Talk Announcement I

- **Joachim Eble** (Title TBA)
  - Major figure in green building design
- March 16, 2004, 4 – 6 PM
"Contour Crafting Construction: Houses Straight from the Printer"

Behrokh "Berok" Khoshnevis, Professor (USC)

Monday, March 22, 2004

2:00 p.m. - 4:00 p.m
Themes from Granli Talk

- Key megaproject issues
  - Management of uncertainty
  - Need for lead indicators to spot problems early
  - Whole lifecycle management
  - Dealing with entire project ecosystem
    - Procurement
    - Partner issues
    - Governance
    - Political support
    - Community concerns
Project Organization

- Award Methods
  - General points
  - Bidding
  - Negotiation
- Lifecycle Costing
- Estimation
  - Introduction
  - Conceptual Estimation
    - Cost indices
    - Cost-capacity factors
    - Component ratios
    - Parameter costs
  - Detailed Estimation
    - Quantity Takeoff
    - Labor Cost Estimation
    - Probabilistic methods
Award Methods: Contractor Selection

- **Extremes**

<table>
<thead>
<tr>
<th>Payment method:</th>
<th>Reimbursable</th>
<th>Fixed Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Type:</td>
<td>Service</td>
<td>Commodity</td>
</tr>
<tr>
<td>Award method</td>
<td>Solicit based on Reputation and agree via Negotiation</td>
<td>Bidding</td>
</tr>
</tbody>
</table>
Project Organization

- **Award Methods**
  - General points
  - Bidding
  - Negotiation

- **Lifecycle Costing**

- **Estimation**
  - Introduction
  - Conceptual Estimation
    - Cost indices
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    - Probabilistic methods
Bidding

- Variants
  - Low bid
  - Multi-parameter bidding
    - Low bid plus arithmetic combination of other factors
    - Low bid divided by ranking of other factors

- To allow for fast-tracking may bid early (30%)

- Fixed price low bid is win-lose

- Typically associated with lump-sum contract

- Prequalifications critical
Bidding Advantages

- Can get good price
- Transparency
- Well-understood method
- Approved by regulatory structures
- For owner: Contract terms can be set by owner
Bidding Disadvantages

- Can set up win-lose situation
- Insufficient consideration of design before pricing
- Low bidders can be unreliable -- Prequalify aggressively!
- Can be very bad for design (design-build, CM at risk)
- Pressure for lowest bid can eliminate profit from bid
  - Cutting corners
  - Placement of low-quality personnel
  - Bad feelings
Bidding Tradeoffs

- **Time provided to bidders to review documents**
  - Too long: Construction delayed
  - Too short:
    - Bids low-quality because too little time to review contract docs (incorporate high risk premium or unrealistically low)
    - Few bidders willing to participate

- **Bid count**
  - Too many bidders: Scare away best contractors
  - Too few bidders: Bid not competitive
Bidding Metrics

- Most common: Price alone
- Bidding “cap”: Bid on how far can go with set amount of money
- Multi-parameter bidding (increasingly popular)
  - Consider non-price items (time, quality, qualification)
  - A+B Additive measures
    - Price+($/day)*days (common for retail), Price+qualification+design rank, price+design rank,…
  - A/B (e.g. B scoring along some metric: Design, etc.)
Bidding Process

- A/E or CM oversight typical
- Publicity (specifies qualification requirements)
- Provide bid documents
  - E.g. fair cost estimate, sample contract, general & specific conditions, specifications & drawings, supplemental provisions
- Answer RFI's
- Pre-bid conference
  - Explain scope, working conditions, answer questions, documented in writing)
Qualifications

- Common items for qualifications
  - Bonds/Insurance (bid, performance, payment)
  - Safety record
  - Reputation
  - Financial strength
  - Total/Spare capacity
  - Licensing
  - Background in type of work
  - Experience in local area/labor market
  - Management system (QA, planning, estimation, control)
  - Interest, adaptability shown
Public vs. Private Bidding

