Construction Knowledge

- 4 – 6 problems
  - Construction documents
  - Procurement methods
  - Project delivery methods
  - Construction operations and methods
  - Project scheduling
  - Project management
  - Construction safety
  - Construction estimating
- Sections in FE Reference Handbook
  - Civil Engineering
  - Industrial & Systems Engineering

Construction Management, Scheduling, & Estimating

- Project Management
- Cost Estimating
- Scheduling
- Activity on Node Networks
- Activity on Arrow Networks
- Monitoring
- Coordinating
- Critical Path Models
- Earned Value Method
- Solving a CPM Problem with an Activity on Node Network

Project Management

- Coordination of the entire process of completing a job, from its inception to final move-in and post-occupancy follow-up
- A Guide to the Project Management Body of Knowledge (PMBOK Guide)
  - Process-based
  - Each process occurs within one of the five process groups
Cost Estimating

- Determine all factors influencing costs
  - Include all fixed costs, variable costs, overhead, or direct material costs and direct labor costs, and profit.
  - All materials,
  - equipment,
  - tools,
  - labor,
  - and incidentals required to complete the item;
  - and for all risk, loss, damage, or expense arising out of the nature or the performance of the work.

Scheduling

Project Schedule

- Engineering/architect has control over design & production of contract documents
- Contractor has control over construction

Construction Sequencing

For the sake of reducing on-site erosion and off-site sedimentation that might affect water resources, construction sequencing is an important concept that seeks to balance timing/sequencing of land disturbance activities with the installation of ESC/EPSC measures.
Fast Tracking

Traditional Construction Process

Fast-Track Construction Process

Schedule Management

Resource Leveling

Activity-on-Node Networks

- Critical path method (CPM) requires all activity durations to be specified by single values:
  - Deterministic method
  - Each activity (task) is represented by a node (junction)
  - Each activity is connected by arcs (connecting arrows, lines, etc.)
    - Arcs have zero (0) duration

- CPM graph depicts the activities required to complete a project and the sequence in which the activities must be completed
  - No activity can begin until all of the activities with arcs leading into it have been completed

Nomenclature
- ES = Early start
- LS = Late start
- EF = Early finish
- LF = Late finish
- FS = Latest finish of predecessor
- LS = Latest start
- DF = Date of finish
- RF = Date of release
- D = Duration
- Float = LS - ES or LF - EF

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Solving a CPM Problem with an Activity-on-Node Network

1. Place the project start time or date in the ES and EF positions of the start activity. The start time is 0 for relative calculations.
2. Consider any unmarked activity, all of whose predecessors have been marked in the EF and ES positions. (Go to #4 if none.) Mark in its ES position the largest number marked in the EF position of those predecessors.
3. Add the activity time to the ES time and write this in the EF box. Go to #2.
4. Place the value of the latest finish date in the LS and LF boxes of the finish mode.
5. Consider unmarked predecessors whose successors have all been marked. Their LF is the smallest LS of the successors. Go to #7 if there are no unmarked predecessors.
6. The LS for the new mode is LF minus its activity time. Go to #5.
7. The float for each node is LS-ES and LF-EF.
8. The critical path encompasses nodes for which the float equals LS-ES from the start node. There may be more than one critical path.

Activity-on-Arrow Networks

- Duration of a project = the sum of all durations of activities on the critical path
- Activity duration is notated by activity-on-arrow network

Activity-on-Arrow Networks Example

An activity-on-arrow diagram for a project is

If the critical path is B-E-G-J-K, what is most nearly the duration of the project?
- (A) 30 days
- (B) 24 days
- (C) 30 days
- (D) 27 days

Activity-on-Arrow Networks Example – Answer

\[ T = \sum_{(i,j) \in CP} d_{ij} = 53.4 \]

From Eq. 53.4, the duration of the project is

\[ T = \sum_{(i,j) \in CP} d_{ij} = d_B + d_E + d_G + d_J + d_K \]
Activity-on-Arrow Networks Example – Answer

From Eq. 53.4, the duration of the project is

\[ T = \sum_{(i,j) \in CP} d_{ij} = d_B + d_G + d_Q + d_I + d_K \]

\[ = 4 \text{ days} + 6 \text{ days} + 4 \text{ days} + 5 \text{ days} + 7 \text{ days} \]

\[ = 26 \text{ days} \]

The answer is (C).

