A SunCam online continuing education course

Construction Cost Estimating for Engineers

by

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Course Outline:

Capital Cost vs Construction Cost
Estimating Approaches
Using a Cost Index
Elements of an Estimate
Software and Calculators
Stage Gate Estimates
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PDRI
Contract Type Impact
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Capital Cost vs Construction Cost

Nearly all capital improvement (CapEx) projects require cost estimating for budget planning and funding purposes. Accurate cost estimates help assure proper funding is provided. Engineers often play a central role in developing these cost estimates and taking responsibility when a cost estimate ends up being inaccurate.

> *An excessively high estimate may result in the project being redesigned, downsized, delayed, or cancelled during the design stage.*
>
> *An excessively low estimate may result in a lack of initial funding and upon receiving higher construction bids, the project is redesigned, downsized, delayed, or cancelled.*

The following definitions help distinguish between construction costs and capital costs:

<u>Construction Cost</u>: Price for supply and installation of improvements, usually from a general contractor.

<u>Capital Cost</u>: Total cost for an improvement project, including land acquisition, design, permitting, construction, construction management, and commissioning.

When performing a construction cost estimate, it is important to consider which items should be included and make a list of assumptions. Although every project is different, Table 1 shows which cost items are normally included in a construction cost estimate.

Table 1: Capital Cost Items Grouped by Likelihood of being Included in a Construction Cost Estimate (**Bold** means Indirect Costs)		
Usually in Construction Cost	Sometimes in Construction Cost	Usually NOT in Construction Cost
Building Permit Submittal and Fees	Training	Land Acquisition
Shop drawings, submittals, RFIs, pay apps, schedule, and other documents	Extended Warranties	Design
Mobilization & Demobilization	Pre-purchased Equipment	Geotechnical Explorations and Engineering
Construction Survey and Staking	Initial Chemical Deliveries for Startup	Topographic Survey and Boundary Survey
Utility Locates	Landscape watering and fertilizing for initial time period	Lead & Asbestos Survey
Traffic Control	Programming and Integration with Existing HMI and SCADA	Environmental Agency Approval Fees
Erosion & Dust Control	Temporary Power, Water, Sewer, & Other Utilities	Planning and Zoning Approval Fees
Shipping & Handling	Job Trailer for Owner or Owner's Representative	Third Party Construction Administration/Management (Owner's Representative)
Special Storage	Access Control	Special Inspections and Tests
Equipment & Material Purchase and Installation	Security CCTV	Legal Fees
Construction Equipment Rentals	Furniture and Appliances	Archeological Finds and Digs
Testing	Laboratory Test Equipment	Office Supplies, Dishware, Cleaning Supplies, and Household Items
Startup & Commissioning		**Reserve for Unforeseen Conditions and Conflicts**
Normal Warranties		**Owners Reserve for Change Orders**
General Conditions, Overhead, Profit, Risk, Contingency		
Taxes		
Insurance & Bonds		

Estimating Approaches

The following are common approaches for estimating construction costs, starting with methods most applicable to the planning stage and ending with the elemental cost analysis (ECA) method with is the most accurate and applicable to final design and bidding. The excel software provided with the course is based on the ECA method.

1. Engineering Judgement
    a. Based on a combination of experience (reference projects) and in-depth knowledge of the project requirements.
    b. An engineer's analytical assessment can consider actual costs from previous projects and account for design complexity, existing conditions, unknowns, inflation, escalation, and market trends.
    c. Costs remembered from previous projects that are confidential or don't have accessible documentation form part of an engineer's judgment.

2. Reference Project Cost
    a. A "top-down" approach, often called analogous estimating.
    b. Take costs from a similar previous project and apply the annual cost increase based on average inflation or construction cost index factors:

       Today' Value = Historic Cost * (1 + inflation) ^ (number of years)

    c. Example: Similar project 5 years ago had a construction cost of $1M. In today's dollars with 5% cost increase per year:

       Estimated Cost = $1,000,000 * (1.05) ^ 5 = $1,276.000.

3. Parametric Cost Modeling
    a. Using mathematical models, formulas, and/or software with data from previous installations to estimate overall construction or capital cost.
    b. Can be simple linear or quadratic formulas. Or can have multiple factors.
    c. Specific approaches include cost-capacity curves, scale of operations factors, Lang factors, Hand factors, Chilton factors, Peters-Timmerhaus factors, and Guthrie factors.
    d. Single factor, linear example: A company recently constructed a 1 million pound per year (mpy) facility for $100M. Now they want to build a new 2 mpy facility. Since capacity is double, the estimated cost is double, or $200M. A time escalation is also need.

4. Duration Plus Materials
    a. This approach is best for small projects when construction duration and crew size is accurately known.
    b. Example: Construction period is 10 weeks with a nominal weekly rate of $10,000 (includes most direct & indirect costs), plus $50,000 in materials, rentals, permit fees, etc.:

Estimated Cost = $10,000 * 10 + $50,000 = $150,000.

5. Equipment Factored
    a. The equipment cost (usually from a supplier quote) is multiplied by an "installation factor" to arrive at a total cost for all work directly associated with the equipment or “unit process”.
    b. Unit process costs are summed and any costs for non-unit process work added, for a total construction cost.
    c. Example: A boiler replacement project has a boiler quote of $400,000 with an installation factor of 1.5. Removal of the existing boiler is estimated at $50,000.

Estimated Cost = $400,000 * 1.5 + $50,000 = $650,000

6. Unit Cost
    a. Also called “single-unit rate” (SUR) method.
    b. Categories: Square Foot, Cubic Foot, Functional Area, Accommodation Method (per parking spot, room, bed, seat, apartment, etc.).
    c. Common for buildings, roads, pipelines, duct banks, ducts, and earthwork.
    d. Common approach for unit line items in an elemental cost analysis.
    e. Example: For a building size of 5,000 sq ft and unit costs of $500 per sq ft:

Estimated Cost = 5,000 sf * $500/sf = $2,500,000

7. Elemental Cost Analysis (ECA)
    a. Bottom-up approach with a detailed list of construction items/elements.
    b. Also called a "detailed estimate" or "detailed take-off".
    c. The most popular approach, especially for final design and bid estimates.
    d. Usually the most accurate estimating method.
    e. Can utilize gross, semi-detailed, or detailed unit costs (sometimes with thousands of line items).
    f. Can be organized by CSI UniFormat (Level 1, 2 or 3) or Uniformat II (Levels 1, 2, 3, and 4), with 1 being most general and 3 or 4 most detailed.
    g. Can be organized by improvement areas (Building A, Building B, garage, standby power, site work, utilities, roadwork, security, etc.).
    h. Can be organized by CSI MasterFormat, which organizes construction work into 16 or 50 divisions, each with common specification sections.
    i. See the excel software provided with this course.
    j. Example:

Item	Calculation	Item Cost
Conveyor Equipment	$30k Quote * 110%	$33,000
Mechanical Sub.	$10k Quote * 110%	$11,000
Electrical Sub.	$8k Quote * 110%	$8,800
Installation Support	40 hrs * $100/hr	$4,000
Startup & Testing	10 hrs * $100/hr	$1,000
…		

Using a Cost Index

Cost indices are also called “cost adjustment factors”.

CCI

A construction cost index (CCI) measures changes over time in the cost of a type of construction (residential, commercial, industrial, roadwork, etc.). A CCI takes into account price changes in materials, equipment, salaries, transportation, and local market conditions. CCI’s are often used by engineers to estimate the cost to escalate a known building/construction cost to today’s value, which can then be utilized for estimating the cost of similar projects. The typical formula is as follows:

Current Cost = Old Cost * (Current CCI / Old CCI)

Example:
A bridge originally cost $1,500,000 in 2014 when the index was 1.20. The current index is 1.60. The estimated construction cost for the same bridge today would be:

Estimated Cost = $1,500,000 * (1.60 / 1.20) = $2,000,000

LCI

A location cost index (LCI), also called area cost factor (ACF) or location cost factor, is the ratio of the cost in one location to that in another location. The national average factor (NAF) is usually set to 1.00 which represents a generic cost estimate. Multiplying by an LCI converts a generic estimate to a localized estimate. Any time conversion is done separately according to the CCI formula above.