- **Public Bidding**
  - Must be publicly advertised (posting in newspapers, public building, etc.)
  - Qualification occurs after submission of bids
  - Typically 60 day period in which can submit bids

- **Private Bidding**
  - May be by invitation only
  - Qualification occurs before submission of bids
Dealing with Way-Out Low Bids

- Forcing collection from unrealistically low bids is dangerous
  - Construction highly contentious, poor morale
    - Risk of extreme corner cutting
  - Default is possible
    - Disruption
    - Insurance companies fulfilling performance bonds very difficult to work with
Subcontracting Bid Issues

- GCs solicit bids from subcontractors
- GCs push subs for lowest possible price before GC bids
  - GC not obligated to use quoted subcontractor
- Can lead to serious predatory behavior
  - Bid shopping (before \textit{and} after GC wins bid)
  - Bid peddling (unsolicited calls from subs to GCs after GC wins bid)
- Some owners/states require listing of chosen subs at bid time or assign based on sub-bidding
Bonding

- **Bid**
  - Public
    - ~20% or as low as 5% of Bid
  - Private
    - 5% to 10% of Bid

- **Miller Act 1935**

- **Performance**
  - 100% Complete Job at Bid Price

- **Payment**
  - Cover Unpaid Bills by Contractor
    - 50% for > $1M
    - 40% for $1M < X < $5M
    - 2.5M for > $5M

- **Cost**
  - 1% per $1K up to $200K
  - Lower for > $200K

- **Calculation**
  - No Track Record: 5 or 6 Net Quick Assets
  - Old Reliable Record: 40+ Net Quick Assets
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    - Labor Cost Estimation
    - Probabilistic methods
Negotiation

- Typically selected based on reputation, qualifications
- Typically used in pure form for two cases
  - Very simple
    - Use trusted, familiar party
  - Very complex/big
    - Get contractor involved in design, start work early
- Requires relatively savvy owner
  - Evaluate proposals, monitor performance
- Important even for DBB for post-bid changes
Negotiation Considerations

- Can get win-win because of differences in
  - Risk preferences
  - Relative preferences for different attributes
- Goal is to find a pareto optimal agreement
- Key skill in negotiation: Ability to find win-win options
Negotiation Tips

- Try to maintain clear sense of reservation price
  - Price or conditions under which will accept offer
- Want to adopt some objective basis for position
  - Without this impersonal criteria, other party can take disagreements personally as arbitrarily demands
- Discuss multiple issues at once
  - Permits trading off issues flexibly
- Formal exposure good—but experience gives edge
Negotiation Tips 2: Major Sins of Negotiation (Thomson, 2001)

- Leaving money on the table: Failing to identify and use win-win opportunities
- Settling for too little: Unnecessarily large concessions
- Walking away from the table: Rejecting terms that are favorable, often due to pride
- Settling for terms worse than existing alternative: Pressure to reach some deal leads to opportunity cost
Project Organization

✓ Award Methods
  ✓ General points
  ✓ Bidding
  ✓ Negotiation

▪ Lifecycle Costing

▪ Estimation
  ▪ Introduction
  ▪ Conceptual Estimation
    ▪ Cost indices
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    ▪ Component ratios
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    ▪ Probabilistic methods
Life-Cycle Costing Stages

- Conceptual Design Phase
- Detailed Design Phase
- Production Phase
- Operation and Maintenance Phase
- Divestment Phase
Effect of Decisions on Life-Cycle Cost of a System
Items where LCC Important

- Focus on non-static portions of structure
  - Portions that move, undergo a lot of use/wear, require maintenance or replacement

- Examples
  - Carpets, HVAC, electrical system, finishings, parking, roofing,…

- Interdependencies critical
  - E.g. HVAC and insulation considered together
Cost Classification by Life-Cycle Phase

- Conceptual Design Phase
- Advanced Development and Detailed Design Phase
- Production Phase
- Operation and Maintenance Phase
- Divestment Phase

System A
System B

Cost Classification by Life-Cycle Phase
Total Life-Cycle Cost of the System
Life-Cycle Cost by Phase

Cost ($1,000)