---

Stochastic Critical Path Models

- Time is distributed as a random variable
- Most common model is PERT
  - Program Evaluation and Review Technique
  - Used for large projects

\[ P_{\text{ERT}}(\mu, \bar{t}, s) = (\text{optimistic, most likely, pessimistic}) \text{ durations} \]

\[ \mu = \text{mean duration of activity } (i, j) \]

\[ \bar{t} = \text{standard deviation of the duration of activity } (i, j) \]

\[ s = \text{standard deviation of project duration} \]

\[ \mu = \frac{a_i + 4b_i + c_i}{6} \]

\[ \bar{t} = \frac{a_i - c_i}{6} \]

\[ s = \sum_{(i,j) \in CP} \bar{t}_j \]

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Stochastic Critical Path Models Example

Durations for a project’s four key activities are shown.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Optimistic</th>
<th>Most Likely</th>
<th>Pessimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>5</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>1-3</td>
<td>5</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>3-4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

What is most nearly the mean duration of activity 1-2?

(A) 3.5 hr

(B) 4.0 hr

(C) 6.2 hr

(D) 7.1 hr
Stochastic Critical Path Models Example – Answer

Use the project evaluation and review technique (PERT) mean equation. For activity 1-2,

$$\mu_{1-2} = \frac{a_{1-2} + 4b_{1-2} + c_{1-2}}{6}$$

$$= \frac{5 \text{ hr} + (4)(5 \text{ hr}) + 12 \text{ hr}}{6 \text{ hr}}$$

$$= 6.17 \text{ hr} \quad (6.2 \text{ hr})$$

The answer is (C).

Monitoring

<table>
<thead>
<tr>
<th>Project</th>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schematic design</td>
<td>Actual</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Construction documents</td>
<td>Actual</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Base/actual</td>
<td>Actual</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>100</td>
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<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>Actual</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Coordinating

Project Managers must constantly coordinate the various stakeholders:

- Architect/engineer’s staff
- The consultants
- The clients
- Building code or regulatory officials
- Internal management
- Contractors

Checklists or meetings can be valuable for coordinating.

Earned Value Method
**Introduction**

The procurement stage is when a project manager
• plans purchases, acquisitions, and contracts;
• requests supplier and contractor responses;
• selects suppliers and contractors;
• and awards, administers, and closes contracts.

3 types of contract structure may be used to deliver the project:
• design-bid-build,
• design-build, and
• management contracting.

Each contract type involves the same parties:
• the design professional,
• the owner, and
• the contractor (responsible for coordinating the work of any subcontractors, fabricators, and suppliers).

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**Design-Bid-Build**

**Design-Build**
Management Contracting

Construction Manager (CM) – a third party who is an expert in the construction, costing, and management of the construction process.
- May be hired to advise on costs and construction methods, but not participate in construction
- May act as an agent; responsible for hiring contractors, advising on costs, and managing the construction process
- Can act as contractor, guaranteeing the price of the project

Traditional D-B-B method can be used, with CM consulting early on with costs/constructability details

Commonly, CM will act as agent of the owner
- Advising the engineer on material selection, costs, and constructability;
- Selecting contractors and subcontractors;
- Negotiating their contracts and construction pricing; and
- Coordinating construction

Awarding Contracts

Negotiation

- The owner, with the assistance of the construction manager or engineer, works out the final contract price and conditions with each contractor

Competitive Bidding

- Lowest responsible bidder
- Lowest bidder whose offer best responds in quality, fitness, and capacity to fulfill the particular requirements of the proposed project, and who can fulfill these requirements with the qualifications needed to complete the job in accordance with the terms of the contract

Awarding Contracts Example

Ethical codes and state legislation forbidding competitive bidding by design engineers are

(A) enforceable in some states
(B) not enforceable on public (nonfederal) projects
(C) enforceable for projects costing less than $5 million
(D) not enforceable

The answer is (D).

Awarding Contracts Example – Answer

Ethical bans on competitive bidding are not enforceable. The National Society of Professional Engineers’ (NSPE) ethical ban on competitive bidding was struck down by the U.S. Supreme Court in 1973 as a violation of the Sherman Antitrust Act of 1890.

The answer is (D).
Introduction

Construction plans, specifications, and any necessary contracts or supporting documents must be produced at the start of a project.

- Collectively, these documents are known as the **Construction Documents**.

Must be of sufficient clarity to indicate...

- Location, nature, and extent of proposed work;
- And how it will conform to code/specifications.

Includes:

- Standard drawings, elevations/profiles, sections, and details, item/material schedules, and specifications

Documentation

- Change orders (i.e. record drawings)
  - Due to unexpected conditions or changes to the plans after bidding
- As-built construction documents
  - Record what was actually installed (as opposed to what was shown in the original construction documents)

Documentation Example

Record drawings ("as-buils") of a buried sewer line installation that will be submitted to the client should be certified by the

(A) contractor
(B) building official
(C) architect
(D) engineer
**Documentation Example – Answer**

The engineer of record certifies engineering design. Architects do not certify engineering work.