Types of LCI’s include:

- City cost index (usually for large cities)
- State cost index
- Regional cost index (Midwest, Southeast, etc.)
- Country cost index

The formula to convert between locations:

Location A Cost = Location B Cost (Location A LCI / Location B LCI)

Example:
A new box store near St. Louis (LCI of 0.96) bid for $2,000,000. A duplicate store is planned in Newark (LCI of 1.18). The construction cost for the Newark store is estimated as follows (rounded):

Estimated Cost = $2,000,000 (1.18 / 0.96) = $2,458,000

The formula to convert a generic estimate to a specific location (assuming NAF = 1.0):

Location A Cost = Generic Cost * Location A LCI

Example:
A new box store is being considered for one of two locations: St. Louis (LCI of 0.96) and Newark (LCI of 1.18). The generic cost estimate is $2,000,000. What is the estimated construction cost adder for choosing Newark versus St. Louis?

Estimated Cost Adder = $2,000,000 (1.18 - 0.96) = $440,000

<u>MCI</u>
A material cost index (MCI) measures changes over time in the cost of a certain material or group of materials. An MCI helps estimate line items within a construction cost estimate. It also helps companies update their cost databases from which cost estimating pulls data. The MCI formula is the same as CCI:

Current Cost = Old Cost (Current MCI / Old MCI)

Example:
A cost database from April 2020 has 1/4” A36 steel plate at $4.10/lb. The April 2020 steel MCI is 220 and the August 2024 steel MCI is 300. The updated unit cost value for 1/4” A36 steel plate is calculated here:

Updated Unit Cost = $4.10 (300 / 220) = $5.59

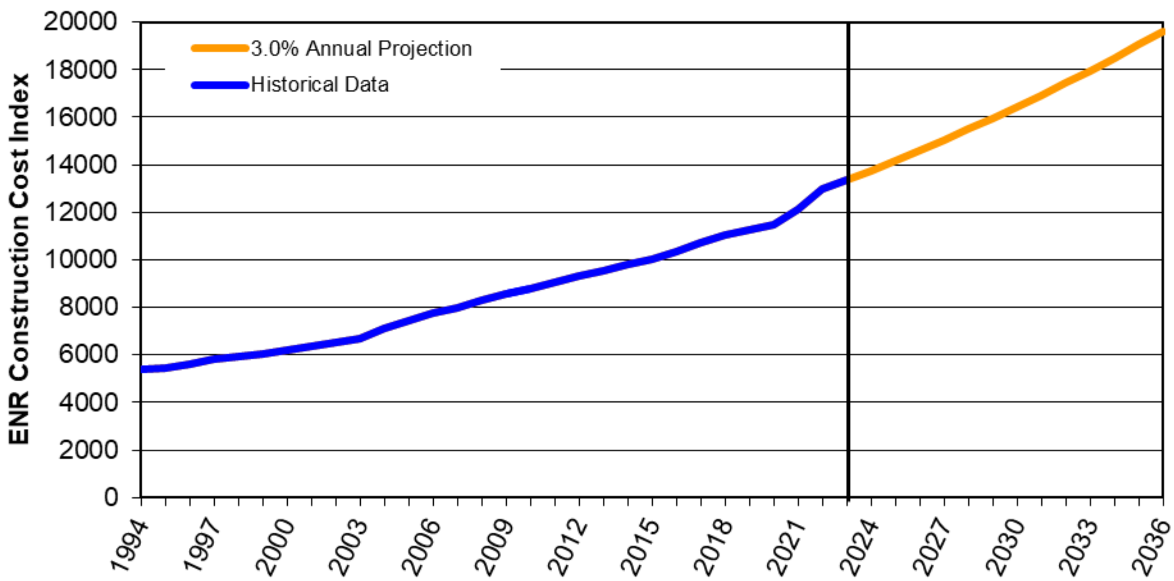
Popular Indices

The following are commonly used cost indices and sources for cost data.

Engineering News Record (ENR):

- The below indices have data from 1978 to present.
- Construction Cost Index (CCI):
  - Shows cost differences between 20 cities and the national average (see chart below)
  - Includes 200 hours of common labor, 25 cwt of structural steel shapes, 1.128 tons of portland cement, plus 1,088 board-ft of 2x4 lumber.
- Building Cost Index (BCI):
  - Shows cost differences between 20 cities and the national average
  - Includes 68.38 hours of skilled labor, 25 cwt of structural steel shapes, 1.128 tons of portland cement, plus 1,088 board-ft of 2x4 lumber.
- Material Price Index: Tracks the weighted price movement of structural steel, portland cement and 2 X 4 lumber.
- Skilled Labor Index: Tracks union wages, plus fringe benefits, for carpenters, bricklayers and iron workers.
- Common Labor Index: Tracks the union wage, plus fringe benefits, for laborers.
- Website: https://www.enr.com/economics

Average Annual ENR Construction Cost Index (CCI)



RSMeans:

- RSMeans City Cost Index
- Cities and national data from 1980 to present.
- Full historical data on 30 major cities and recent data on 318 cities.
- Lists materials, labor, and equipment separately.
- Cost estimating data for over 92,000 line items available online, in books, or on CDs (formerly known as CostWorks)
- Website: https://www.rsmeans.com/resources

Turner Building Cost Index (TBCI):

- Nationwide with focus on nonresidential buildings.
- Determined by labor rates, productivity, material prices, and the competitive condition of the marketplace.
- Website: www.turnerconstruction.com/cost-index

Census Bureau Construction Price Index:

- Two nationwide construction indices from 2005 to present:
    - Single-Family Houses Under Construction
    - Multifamily Houses Under Construction
- Two tables: Constant Quality (Laspeyres) and Price Deflator (Fisher).
- Website: www.census.gov/construction/cpi/index.html

Elements of an Estimate

Tables 1 and 2 provide a list of common direct and indirect costs. The items in Table 2 match the items in the software provided with this course. For simplicity, often the various indirect terms are grouped into a "GCs and Overhead" line of 15 to 30%.

Table 2: Common Direct and Indirect Cost Items		
Cost Type	Items	Sources & Typical Values
Direct	Materials	Material items, equipment, assemblies, pipe, conduit, items to install, chemicals
	Labor	Raw hourly pay times overhead factor (2 to 3)
	Subcontractors	Contractor quotes, rate sheets, proposals
	Other	Shipping, rentals, storage, tools, fuel, temporary items, travel & misc. expenses
Indirect	Sales Tax	3 to 8%
	Permit Fees	0.5 to 2%
	General Conditions	5 to 15%
	Overhead	3 to 8%
	Markup and Profit	4 to 15%
	Bonds and Insurance	0.5 to 4%
	Escalation to Mid-Point	0 to 10%
	Contingency	5 to 50%
	Accuracy Range	0 to 30%

Indirect Costs

The following is a description of common indirect cost items.

- **Sales Tax**. Sales tax is often 3 to 8% of material costs since labor is not taxable. A convenient approach is 3 to 8% of 50% of the total direct cost. Some projects qualify for a tax-exempt status which can require a careful evaluation and proper documentation.
- **Permit Fees.** Building permit fees are usually the vast majority of permit fees. The fees can depend on the building department rates, building area, building stories/height, construction type, location, total disturbed area, building cost, or total construction cost. Permit fees typically range from 0.5 to 2% of the direct cost.
- **General Conditions.** Project specific expenses including project management, administration, temporary site facilities (job trailer, port-a-potty, storage area, fence, etc.), safety compliance, weather protection, waste removal, testing, and warranty. Mobilization and demobilization costs (1 to 5%) can be either general conditions or a direct cost. General conditions with mob/demob typically ranges from 5 to 15% of direct costs.
- **Overhead.** Non-project specific expenses to cover the contractor's main office operations, including the administration of subcontracts. Overhead typically ranges from 3 to 8% of direct costs.
- **Markup and Profit**. Contractor's markup and profit typically ranges from 4 to 15% of the sum of direct costs, sales tax, general conditions, and overhead.
- **Bonds and Insurance.** Include insurance and bond premiums with limits that vary based on the contract requirements and contractor standards. Bonds and insurance often range from 0.5 to 4% of the total construction cost (often without the indirect cost items below).
- **Escalation to Mid-Point**. The cost of the project is increased based on projected cost increases and the time to the mid-point in the construction duration. Recent cost index data can help project the annual percent cost increase. For example, a two-year construction project set to start in one year would be two years to the mid-point, and at a projected 5% per year the escalation to mid-point would be 10%.
- **Contingency**. Contingency accounts for minor scope adjustments, unforeseen conditions, market condition changes, estimator errors and omissions, design errors and omissions, undesigned details, and liquidated damages. As the design advances, the contingency can be reduced as explained in the next section. Typical contingency values are 5 to 50%.
- **Accuracy Range**. An estimate can be provided as a range based on high and low accuracy factors. As a design progresses, accuracy increases and the range decreases.