Quarter

Conceptual Design Phase
Advanced Development Phase
Production Phase
Operation Phase
Divestment Phase
Cumulative LCC
Cost Breakdown by Labor and Material
Project Organization

✓ Award Methods
  ✓ General points
  ✓ Bidding
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✓ Lifecycle Costing
  ▪ Estimation
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Different types of estimates are required as a project evolves

- Conceptual and Preliminary Estimates
  - Prior to engineering design completion

- Definitive Estimates
  - Forecast the project cost within allowable limits from a combination of conceptual and detailed information often including partial contract and other procurement awards

- Detailed Estimates (Engineer’s and bidding)
  - Prepared from completed plans and specifications
### Elements of Estimation

<table>
<thead>
<tr>
<th>Description</th>
<th>Type</th>
<th>Probable Contingency as A%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bid</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Engineers</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Definitive</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Preliminary</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Conceptual</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Magnitude</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Basic Data
1. Craft Wage Rates and Fringe Benefits
2. Payroll taxes and Insurance
3. Local Sales Use Other Taxes
4. Design and Construction Schedule
5. Insurance Requirements

## Further Estimate Details I

<table>
<thead>
<tr>
<th>Class</th>
<th>Project Phase</th>
<th>Approx. Design Complete</th>
<th>Typical Contingency</th>
<th>Information Required</th>
<th>Major Equipment</th>
<th>Other Materials</th>
<th>Labor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Order of Magnitude</td>
<td>Business Planning</td>
<td>&lt; 1%</td>
<td>100-200%</td>
<td>Project purpose/ product</td>
<td>Index methods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2: Conceptual</td>
<td>Feasibility</td>
<td>2-5%</td>
<td>30-50%</td>
<td>Facility capacity Site selected (perhaps Owner’s Project Mgt. selected Consulting engr., CM, or turnkey contractor selected</td>
<td>Index methods Cost-capacity curves Comparable projects Industry published data Licenser estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3: Preliminary</td>
<td>Conceptual Design</td>
<td>15-30%</td>
<td>15-40%</td>
<td>Facility capacity Geotechnical info PID’s, PFD’s Preliminary equipment list Preliminary Project Schedule</td>
<td>Cost curves Vendor quotes by phone Recent purchases Published estg. data</td>
<td>Ratio to major eqpt. Ratio from similar facilities</td>
<td>Labor / material ratios</td>
</tr>
<tr>
<td>4: Definitive</td>
<td>Detailed Design</td>
<td>50-75%</td>
<td>10-20%</td>
<td>Detailed design dwgs. Specifications Contracting plan Long-lead equipment ordered CPM-level schedule</td>
<td>Eqpt. vendor quotes Long-lead equipment ordered Escalation defined</td>
<td>Ratio to major eqpt. Escalation defined Key quantities defined</td>
<td>Labor / material ratios Labor-hour units Productivity for area Wage rates</td>
</tr>
<tr>
<td>5: Engineer’s or Owner’s</td>
<td>Pre-bid</td>
<td>90%</td>
<td>5-10%</td>
<td>Complete design &amp; bidding data</td>
<td>Long-lead eqpt. prices firmed Deliveries defined</td>
<td>Detailed take-off Firm unit cost quotes</td>
<td>Defined indirects</td>
</tr>
<tr>
<td>6: Bid Level</td>
<td>Construction</td>
<td>100%</td>
<td>5%</td>
<td>Contractors, sub’s &amp; vendors. CPM. Resource-leveled schedule Bid Addenda</td>
<td>Actual or committed costs to-date</td>
<td>Bulk mat’l prices and delivery terms quoted</td>
<td>Detailed evaluation of labor crafts and productivity Sub bids rec’d</td>
</tr>
</tbody>
</table>
## Further Estimate Details II