*The answer is (D).*

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**Construction Plans**

Also called *plan views, floor plans, and partition plans.*

- Required for every project regardless of size or complexity
- Drawn at different scales depending on project
  - 1/8 in = 1 ft 0 in (1:100)
  - 1/4 in = 1 ft 0 in (1:50)
  - 1/2 in = 1 ft 0 in (1:25)
- All plans should be drawn at the same scale as the primary construction plan.

---

**Specifications**

- Dictate which materials and methods must be used
- Separate from the plans and drawings
- Become part of the construction contract
- Assembles and consolidates all of the specific and technical details that apply to a project

Often possible to adopt commercial documents that use standard information, language and content.

* E.g., The Construction Specifications Institute (CSI) MasterFormat™ document

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**Construction Operations & Management**

- Equipment Productivity & Selection
- Cranes
- Rigging
- Site Dewatering & Pumping
- Productivity Analysis & Improvement
Equipment Productivity & Selection

- A major influence on the efficiency and profitability of a construction operation.
- Most important considerations are the equipment’s ability to perform the work, its efficiency, and its cost.
- Evaluated by the cost per unit of production (CPP).
- Basic method for calculating production capability is based on the equipment’s capacity and cycle time.
  - 2 ways to estimate cycle time
    1. Number of effective working minutes per hour
    2. Multiply the theoretical number of cycles per hour by a numerical efficiency
- Common categories:
  - Excavation and loading equipment
  - Hauling and placing equipment
  - Compaction equipment
  - Grading and finishing equipment

Cranes

- Engineer’s must understand:
  - How to select the right crane for the right activity,
  - How to properly erect a crane and
  - How to keep it stable.
- Crane evaluation includes determining:
  - Type and size of crane needed,
  - Load capacity required, and
  - Other specifications as required for the project.
- Crane Types
  - Rough terrain
  - Truck mounted
  - All terrain - road worthy blend of rough terrain and truck mounted
  - Crawler lattice – high capacity, long reach
  - Tower – small footprint, moving counterweight
- Load capacity for a crane is never more than 75% of its tipping load.
Cranes

- Static Basis for a Horizontal Boom Tower Crane.

Rigging

- Slings, spreader beams, lifting brackets, and pincers are different methods to attach a load to the hook block of a crane.
- Slings are most commonly used.
- Beams are usually lifted using a choker at the center of gravity.
- A beam may also be hoisted with two cables.

Rigging

- A spreader beam is used to attach the multiple loads to the rigging.
- OSHA Subpart R has specific requirements for multiple lift rigging.
- In all cases, the first step is to determine the center of gravity of the combined load.
- The lifting point is always directly above the center of gravity.

Productivity Analysis & Improvement

- Understanding productivity requires optimizing both
  - The production capability of the equipment used on the project,
  - The production capability of the crew working on the project.
- Requires careful observation and sound judgment using established methods.
- Productivity analysis categories:
  - Productive work
  - Contributory work
  - Nonproductive work
  - Obstructive work
- Most basic method is to observe the percentage of time a crew performs effective work.
- Better method is the calculation of a labor utilization factor.
Productivity Analysis & Improvement

Learning Curves

- A mathematical representation of time spent to produce a unit of work.
- By integrating the area under the curve, an estimator can calculate the total hours of labor needed to complete an activity.

Site Dewatering & Pumping

- Dewatering (unwatering)
  - The removal of water from the job site, typically requiring a lowering of the water table.
  - Costs are primarily a function of the volume of water removed.
- Deep wells
  - Use submersible electric pumps to lower the water table.
- Vacuum dewatering
  - Use wellpoints to draw water up small-diameter (e.g., 2 in) tubes with side perforations in the liquid water zone.
  - Typical when depth is less than about 15-20 ft.
  - Wellpoints are usually installed around the projects periphery.
  - Sites can be dewatered to depths greater than 15-20 ft by using multiple wellpoint stages.

Site Dewatering & Pumping

Construction Safety
Introduction

- In the U.S., workers’ safety is regulated by the federal Occupational Safety and Health Act (OSHA).
  - State divisions are charged with enforcing federal and state safety regulations.
- Surface and underground mines are regulated by the federal Mine Safety and Health Act (MSHA).
- All federal OSHA regulations are published in the Congressional Federal Register (CFR).
  - 2 main categories:
    - The “1910 standards” for general industry
    - The “1926 standards,” for construction industry
- Subjects include: Fall protection, trenching, scaffolds, and confined space entry, to name a few.