Example Cost Summary Page

The following is an example cost summary page taken from the free software with this course. In this case, the direct costs are presented as four items, each representing a major element of work. The other option is to present the totals by each specification division.

Contingency is assigned for each direct cost item based on percent complete of the design, with a total contingency value calculated and utilized.

Construction Cost Estimate

Client:	City of ABC	Date:	8/19/2024
Project:	Building Addition	By:	MNL
Job No.:	53ABC24.01	Check:	ABC

No.	Description		Total	Percent of Total	Percent Complete	Contin-gency	Typical Values
1	Demolition		$ 352,000	4%	40%	15%	
2	Sitework		$ 412,964	5%	40%	15%	
3	Building ABC		$ 5,850,000	74%	20%	30%	
4	Storage Canopy		$ 1,275,000	16%	30%	20%	
	Total Direct Cost		**$ 7,889,964**	100%	24%	27%	
	Sales Tax	6.0%	$ 236,699				3 to 8% of 50% of direct
	Permit Fees	1.0%	$ 78,900				0.5 to 8% of direct
	General Conditions	10.0%	$ 788,996				5 to 15% of direct
	Overhead	5.0%	$ 449,728				3 to 8% of sum of above items
	Markup and Profit	5.0%	$ 77,716				4 to 15% of sum of above items
	Bonds and Insurance	3.0%	$ 285,660				0.5 to 4% of sum of above items
	Escalation to Mid-Point	3.0%	$ 294,230				0 to 10% of sum of above items
	Contingency	27%	$ 2,720,411				5 to 50% of sum of above items
	Total Indirect Cost		**$ 4,932,340**				
	Estimated Construction Cost		**$ 12,820,000**				Rounded
	Accuracy Range - Low	0%	$ -				-20 to 0% of estimate
	Accuracy Range - High	20%	$ 2,564,000				10 to 50% of estimate
	Estimate Range - Low		**$ 12,820,000**				
	Estimate Range - High		**$ 15,384,000**				

Example Cost Detail Page

The following is one of four “tabs” in the excel cost estimate. Each tab represents a unit process or major element of work. The detailed cost line items are grouped by Division.

Construction Cost Estimate No.: **2**
Description: **Sitework**

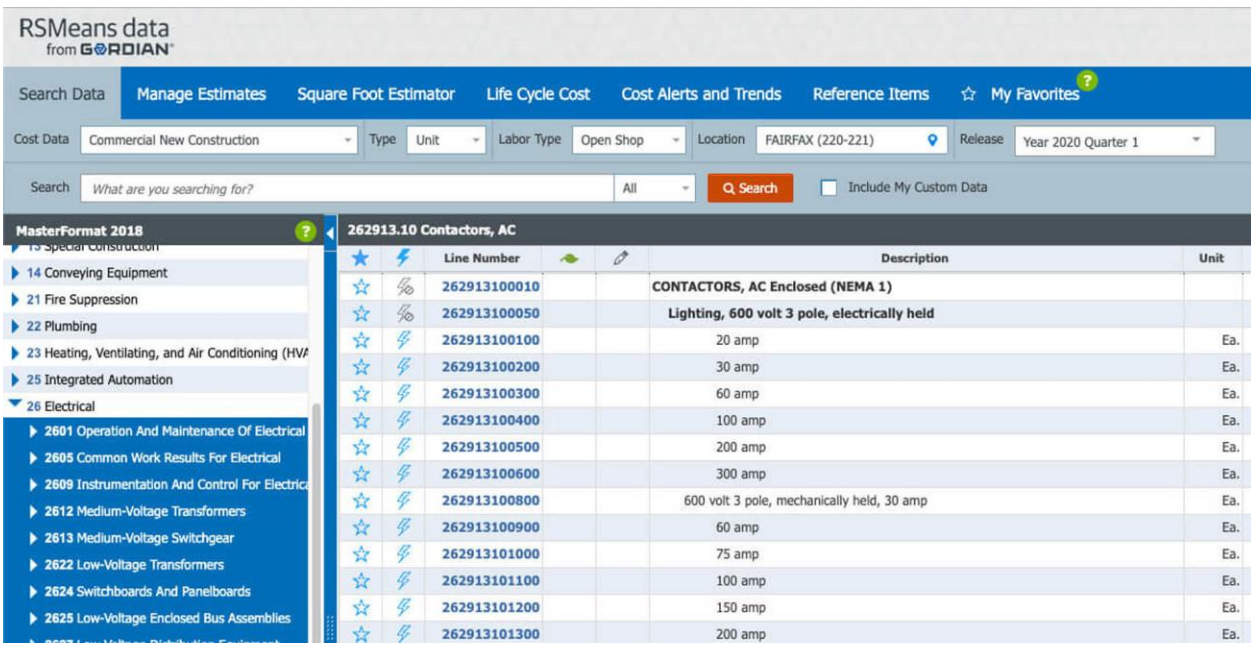
DIVISION & SECTION	LINE ITEM DESCRIPTION	QUANTITY	UNIT	MATERIALS		LABOR				SUBCONTRACTS		OTHER		TOTAL
				UNIT COST	MATERIAL COST	UNIT HRS	TOTAL HRS	LABOR RATE	LABOR COST	UNIT COST	SUB COST	UNIT COST	OTHER COST	
DIVISION 1	**GENERAL REQUIREMENTS**													
					$0				$0		$0		$0	$0
					$0				$0		$0		$0	$0
		SUBTOTAL			**$0**				**$0**		**$0**		**$0**	**$0**
DIVISION 2	**SITEWORK**													
	Site Clearing	1,600	SY		$0	0.10	160	$75.00	$12,000		$0	$4.00	$6,400	$18,400
	Excavation	1,000	CY		$0	0.30	300	$80.00	$24,000		$0	$20.00	$20,000	$44,000
	Hauling Dirt	1,000	CY		$0	0.20	200	$80.00	$16,000		$0	$2.00	$2,000	$18,000
	Backfill and Compaction	1,500	CY	$2	$3,000	0.20	300	$80.00	$24,000		$0	$10.00	$15,000	$42,000
	Aggregate Purchase	400	CY	$50	$20,000		0		$0		$0		$0	$20,000
	Grading	1,600	SY		$0	0.20	320	$75.00	$24,000		$0	$4.00	$6,400	$30,400
	Landscaping	1	LS		$0		0		$0	$1.00	$40,000	$4.00	$4	$40,004
	Erosion Control Fence	1,000	LF	$1	$1,000	0.10	100	$70.00	$7,000		$0		$0	$8,000
		SUBTOTAL			**$24,000**				**$107,000**		**$40,000**		**$49,804**	**$220,804**
DIVISION 3	**CONCRETE**													
	Sidewalk	800	SF	$10	$8,000	0.20	160	$80.00	$12,800		$0		$0	$20,800
	Pipe Bollards	12	EA	$500	$6,000	16.00	192	$80.00	$15,360		$0		$0	$21,360
		SUBTOTAL			**$14,000**				**$0**		**$0**		**$0**	**$42,160**
DIVISION 4	**MASONRY**													
					$0		0		$0		$0		$0	$0
					$0		0		$0		$0		$0	$0
		SUBTOTAL			**$0**		**0**		**$0**		**$0**		**$0**	**$0**