<table>
<thead>
<tr>
<th>Class</th>
<th>Order of Magnitude</th>
<th>Conceptual</th>
<th>Preliminary</th>
<th>Definitive</th>
<th>Engineer's or Owner's Control</th>
<th>Bid Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimate Prepared by</td>
<td>Owner</td>
<td>Owner, Consultant, CM or Turnkey Contractor</td>
<td>Owner, Consultant, CM or Turnkey Contractor</td>
<td>Owner, Consultant, CM or Turnkey Contractor</td>
<td>Owner, Consultant, CM or Turnkey Contractor</td>
<td>Construction Contractor</td>
</tr>
<tr>
<td>Contingency and Escalation Estimated by</td>
<td>Single %</td>
<td>Broad evaluation</td>
<td>Broad evaluation</td>
<td>Detailed evaluation</td>
<td>Detailed estimate</td>
<td>Detailed estimate Risk simulation</td>
</tr>
<tr>
<td>Engr. &amp; Mgt. Fee</td>
<td>% of constructed cost</td>
<td>% of constructed cost</td>
<td>Broad estimate</td>
<td>Broad estimate</td>
<td>Detailed estimate</td>
<td>Detailed estimate</td>
</tr>
<tr>
<td>Contractor's Overhead &amp; Profit</td>
<td>Implicitly included</td>
<td>% of direct cost</td>
<td>% of direct cost</td>
<td>% of direct cost</td>
<td>% of direct cost</td>
<td>Detailed estimate</td>
</tr>
<tr>
<td>Const. Plan</td>
<td>None</td>
<td>Not required</td>
<td>Desirable</td>
<td>Desirable</td>
<td>Highly Desirable</td>
<td>Required</td>
</tr>
</tbody>
</table>
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Conceptual/Preliminary Estimates

- Help decide feasibility
- Very useful for rapid iteration of design plans
- Great variability according to type
- Categories:
  - Time-referenced cost indices
  - Cost-capacity factors
  - Component ratios
  - Parameter costs
Cost Indices

- Show changes of costs over time
- Changes in:
  - Technology
  - Methods
  - Productivity
  - Inflation
- Both input and output cost indices available
- Published periodically by Engineering News-Record and other publications
Input Cost Indices

- Reflect price changes for a certain “basket” of goods
  - Like Consumer price index
- Very general
- Problems
  - May not reflect particular inputs of project
  - Ignore productivity changes
  - Ignore technology changes
  - Competitiveness of contractors (lowered overhead)
Cost Indices Component Calculations

ENR’s Building Cost Index is computed as follows:

Components:
- 1,088 board feet of lumber (2x4, 20-city average)
- 2500 pounds of structural-steel shapes (20-city average, base mill price before 1996, fabricated after 1996)
- 1.128 tons of Portland cement (bulk, 20 city average)
- 66.38 hours of skilled labor (20-city average of Bricklayers, Carpenters, and Structural Ironworkers)

http://www.enr.com/cost/costbci.asp
We convert from one base period to another

“current cost” = 3802 (February 2004)
Base cost (1913) = 100
Index on 1913 base = 3802%

Example 1:

Warehouse estimate: Assume you have an estimate to a similar warehouse completed in 1978 for a cost of $4,200,000. We are planning to build the new one in 2002. The ENR index for 1978, relative to the base date of 1913, was 1654%

\[
\frac{3802\%}{1654\%} \times 4,200,000 = \$9,654,413.54 \approx \$9,650,000
\]
Output Cost Indices

- Look at historical costs for similar projects
- Tend to be rather narrow in definition
  - May not find close match for facility in question
Cost Indices Use and Accuracy

- 20% to 30% Accuracy
- Negligible time and effort
- Valuable for Preliminary Planning
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**Cost-Capacity Factor**

- **Apply to changes in size, scope, or capacity of projects of similar types**
- **Reflect the nonlinear increase in cost with size (economies of scale, learning curves)**

\[ C_2 = C_1 \left( \frac{Q_2}{Q_1} \right)^x \]

- **Where**
  - \( C_2 = \text{estimated cost of the new facility with capacity } Q_2 \)
  - \( C_1 = \text{known cost of facility of capacity } Q_1 \)
  - \( x = \text{the cost-capacity factor for this type of work} \)
Cost-Capacity Factor II

- X is empirically derived factors based on well-documented historical records for different kinds of projects
- Q are parameters that reasonably reflects the size of the facility (barrels per day produced by a refinery, tons of steel per day produced by a steel mill, gross floor area for a warehouse, etc)
Cost-Capacity Factor Example

- Consider the cost-capacity factor $x = 0.8$ for a warehouse.
- We have available an estimate for a similar warehouse located nearby with a usable area of 120,000 square feet (from Example 1), cost $4.2 \times 10^6$ in 1978.
- The prospective owner for the new warehouse wants a structure with a usable area of 150,000 square feet.

