projects suffer from scope-creep syndrome, in which COs keep adding to the project budget and put it at levels far beyond what the owner originally planned.
REASONS FOR DELAY CLAIMS

Claims usually occur because of unexpected events or development, regardless of who is at fault.
Unlike projects in other industries, no two construction projects are the same. Even when two projects have the same design and are performed by the same company, they may differ with regard to site conditions, climate, regulations, subcontractors, market condition, and team members. When the projects are substantially similar, a claim may arise during any construction project for several reasons.
Differing site conditions

A contractor may initiate a claim if the actual site conditions differ from those mentioned in the contract documents. For example, existing of ground water that are not mentioned in contract document, or differing in soil types that are not mentioned in geological report.

Design Errors or omissions

Errors or omissions in the design require the contractor to perform additional work than originally contemplated. However, not all design errors or emissions from the basis for a compensable claim. Judges have rejected some claims when an error was patently obvious and a construction professional could have discovered it during the bidding or negotiation phase.
CONT...

- **Changes in Owner’s Requirements**
  
  Changes in the owner’s requirement may constitute in the contract and provide a foundations for COs.

- **Unusually Adverse Weather**

- **Miscellaneous Factors**
  
  Failure of the owner to provide a project site, a late notice to proceed (NTP), labor strikes, a delay in the delivery of the owner’s furnished equipment.
**Force Majeure**

This term usually involves three important elements:

1. sth superior, over whelming, or overpowering (can not be prevented).
2. sth unexpected or cannot be reasonably anticipated or controlled.
3. sth destructive or disruptive effect on the construction process.

Examples: earthquakes, hurricanes, tornados, wars
TYPES OF DELAYS RESULTING IN CLAIMS

1) **Excusable delays**: it entitles the contractor to additional time to complete the contract work.
   
   a) Non-compensable delays: it is beyond the control and not the fault such as weather conditions, natural disasters, wars...
   
   b) Compensable delays: caused by the owner or the designer.

2) **Non excusable delays**: it caused by contractor and does not entitle the contractor to either a time extension or monetary compensation.

3) **Concurrent delays**: involves a combination of two or more independent causes of delay during the same period. Often, a concurrent delay involves an excusable delay and non excusable delay.
DELAY-CLAIMS PREVENTION

1) Baseline schedules that do not show logic.
2) Baseline schedules with dates rather than logic.
3) Overuse of constraints.
4) “Erasing Footprints”.
5) Unrealistic baseline schedule.
6) Schedules with logic errors.
7) Skipping periodic updates.
8) Lack of proper documentation.
9) Lack of a reasonable time contingency.
Documentation generally means saving the information in an organized manner for possible future retrieval.

For delay claims prevention and resolution the following 14 pieces of information must be documented:

1) The project baseline schedule that the owner accepted.

2) Periodic schedule updates.
3) Change orders.

4) project manager's daily log, includes information such as:
   a) weather conditions.
   b) Work performed during that day.
   c) The number of workers on-site (including work and overtime hours).
   d) Equipment on-site and its condition.
   e) Any material delivered to the site.
   f) Materials used and stored on-site.
   g) Any telephone calls.
   h) Any visitors to the site.
   i) Any accidents that occurred on-site.
   j) Any other events that may be related to the project.
5) Job diary, contain personal observations, suggestions, and opinions.

6) Submittal records, such as shop drawings and material samples.

7) Records of any transmittals.

8) Correspondence with the owner, architect or engineer, subcontractors, vendors and suppliers, and other contracting parties.
9) Correspondence with the home office.
10) Meeting minutes. subject, date, location of meeting, names of people.
11) Procurement records: materials and equipment orders.
12) Government records include permits, code nonconformance reports, and (OSHA) forms and citations.
13) Record of payments (owner to general contractor and general contractor to subcontractors and vendors).
14) Photos of important events.
DELAY-CLAIMS RESOLUTION

The following five methods are usually used in resolving claims:

1) **Negotiation**, it is the most direct method for resolving any type of construction claim.

2) **Mediation**, When negotiation does not work due to lack of trust or a lack of skills, mediation may be an option. A mediator may be an individual or a team.

3) **Dispute review boards (DRBs)**: it resolve disputes as they arise rather than waiting until the end of a project to settle claims.

4) **Arbitration** defined by the (AAA) as a "referral of a dispute to one or more impartial persons for final and binding determination.

5) **Litigation**: the last resolution that can be followed to go to judges and it is lengthy and expensive.

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THE IMPORTANCE OF CPM SCHEDULE IN DELAY CLAIMS

CPM schedules are important in delay claims because, on the one hand, the claimant usually provides at least two CPM schedules—one without the impact of the change and one with the impact—in an attempt to prove that the change caused the claimed delay. On the other hand, the investigator builds several CPM schedules, each representing one factor isolated from other factors, to show exactly how much of the alleged delay, if any, can be attributed to the change.
METHODS OF SCHEDULE ANALYSIS

- **As-Build schedule**: reflect what actually happened in the field, activities plotted by their real start and finish with no logic ties.

- **Updated impacted schedule**: The original schedule is updated with progress information and then compared with impacted completion date on another schedule on which a delay is included.

- **As-Planned schedule**: describes the manner in which the contractor intended to build the project.
Comparison schedule: based on comparing two schedules for a delay claims, one without the causative factors and another with causative factors (impacted schedule)

Accelerated schedule: the contractor try to collect the cost associated with the acceleration of the project so he can finish by contract finish date. The owner make sure that the contractor used all available float without crashing any schedule.