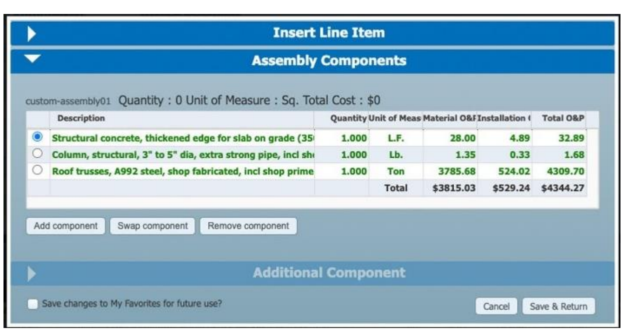
Software and Calculators

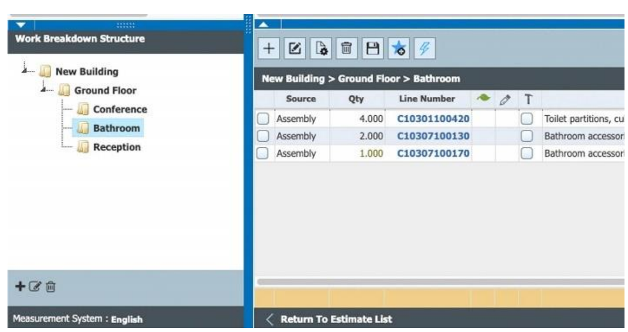
Software, calculators, and other digital tools are increasingly utilized for cost estimating purposes. Some are available commercially and others are developed by companies for internal use only. “Integrated estimating” is an approach that focuses on utilizing costing software that integrates with scheduling software, BIM, or other project management software.

Estimating Software

There are several cost estimating software options available for purchase. Many target a particular sector such as residential houses, apartments, or commercial buildings. The most common software is RSMeans Data Online Construction Cost Estimating Software, which has over 92,000 line items available. This was formerly known as CostWorks, which is still available offline on a CD format. See below for RS Means Data Online screenshots from www.rsmeans.com/products/online.



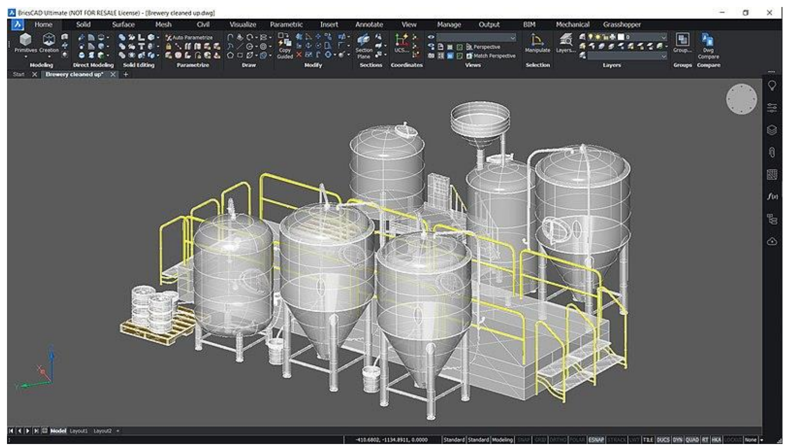




BIM Quantity Take-offs
Most projects have 3D models drawn in CAD. These models can have material properties assigned, which allows the creation of bills of materials which are helpful for cost estimating. These advanced 3D models are often referred to as BIM models. BIM stands for *Building Information Modeling.* BIM allows multiple types of software to create a single 3D model of the improvements. BIM approaches can interface directly with cost estimating software. This is an "integrated estimating" approach.

Example software includes:

- Autodesk Takeoff
- Simplified 2D Takeoff
- RSMeans eTakeoff
- BeckTech Destini Estimator
- Bentley Synchro
- Sage Estimating
- CostX
- HCSS HeavyBid



Source: https://commons.wikimedia.org/wiki/File:BricsCAD_User_Interface.jpg

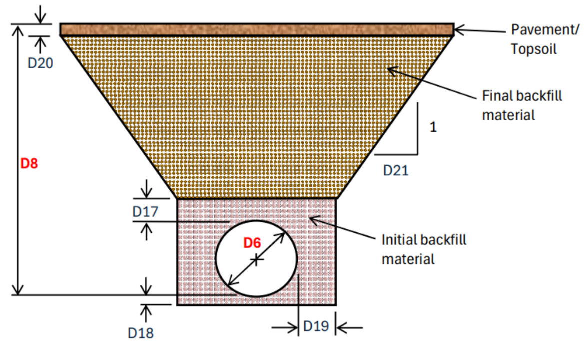
Calculators
In order to determine material quantities, special calculations are often required. These calculations are often done by the design engineer with the help of special calculator tools. As an example, a pipe trenching calculator is included with this course. The result is an estimated direct cost which still needs the indirect costs added.

INPUTS: Project Specific

Description	Label	Inputs	Units	Notes and References
Pipe diameter	D6	30	in	Nominal, assumed as OD for backfill calculations
Pipe material	D7	RCP	n/a	enter costs -see table for PVC, HDPE, DI, PCCP, RCP
Pipe depth to invert	D8	8	ft	Consider local frost cover required; min. 1' rigid, 1.5' flexible
Length of pipe run	D9	1	ft	Divide into runs by coping this tab; set to 1 for "cost per foot"
Percent pavement	D10	50%	%	Includes subbase (restoration material), base, finish
Percent grass	D11	50%	%	Includes new topsoil, seed, mulch & fertilizer
Percent slope >10%	D12	5%	%	Erosion control mat for greater than 10% slopes
# of trees	D13	0	no.	Enter number of trees to be demolited

DIMENSION ASSUMPTIONS: Adjust as needed

Description	Label	Inputs	Units	Notes and References
Initial backfill cover	D17	12	in	Usually 10" to 12" depending on pipe size and material
Bedding depth	D18	4	in	Usually 4" to 6" depending on pipe size and material
Initial backfill width from Pipe OD	D19	18	in	Usually 9" to 18" depending on pipe size and material
Pavement or topsoil depth	D20	8	in	Restoration material including topsoil for grass or subgrade for pavement
Slope run (_H:1V)	D21	1	-	OSHA: 3/4 for soil type A, 1 for soil type B, 1.5 for soil type C For no slope (shielding or rock) input run as 0.00001 (not zero)
Pipe wall thickness	D22	1	in	Can range from 1/4" to 2" depending on pipe



COST TABLE:

Description	Value	Units	MATERIALS $/Unit	MATERIALS Cost	LABOR Hrs/Unit	LABOR Hours	LABOR Rate	LABOR Cost	EQUIPMENT FOR INSTALL $/Unit	EQUIPMENT FOR INSTALL Cost	Total Cost	Notes and References (CostWorks line items as CW)
Excavation	2.5	cy	$ -	$ -	0.10	0.25	$ 80.00	$ 20.20	$ 5.10	$ 12.63	$ 32.83	1 CY excavator CW 312316-0600 + minimal haul & dewatering
Initial backfill	0.6	cy	$ 51.00	$ 30.55	0.17	0.10	$ 80.00	$ 8.15	$ 10.20	$ 6.11	$ 44.81	Aggregate, crushed stone - 0.5" CW 310516-0340 + compaction vibrating roller, 6" lifts
Final backfill	1.4	cy	$ 3.40	$ 4.64	0.17	0.23	$ 80.00	$ 18.58	$ 10.20	$ 13.93	$ 37.16	Borrow material w $2/cy for sand addition CW 310513-0020 + compaction vibrating roller, 6" lifts
Demo Existing Pavement	0.7	sy	$ -	$ -	0.07	0.05	$ 80.00	$ 4.03	$ 2.55	$ 1.89	$ 5.92	Demolition of existing pavement, backhoe, hydralic hammer CW 024113-5050/5200 - 6" thick bituminous/concrete (avg)
New Pavement	0.7	sy	$ 39.10	$ 28.96	0.77	0.57	$ 80.00	$ 45.33	$ 4.71	$ 3.49	$ 77.78	Sand-gravel sub-base with concrete or asphalt pavement CW 321216-1080 - 6" thick asphalt w subbase, 5 ton roller
Topsoil	0.2	cy	$ 39.10	$ 6.44	0.09	0.01	$ 80.00	$ 1.12	$ 7.23	$ 1.19	$ 8.74	New topsoil spread CW 310513-0800 (2 mi. haul, no compaction, 200 HP dozer)
Grass restoration	0.7	sy	$ 0.56	$ 0.42	0.09	0.06	$ 80.00	$ 5.04	$ 0.60	$ 0.44	$ 5.89	Seeds, fertilizer and mulch CW R329219-0310 + 1100
Silt fence	1.0	ft	$ 0.60	$ 0.60	0.03	0.03	$ 80.00	$ 2.04	$ -	$ -	$ 2.64	Length based on both sides of trench, $2/ft (WSG), only in "grass" CW 312513-1100 (adverse conditions - $1.16/ft)
Erosion control	0.1	sy	$ 8.25	$ 0.61	0.03	0.00	$ 80.00	$ 0.20	$ 0.71	$ 0.05	$ 0.87	erosion control mat placed CW 312513-0060/0120
Tree removal	0	No.	$ -	$ -	11.05	0.00	$ 80.00	$ -	$ 510.00	$ -	$ -	assumes avg 10" dia, 2 mi haul to dump CW 311313-2050+3100 (chain saw, chipper, stump w backhoe)
Pipe Purchase & Install	1	ft	$ 90.00	$ 90.00	0.50	0.50	$ 80.00	$ 40.00	$ 15.00	$ 15.00	$ 145.00	Edit red values
Total	-	-		$ 162.22		1.81	-	$ 144.69		$ 54.73	**$ 361.64**	**Total Estimated Direct Cost**