Pena-Mora, 2003
Solution:

\[ C_2 = 4,200,000 \times \left( \frac{3802}{1654} \right) \times \left( \frac{150,000}{120,000} \right)^{0.8} = \$11,541,278 \]

Cost-capacity factor can be accurate to within 15 to 20% of actual costs

Pena-Mora, 2003
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Component Ratios

- Focus on Major Equipment
  - Compressors
  - Pumps
  - Furnaces
  - Refrigeration Units
  - Belt Conveyors
  - Turbine Generators
- “Equipment-Installation-Cost-Ratios”
- “Plant-Cost-Ratios”
Component Ratios: Installation Cost

- Multiply the Purchase Cost by Installation Cost Factor
- +/- 10 to 20% Accuracy
# Typical Equipment Installation Factors*

<table>
<thead>
<tr>
<th>ITEM</th>
<th>INSTALLATION COST, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belt conveyors</td>
<td>20 - 25</td>
</tr>
<tr>
<td>Bucket elevators</td>
<td>25 - 40</td>
</tr>
<tr>
<td>Centrifugals, disk or bowl</td>
<td>5 -6</td>
</tr>
<tr>
<td>Top suspended</td>
<td>30 - 40</td>
</tr>
<tr>
<td>Continuous</td>
<td>10 - 25</td>
</tr>
<tr>
<td>Crystallizers</td>
<td>30 - 50</td>
</tr>
<tr>
<td>Dryers, continuous drum</td>
<td>100*</td>
</tr>
<tr>
<td>Vacuum rotary</td>
<td>150 - 200†</td>
</tr>
<tr>
<td>Rotary</td>
<td>50 - 100†</td>
</tr>
<tr>
<td>Dust collectors, wet</td>
<td>220 - 450†</td>
</tr>
<tr>
<td>Dry</td>
<td>10 - 200†</td>
</tr>
<tr>
<td>Electrostatic precipitators</td>
<td>33 - 100†</td>
</tr>
<tr>
<td>Electric motors plus controls</td>
<td>60</td>
</tr>
<tr>
<td>Filters</td>
<td>25 - 45</td>
</tr>
<tr>
<td>Gas producers</td>
<td>45 - 250</td>
</tr>
<tr>
<td>Instruments</td>
<td>6 - 300</td>
</tr>
<tr>
<td>Ion exchangers</td>
<td>30 - 275‡</td>
</tr>
<tr>
<td>Towers</td>
<td>25 - 50</td>
</tr>
<tr>
<td>Turbine generators</td>
<td>10 - 30</td>
</tr>
</tbody>
</table>


† Includes accessories.
Component Ratios Plant Cost

- Plant-cost-ratios use equipment-vendor-price-quotations

<table>
<thead>
<tr>
<th>ITEM</th>
<th>COST</th>
<th>FACTOR</th>
<th>PLANT COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blowers and Fans</td>
<td>$10,000</td>
<td>×</td>
<td>$25,000</td>
</tr>
<tr>
<td>Compressors</td>
<td>50,000</td>
<td>×</td>
<td>115,000</td>
</tr>
<tr>
<td>Furnaces</td>
<td>100,000</td>
<td>×</td>
<td>200,000</td>
</tr>
<tr>
<td>Heat Exchangers</td>
<td>80,000</td>
<td>×</td>
<td>384,000</td>
</tr>
<tr>
<td>Instruments</td>
<td>50,000</td>
<td>×</td>
<td>205,000</td>
</tr>
<tr>
<td>Motors, Electric</td>
<td>60,000</td>
<td>×</td>
<td>510,000</td>
</tr>
<tr>
<td>Pumps</td>
<td>20,000</td>
<td>×</td>
<td>140,000</td>
</tr>
<tr>
<td>Tanks</td>
<td>125,000</td>
<td>×</td>
<td>260,000</td>
</tr>
<tr>
<td>Towers</td>
<td>200,000</td>
<td>×</td>
<td>800,000</td>
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<tr>
<td><strong>Total</strong></td>
<td>$685,000</td>
<td>×</td>
<td><strong>$2,639,000</strong></td>
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Component Ratios Factors