Recovery schedule: same as accelerated schedule in trying to compress the schedule to finish in the certain time
Float (sometimes called slack) may be defined technically as the maximum amount of time an activity can be delayed from its early start date without delaying the entire project.

In the next example owner issued a work order to the contractor that would delay the start of activity E till day 16(LSD), would the contractor be entitled a time extension, compensation, both or neither?
FIGURE 12.1  Logic network for example 12.1
EXAMPLE 12.1 solution

- We see that activities C, E and F have total float 5, 3 and 8 respect.
- Now see the schedule as bar chart.

![Bar chart for example 12.1, showing float](image)
CONT EXAMPLE 12.1

Assume these three activities require the same crew, for the most efficient use of crew contractor choose the plan shown which indicates that all activities are critical.

FIGURE 12.3 Final plan for example 12.1
Linear Scheduling Method
Linear Scheduling Method

Definition

A simple diagram to show location and time at which a certain crew will be working on a given operation.
Characteristics

- Shows repetitive nature of the construction.
- Progression of work can be seen easily.
- Sequence of different work activities can be easily understood.
- Have fairly high level of detail.
- Can be developed and prepared in a shorter time period than other formats.
Advantages of LSM

- Provides more information concerning the planned method of const. than a bar chart.
- In certain types of projects, LSM offers some advantages over the network approach.
Line of Balance Technique

- LSM has relationships to the line of balance (LOB) technique, developed by US. Navy in the early 1950s.
- First applied to industrial manufacturing and production control.
Three diagrams are used in LOB:

1. Production Diagram
   Shows the relationships of the assembly operations for a single unit. Similar to AOA, except that it shows only one unit of production.

2. Objective Diagram
   Used to plot the planned or actual number of units produced vs. time. LSM diagram resembles this diagram.

3. Progress Diagram
   Shows the number of units for which each of the subassembly operations has been completed.
Difference between Objective Diagram and LSM:

- **O.D.** is used to schedule or record the cumulative events of unit completion.
- **LSM** is used to plan or record progress on multiple activities that are moving continuously in sequence along the length of a single project.
Implementation of LSM

- Can be used for continuous activities rather than discrete activities.
- Transportation projects; highway const., highway resurfacing and maintenance, airport runway const. and resurfacing, tunnels, mass transit systems, pipelines, railroads.
- High-rise building construction
- Repetitive building units
Elements of the LSM

- **Axis Parameters**
- **Location**
- Measure of progress.
- In high-rises and housing const., measures may be stories, floors, subdivisions, apartments, housing units.
- In Transportation projects, distance (ft. or mile can be used, but division by stations (100ft.) is common) is general.
Time

- Hours, days, week, or month - depends on the total project time and level of detail desired in the schedule.
- Preferable to prepare the schedule based on working days and convert to calendar days only at the end.
Activity Production Rates

- Obtained by the usual estimating methods as a function of the activity, equip. characteristics, labor, and job conditions.

- The initial rate should be associated with the min. direct cost of accomplishing the single activity.
Activity Interruption and Restraint

- Prod. rate may vary with locations or time periods.
- Progress may be interrupted intentionally and restraints may occur between activities due to limited equip. or crews.

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Buffers

- When const. activities progress continuously in a chain, some spacing between activities is required.
- This spacing serves as a buffer and may require distance or time interval between activities.
Activity Intervals

- Used to describe the period of time between the start and finish of an activity at a particular location.
- Intervals can be indicated by a broad line, two narrow lines, etc.
- Monitoring Progress
- Working calendar can be marked with a moving symbol or a line, tape, etc. vertically across the diagram.
- Progress on individual activities would be marked by location rather than time.
1. Project Time Optimization

- The total project time may be such that indirect costs and liquidated damages assessed are more costly than the expense of accelerating certain activities.

- Cost-duration analysis can be used to minimize the total cost, as follows:
a) Identify all activities that can be accelerated or decelerated.

b) Among the above, consider only those that are at a buffer limitation at both the start and the finish of the activity.

c) Of these, select the one activity with the lowest cost slope associated with acceleration (or deceleration).

d) Accelerate (or deceleration) the activity rate of production the maximum feasible amount.

e) Repeat the above steps successively until the optimum project cost and associated duration are obtained.
2. Discrete Activities

Discrete are best scheduled by other methods. Once the duration is determined by network analysis, it can be scheduled on the LSM diagram and coordinated with the linear activities.

3. Seasonal Adjustments

When developing LSM, appropriate adjustments can be made for seasonal effect on construction progress.
4. Project Progress and Resource Management

- Project progress is often estimated by the S-curve with bar chart development.

- In LSM, the determination of activity progress is facilitated and made more rigorous.
LSM Schedule

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LSM Schedule with Brickwork

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Four-unit Duplex I-J
Fragnet

EXC FNDS BLDG 1
F&P FNDS & SLAB BLDG 1
FRAME BLDG 1

EXC FNDS BLDG 2
F&P FNDS & SLAB BLDG 2
FRAME BLDG 2

EXC FNDS BLDG 3
F&P FNDS & SLAB BLDG 3
FRAME BLDG 3

EXC FNDS BLDG 4
F&P FNDS & SLAB BLDG 4

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LSM Schedule

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