Stage Gate Estimates

Engineering design is often performed in a series of steps called stages, phases, or tasks. For example, here is a simple three step approach:

Preliminary Study **>** Conceptual Design **>** Final Design

At the end of each step a cost estimate is often provided along with other deliverables. The estimate is reviewed by stakeholders and key decisions are made before advancing to the next step. These pauses between steps are referred to as "gates" or "stage gates".

Preliminary Study **>** Conceptual Design **>** Final Design

Gate 1	Gate 2
-Deliverables Review -Decision to Proceed	-Deliverables Review -Decision to Proceed

Most projects involve some form of a stage gate process. Many organizations have developed a stage gate methodology that fits the needs of the organization. Project managers are generally tasked with ensuring the stage gate methodology is being followed for each project.

The stage gate approach typically results in additional engineering effort early in the project. However, this extra engineering cost, typically 2 to 5% of the construction cost, is usually justified as it decreases construction cost and duration. According to a 2009 survey by Construction Industry Institute (CII), owners that put effort into front end planning with stage gates save an average of 8% on capital costs.

Making key decisions early allows a greater influence on the final cost and schedule for relatively less effort. Figure 1 depicts how design changes early in the project have the greatest potential to decrease the construction cost and overall project cost.

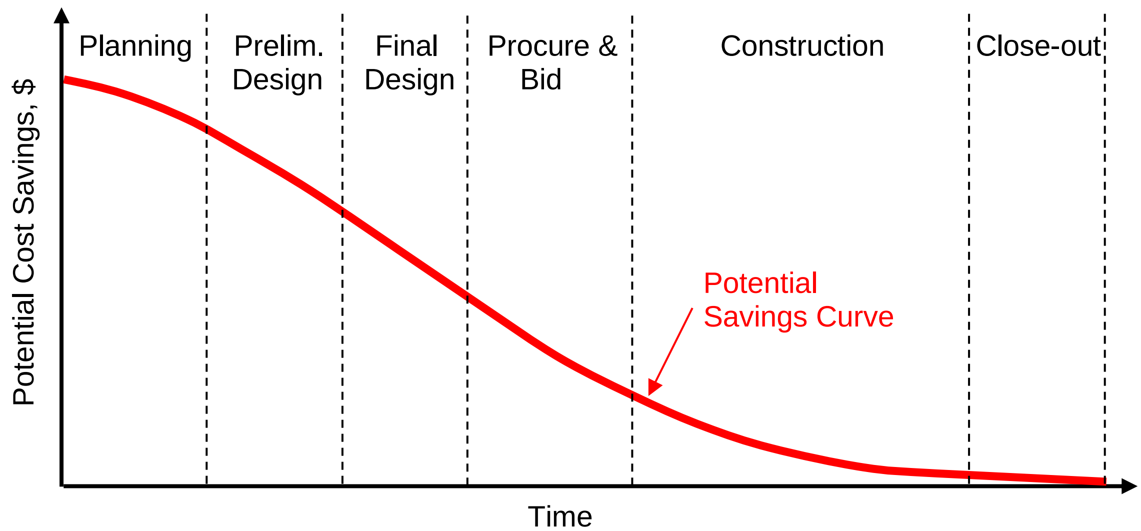
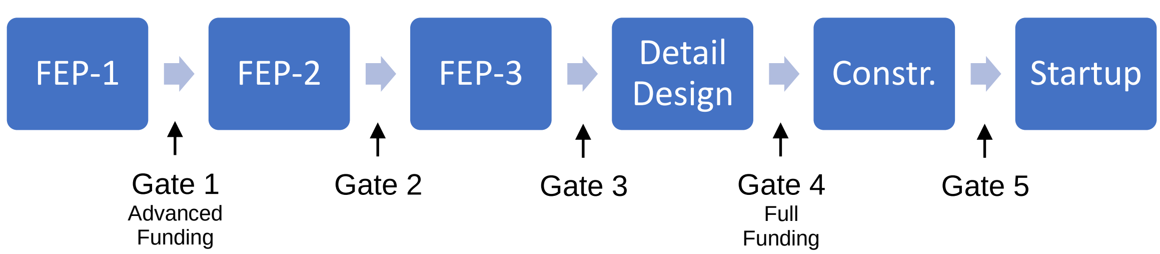


Figure 1 – Curve in red showing decreasing ability over time to lower the total project cost by making design changes. Each dashed vertical line is a stage gate.
Source: Author

Front-End Planning

The most common stage gate methodology is Front-End Planning (FEP), also called Front-End Loading (FEL). FEP focuses on the early development of strategic information to confirm the business case for the project. The idea is to put more effort into planning so the end results will more closely align with success criteria. FEP standards are published by the Construction Industry Institute (CII).

The FEP workflow is as follows (a bidding stage may be added after Detail Design):



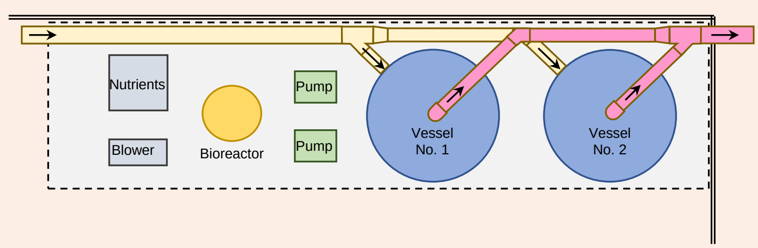
The engineering stages FEP1 through DD are described in detail on the next pages.

FEP-1 / FEL-1

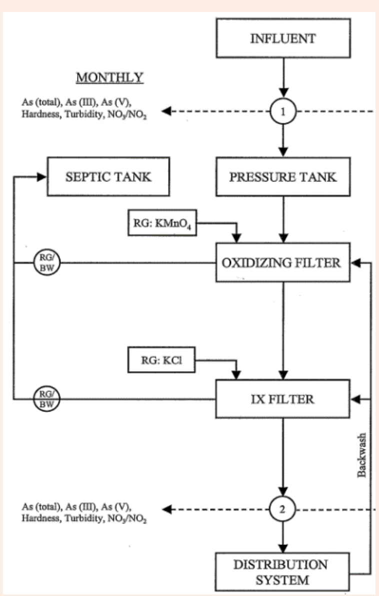
Known As	Inputs (if available)	Deliverables
• Feasibility • Assess • Business Planning • Rough Order of Magnitude • Ballpark • Study • Planning	• Business Objectives • Business Case • Regulatory Requirements • Previous Studies • Existing Drawings • Other Existing Information	• Scope Description • Business Case • Schematic Layout • Feasibility Report • Block Flow Diagram (BFD) • Project Timeframe • Major Equipment List • Alternatives Comparison • PDRI 1

- Percent of Engineering Fee: 2 to 5%
- Percent Complete of Construction Documents: 0 to 5%
- **AACE Cost Estimate Class: 5**