Soil Classification

- Soils are classified into stable rock and types A, B, or C, with type C being the most unstable.
- Where a layered geologic structure exists, the soil must be classified on the basis of the soil classification of the weakest soil layer.
- OSHA requires that at least one visual and one manual method be used to classify the soil type as A, B, and C.

Trenching & Excavation

Competent Person: Soil Excavating

Example

The first person to enter an excavation should normally be a

(A) competent person  
(B) trained person  
(C) newly hired person  
(D) supervisor
Confined Spaces & Hazardous Atmospheres

- Employees entering confined spaces (e.g., excavations, sewers, tanks) must be properly trained, supervised, and equipped.
- Atmospheres in confined spaces must be monitored for oxygen content and other harmful contaminants.
- Oxygen content must be maintained at 19.5% or higher unless a breathing apparatus is provided [OSHA 1910.146].
- Employees entering deep confined excavations must wear harnesses with lifelines [OSHA 1926.651].

Power Line Hazards

- Critically important to be aware of the possibility of inadvertent power line contact.
- Site must be thoroughly inspected for the danger of power line contact.
- OSHA provides specific minimum requirements for safe operating distances.
- A good rule of thumb for voltages >50 kV is a clearance of 35 ft.
Fall & Impact Protection

- Fall protection can take the form of barricades, walkways, bridges (with guardrails), nets, and fall arrest systems.
- Personal fall arrest systems include lifelines, lanyards, and deceleration devices.
- Employees must be protected from impalement hazards from exposed rebar (OSHA 1926.701 (b)).
- Head protection is required where there is a danger of head injury from impact, flying or falling object, electrical shock, or burns. [OSHA 1910.132(a) and (c)].

Noise

- OSHA sets maximum limits on daily sound exposure.
- The “all-day” eight-hour noise level limit is 90 dBA.
- In the U.S., employees may not be exposed to steady sound levels above 115 dBA, regardless of the duration.
- Impact sound levels are limited to 140 dBA.
- Permissible Noise Exposure Levels shown on Table 57.4.

Table 57.4 Typical Permissible Noise Exposure Levels*

<table>
<thead>
<tr>
<th>sound level (dBA)</th>
<th>exposure (hr/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>8</td>
</tr>
<tr>
<td>92</td>
<td>6</td>
</tr>
<tr>
<td>95</td>
<td>4</td>
</tr>
<tr>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>102</td>
<td>1 1/2</td>
</tr>
<tr>
<td>105</td>
<td>1</td>
</tr>
<tr>
<td>110</td>
<td>1/2</td>
</tr>
<tr>
<td>115</td>
<td>1/8 or less</td>
</tr>
</tbody>
</table>

Scaffolds

- Construction and use of scaffolds are regulated in detail by OSHA Std. 1926.451.
- Fall protection required on a scaffold more than 10’ above a lower level.
- Planking or decking cannot deflect more than 1/60 of the span when loaded.
- Each platform and walkway must be at least 18 in wide.

Temporary Structures

- Temporary structures are those that exist for only a period of time during construction and are removed prior to project completion.
- They include:
  - temporary buildings for occupancy and storage,
  - shoring and underpinning,
  - concrete formwork and slipforms,
  - scaffolding
  - diaphragm and slurry walls,
  - Wharves and docks,
  - temporary fuel and water tanks,
  - cofferdams, earth-retaining structures,
  - bridge falsework, tunneling
  - supports, roadway decking, and ramps and inclines.
Truck & Tower Cranes

- Crane capacities also depend on the reeving.
  - the path of the wire rope as it comes off the hoist drum and wraps around the various upper and lower sheaves.
  - When the hoist line is not centered over the boom tip, eccentric reeving occurs

Crane Use & Safety

- OSHA federal crane safety regulations for general industry are covered in 3 sections of the CFR (29 CFR Sections 1910.179, 1910.180 and 1917.45).
- OSHA (Section 29 CFR 1926.1412) makes a distinction between competent and qualified persons.
- Only a qualified person can conduct annual inspections of equipment; inspections of modified, repaired, and adjusted equipment; and inspections after equipment has been assembled.
- A competent person may conduct the work shift and monthly equipment inspections, as long as that person has been trained in the required elements of a shift inspection.
- The crane or derrick operator can be the inspector, but only if the operator meets the respective requirements for a qualified or competent person.

Question

What is the danger of eccentric boom reeving?

(A) boom twisting
(B) decreased jib capacity
(C) increased wire rope wear
(D) increased sheave wear

THANK YOU