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>FACTOR⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blender</td>
<td>2.0</td>
</tr>
<tr>
<td>Blowers and fans (including motor)</td>
<td>2.5</td>
</tr>
<tr>
<td>Centrifuges (process)</td>
<td>2.0</td>
</tr>
<tr>
<td>Compressors:</td>
<td></td>
</tr>
<tr>
<td>Centrifugals, motor-driven (less motor)</td>
<td>2.0</td>
</tr>
<tr>
<td>Steam turbine (including turbine)</td>
<td>2.0</td>
</tr>
<tr>
<td>Reciprocating, steam and gas</td>
<td>2.3</td>
</tr>
<tr>
<td>Motor-driven (less motor)</td>
<td>2.3</td>
</tr>
<tr>
<td>Ejectors (vacuum units)</td>
<td>2.5</td>
</tr>
<tr>
<td>Furnaces (package units)</td>
<td>2.0</td>
</tr>
<tr>
<td>Heat exchangers</td>
<td>4.8</td>
</tr>
<tr>
<td>Instruments</td>
<td>4.1</td>
</tr>
<tr>
<td>Motors, electric</td>
<td>8.5</td>
</tr>
<tr>
<td>Pumps:</td>
<td></td>
</tr>
<tr>
<td>Centrifugal, motor-driven (less motor)</td>
<td>7.0</td>
</tr>
<tr>
<td>Steam turbine (including turbine)</td>
<td>6.5</td>
</tr>
<tr>
<td>Positive displacement (less motor)</td>
<td>5.0</td>
</tr>
<tr>
<td>Reactors-factor as approximate equivalent type of equipment</td>
<td>2.5</td>
</tr>
<tr>
<td>Refrigeration (package unit)</td>
<td></td>
</tr>
<tr>
<td>Tanks:</td>
<td></td>
</tr>
<tr>
<td>Process</td>
<td>4.1</td>
</tr>
<tr>
<td>Storage</td>
<td>3.5</td>
</tr>
<tr>
<td>Fabricated and field-erected (50,000 + gal)</td>
<td>2.0</td>
</tr>
<tr>
<td>Towers (columns)</td>
<td>4.0</td>
</tr>
</tbody>
</table>


⁺ Multiply purchase cost by factor to obtain installed cost including cost of site development, buildings, electrical installations, carpentry, painting, contractor's fee and rentals, foundations, structures, piping, installation, engineering, overhead, and supervision.
## Project Organization

- **Award Methods**
  - General points
  - Bidding
  - Negotiation

- **Lifecycle Costing**

- **Estimation**
  - Introduction
  - Conceptual Estimation
    - Cost indices
    - Cost-capacity factors
    - Component ratios
      - Parameter costs
  - Detailed Estimation
    - Quantity Takeoff
    - Labor Cost Estimation
    - Probabilistic methods
Parameter Costs Source Data

- Commonly used in building construction
- ENR “Quarterly Cost Roundup”
- R.S.Means “Means Square Foot Costs”
  - NB: Different from RS Means Building Construction Cost Data!
Parameter Costs Characteristics

- Relates all costs of a project to just a few physical measures, or “parameters”, that reflect the size or scope of the project.
- Warehouse - the “parameter” would be “gross enclosed floor area”.
- With good historical records on comparable structures, parameter costing can give reasonable levels of accuracy for preliminary estimates.
Project Organization

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