Schematic Layout



BFD



Alternatives Comparison

Table 4: Example Multi-criteria Scoring Table

Indicator	Weight Factor	Asphalt Shingle Normal. Index	Asphalt Shingle Weighted Index	Clay Tile Roof Normal. Index	Clay Tile Roof Weighted Index	Metal Roof Normal. Index	Metal Roof Weighted Index
Installation Time	10	1.0	10	0.4	4	0.6	6
Constr. Cost	30	1.0	30	0.2	6	0.3	9
Colors Available	10	0.2	2	0.1	1	1.0	10
Aesthetics	10	0.4	4	1.0	10	0.6	6
Life Span	20	0.3	6	1.0	20	0.8	16
Storm Resist.	20	0.7	14	0.8	16	1.0	20
Aggregated Index		-	66	-	57		**67**
Final Score (Normalized to 1)		-	0.99	-	0.85		**1.0**

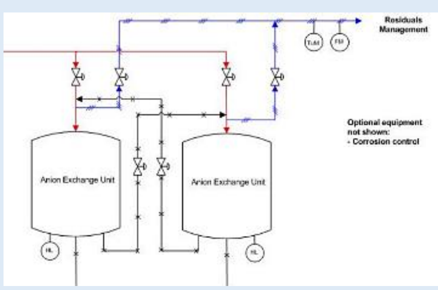
Figure 2: Example FEP-1 Deliverables

Source: Author

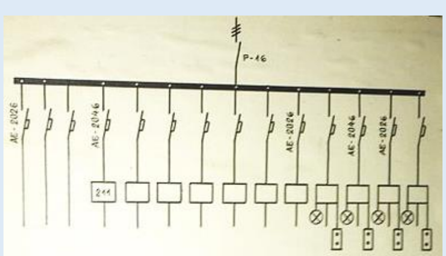
FEP-2 / FEL-2		
Known As	**Inputs (if available)**	**Deliverables (U = Updated from FEP-1)**
• Concept • Conceptual Design • Select • Preliminary • Pre-Design • Pre-FEED • Feasibility Design • Study (II)	• FEP-1 Deliverables • Safety Requirements • Client Specifications & Standards	• Updated FEP-1 Deliverables • Preliminary Design Report • Site Layout • Process Flow Diagram (PFD) • Power One-Line Diagram • Controls Architecture • Project Schedule • Drawing & Specification List • Geotechnical Report • Environmental Assessment • Topographical Survey • PDRI 2

- Percent of Engineering Fee: 5 to 10%
- Percent Complete of Construction Documents: 5 to 30%
- **AACE Cost Estimate Class: 4**

PFD



One-Line



Site Layout

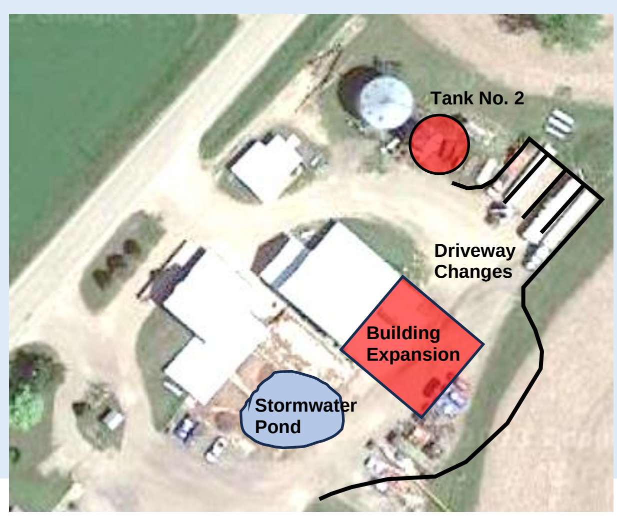


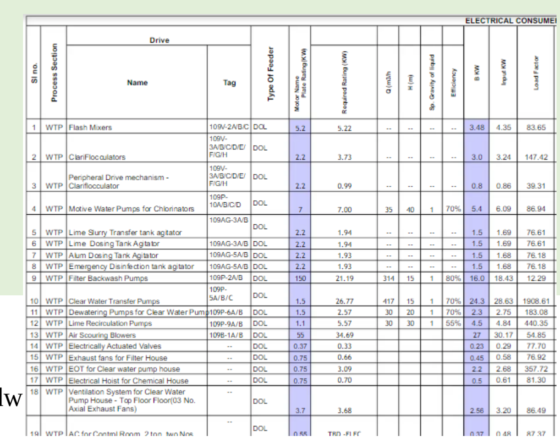
Figure 3: Example FEP-2 Deliverables

Source: commons.wikimedia.org/wiki/File:Soviet-era_one-line_diagram.jpg, Dmitry G, CC-BY-SA-3.0 (lower left)

FEP-3 / FEL-3 Front-End Engineering Design (FEED)		
Known As	**Inputs (if available)**	**Deliverables (U = Updated from FEP-1)**
• Define • Budget • Basic Engineering • Detailed Scope • Front-End Engineering • Preliminary Design	• FEP-2 Deliverables • Existing Conditions & Data • Site Assessment Reports • Property Deeds & Easements • Utility Agreements & Bills • Detailed Regulatory Requirements • Reference Project Information	• Updated FEP-2 Deliverables • Issue for Design (IFD) Drawings and Specifications • P&IDs • Building Plans and Elevations • Foundation Plans • Equipment Arrangements • Equipment Specifications • 3D Model (Draft) • Motor List and Power Requirements • Controls Strategy • PDRI 3
• Percent of Engineering Fee: 10 to 20% • Percent Complete of Construction Documents: 10 to 60% • **AACE Cost Estimate Class: 3**		

Elevation

Motor Load List



		ELECTRICAL CONSUME												
Sl no.	Process Section	Drive		Type Of Feeder	Motor Name Plate Rating(KW)	Required Rating (KW)	Q (m3/h	H (m)	Sp. Gravity of liquid	Efficiency	B KW	Input KW	Load Factor
		Name	Tag										
1	WTP	Flash Mixers	109V-2A/B/C	DOL	5.2	5.22	--	--	--	--	3.48	4.35	83.65
2	WTP	ClariFlocculators	109V-3A/B/C/D/E/F/G/H	DOL	2.2	3.73	--	--	--	--	3.0	3.24	147.42
3	WTP	Peripheral Drive mechanism - Clariflocculator	109V-3A/B/C/D/E/F/G/H	DOL	2.2	0.99	--	--	--	--	0.8	0.86	39.31
4	WTP	Motive Water Pumps for Chlorinators	109P-10A/B/C/D	DOL	7	7.00	35	40	1	70%	5.4	6.09	86.94
5	WTP	Lime Slurry Transfer tank agitator	109AG-3A/B	DOL	2.2	1.94	--	--	--	--	1.5	1.69	76.61
6	WTP	Lime Dosing Tank Agitator	109AG-3A/B	DOL	2.2	1.94	--	--	--	--	1.5	1.69	76.61
7	WTP	Alum Dosing Tank Agitator	109AG-5A/B	DOL	2.2	1.93	--	--	--	--	1.5	1.68	76.18
8	WTP	Emergency Disinfection tank agitator	109AG-5A/B	DOL	2.2	1.93	--	--	--	--	1.5	1.68	76.18
9	WTP	Filter Backwash Pumps	109P-2A/B	DOL	150	21.19	314	15	1	80%	16.0	18.43	12.29
10	WTP	Clear Water Transfer Pumps	109P-5A/B/C	DOL	1.5	26.77	417	15	1	70%	24.3	28.63	1908.61
11	WTP	Dewatering Pumps for Clear Water Pump	109P-6A/B	DOL	1.5	2.57	30	20	1	70%	2.3	2.75	183.08
12	WTP	Lime Recirculation Pumps	109P-9A/B	DOL	1.1	5.57	30	30	1	55%	4.5	4.84	440.35
13	WTP	Air Scouring Blowers	109B-1A/B	DOL	55	34.69					27	30.17	54.85
14	WTP	Electrically Actuated Valves	--	DOL	0.37	0.33					0.23	0.29	77.70
15	WTP	Exhaust fans for Filter House	--	DOL	0.75	0.66					0.45	0.58	76.92
16	WTP	EOT for Clear water pump house	--	DOL	0.75	3.09					2.2	2.68	357.72
17	WTP	Electrical Hoist for Chemical House	--	DOL	0.75	0.70					0.5	0.61	81.30
18	WTP	Ventilation System for Clear Water Pump House - Top Floor Floor(03 No. Axial Exhaust Fans)	--	DOL	3.7	3.68					2.56	3.20	86.49
19	WTP	AC for Control Room, 2 ton, two Nos	--	DOL	0.55	TBD -ELEC					0.37	0.48	87.37

P&ID

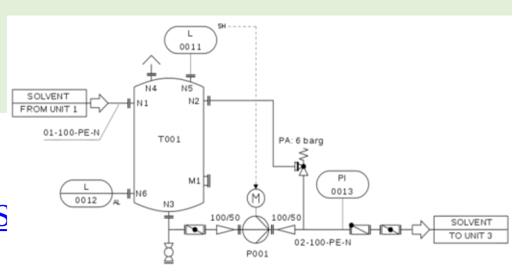
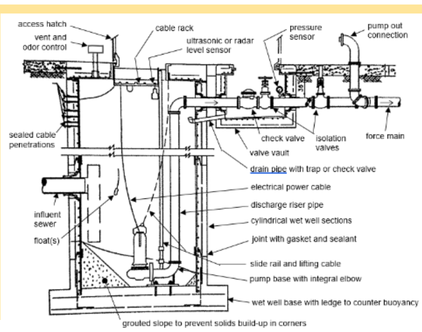


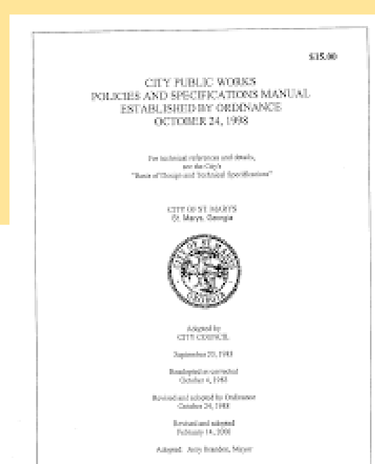
Figure 4: Example FEP-3 Deliverables
Source: commons.wikimedia.org/wiki/ File:Pump_with_tank_pid_en.svg, Con-struct, CC-BY-SA-3.0

FEP-4 / FEL-4 Detailed Design (DD)		
Known As	**Inputs (if available)**	**Deliverables (U = Updated from FEP-1)**
• Detail Design • Final Design • Detailed Engineering • Design • FEP-4 • FEL-4	• FEP-3 Deliverables • Existing Systems Information • Existing Tie-in Details • Lessons Learned from Reference Projects • Standard Operating Procedures • Project Requirements and Constraints	• Updated FEP-3 Deliverables • Issue for Construction (IFC) Drawings and Specifications • Detailed Equipment List • Pipe Schedule • Detailed Project Schedule • 3D Model (Final) • Controls Descriptions • Regulatory Approvals • Calculations Packages • I/O Lists • Wire & Conduit Schedules • Control Panel Layouts
• Percent of Engineering Fee: 60 to 70% • Percent Complete of Construction Documents: 60 to 100% • **AACE Cost Estimate Class: 1 or 2**		

Detail Drawing



Specifications


$15.00

CITY PUBLIC WORKS
POLICIES AND SPECIFICATIONS MANUAL
ESTABLISHED BY ORDINANCE
OCTOBER 24, 1998

CITY OF ST. MARYS
St. Marys, Georgia

Conduit Schedule

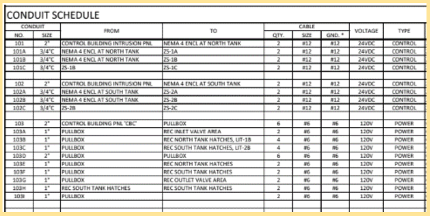

CONDUIT SCHEDULE

Figure 5: Example Detailed Design Deliverables

AACE Estimate Classes

The Association of Advancement for Cost Engineering (AACE) developed a recognized standard for cost estimating entitled "Cost Estimate Classification System" (18R-97). The standard defines five (5) classes of estimates, with one (1) being the most detailed take-off before bidding or procurement. Table 3 summarizes important AACE classifications with typical continency values added for convenience. AACE uses the term "level of project definition" for what is called "percent complete" in this course.

Table 3: AACE Cost Estimate Classes

Estimate Class	Percent Complete	Typical Stage	Contingency, %		Accuracy Range, %	
			Low	High	Low	High
5	0 to 2%	FEP-1	20	50	-20 to -50	30 to 100
4	1 to 15%	FEP-2	20	30	-15 to -30	20 to 50
3	10 to 40%	FEP-3	15	25	-10 to -20	10 to 30
2	30 to 75%	DD	10	20	-5 to -15	5 to 20
1	65 to 100%	DD/Bid	5	10	-3 to -10	3 to 15

Contingency

As the project advances, the contingency value decreases, with the AACE recommended values shown in Table 3.

Accuracy Range

As the design progresses and additional details are identified, the accuracy of a construction cost estimate increases, which means the expected cost range between high and low bidders will tighten. Table 3 shows the AACE recommended accuracy ranges. Often construction cost ranges will be presented with a low accuracy factor of

0% instead of the negative factors provided, especially if a low contingency value is being utilized, as it would be unlikely for construction costs to end up below such an estimate.

See Figure 6 for a depiction of how the accuracy range decreases as the design progresses.

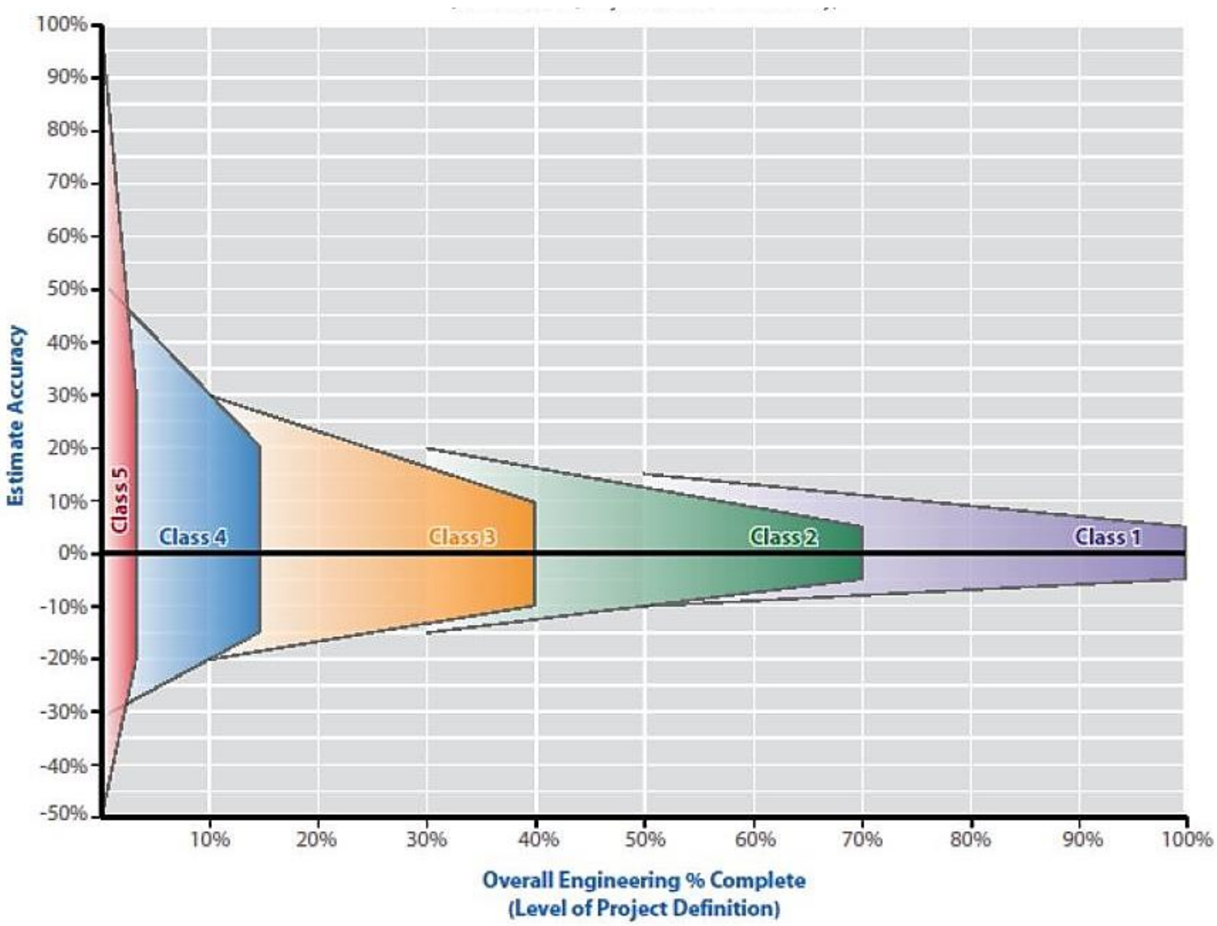


Figure 6: Estimate accuracy range by percent complete of design based on AACE 18R-97.
Source: www.linkedin.com/pulse/maturity-level-engineering-deliverable-estimate-class-haider-ali/

<u>*Example Problem*</u>
Engineer Maya has estimated a construction cost of $3.5M for a project that is 50% complete. She needs to add a contingency value and present a low and high range for the cost. Help Maya by using the AACE values in Table 3 with the high-end contingency value and the greatest accuracy range for the appropriate class.

Solution:
A project at 50% complete would be at Estimate Class 2. Per Table 3, the high-end contingency is 20% and the largest accuracy range would be -15% to 20%. The calculations are as follows (values rounded):

Contingency = $3.5M * 20% = **$0.7M**

Cost Estimate = $3.5M + $0.7M = $4.2M

Cost Range Low = $4.2M - ($4.2M * 15%) = **$3.6M**

Cost Range High = $4.2M + ($4.2M * 20%) = **$5.0M**

PDRI

PDRI (Project Definition Rating Index) measures the level of scope definition for a project. Scope definition is recognized as an important factor in predicting the accuracy of a construction cost estimate. The PDRI approach doesn't assume that a design has progressed based on a subjective percent complete. Instead, a more objective assessment is made to estimate the project completeness. This then translates into a FEP level, contingency and accuracy range.

The PDRI approach was first developed by the Construction Industry Institute (CII). PDRI calculation templates are available on the CII website (see Helpful References):

- IR113-2, PDRI for Industrial Projects
- IR155-2, PDRI for Building Projects
- IR268-2, PDRI for Infrastructure Projects
- IR314-2 & a-2, PDRI for Small Projects

A PDRI assessment is performed by scoring different elements of scope definition, multiplying each by a weight factor (based on which elements are perceived as most important), and then summing for a total score. The elements (approx. 60 to 70) are grouped into sections and categories, as summarized in Table 4. Scoring in each section and category can be analyzed to determine which areas of the scope of work need further definition.

<table>
<tr><th colspan="5">Table 4: Typical PDRI Sections and Categories</th></tr>
<tr><th rowspan="2">Section</th><th rowspan="2">Category</th><th colspan="3">Maximum Score</th></tr>
<tr><th>Category</th><th>Section</th><th>Overall</th></tr>
<tr><td rowspan="3">1. Basis of Project</td><td>A. Business Strategy</td><td>214</td><td rowspan="3">413</td><td rowspan="11">1000</td></tr>
<tr><td>B. Owner Philosophies</td><td>68</td></tr>
<tr><td>C. Project Requirements</td><td>131</td></tr>
<tr><td rowspan="4">2. Basis of Design</td><td>D. Site Information</td><td>108</td><td rowspan="4">429</td></tr>
<tr><td>E. Building Programming</td><td>162</td></tr>
<tr><td>F. Design Parameters</td><td>122</td></tr>
<tr><td>G. Equipment</td><td>36</td></tr>
<tr><td rowspan="4">3. Execution Approach</td><td>H. Procurement Strategy</td><td>25</td><td rowspan="4">158</td></tr>
<tr><td>J. Deliverables</td><td>11</td></tr>
<tr><td>K. Project Control</td><td>63</td></tr>
<tr><td>L. Project Execution Plan</td><td>60</td></tr>
</table>

SECTION I - BASIS OF PROJECT DECISION									
CATEGORY	Definition Level								Max
Element	0	1	2	3	4	5	Level	**Score**	Score
A. BUSINESS STRATEGY (Maximum Score = 214)									
A1. Building Use	0	1	12	23	33	44	3	**23**	44
A2. Business Justification	0	1	8	14	21	27	3	**14**	27
A3. Business Plan	0	2	8	14	20	26	3	**14**	26
A4. Economic Analysis	0	2	6	11	16	21	3	**11**	21
A5. Facility Requirements	0	2	9	16	23	31	3	**16**	31
A6. Future Expansion/Alteration Considerations	0	1	7	12	17	22	3	**12**	22
A7. Site Selection Considerations	0	1	8	15	21	28	3	**15**	28
A8. Project Objectives Statement	0	1	4	8	11	15	3	**8**	15
CATEGORY A TOTAL								**113**	214

0 = Not Applicable
1 = Complete Definition
2 = Minor Deficiencies
3 = Some Deficiencies
4 = Major Deficiencies
5 = Incomplete/Poor Definition

Figure 7: Example portion of a PDRI calculation table. In this case, the Level score (in red) is 3 of 5 in all 8 elements of the category “Business Strategy”. This results in a score of 113 of 214. Lower values mean greater definition level.

The PDRI scoring is inverted, so a low score means the scope is better defined. Zero is the best score while 1000 is the worst. A goal of front-end planning is to reduce the PDRI to an acceptable level. A PDRI score of 200 or less is often considered sufficient to proceed with final design and construction of a project. Table 5 lists typical PDRI ranges at the end of each FEP stage.

Table 5: Typical PDRI Ranges by FEP Stage

	FEP-1	FEP-2	FEP-3	FEP-4 / DD
Min.	500	400	200	100
Max.	800	600	450	250

Often PDRI scoring is required at design stage gates. The PDRI results can indicate if the contingency and accuracy values should be towards the high or low end of the AACE ranges shown in Table 3.

Contract Type Impact

There are several project delivery approaches available for capital improvement projects. The following are common approaches and impacts to cost estimating.

Design-Bid-Build (DBB)
This is the traditional method of executing a project. The competitive bid process often results in a lower cost than the design-build approach.

DBB projects typically last longer which increases the escalation to mid-point cost. Bidding contractors must decide how much profit and contingency to include, which depends on their confidence level in a defined scope of work and the organization's risk tolerance. The pressure is on to reduce indirect costs and win the work.

Design-Build (DB)
Design-build is a project delivery approach in which a design-builder performs both design and construction services under a single contract. The contract is typically a guaranteed maximum price (GMP). The design-builder can be a single contractor or a partnership/team. It is sometimes called a "turnkey" approach because the design-builder does everything including turning on (starting up) the system. The DB approach is simple and fast.

DB projects do not have competitive general contractors and thus tend to have higher costs. DB projects are often faster which decreases the escalation to mid-point cost. The design-builder can negotiate directly with the owner on terms and conditions which can result in lower values for the following indirect costs:

- General Conditions
- Overhead
- Bonds and Insurance

Progressive Design-Build (PDB)
The PDB approach adds one or more intermediate stages to the DB process. The goal is to allow a preliminary design prior to establishing a GMP, which reduces risk for the design-builder and often reduces the overall project cost. Sometimes projects start as DB but if the GMP prices are overbudget, using a PDB approach combined with value engineering allows the project to proceed within budget.

PDB is similar to DB, although the additional stages and value engineering often result in a better defined scope and a more efficient design which reduces the construction cost. A PDB approach may last a little longer resulting in a slightly higher escalation to mid-point cost.

Engineer-Procure-Construct (EPC)
The EPC approach is very similar to Design-Build, with a single contract to a contractor or joint venture team. With DB, the design-builder is typically given specifications or "bridging documents". With EPC, the contractor is often given little more than performance requirements.

Potential cost impacts:

- With EPC, the contractor is expected to take on additional risks for unknown conditions or unforeseen escalations, which increases the contingency value.
- With EPC, there are often liquidated damages and/or consequential damages in the contract, which increases general conditions.
- With EPC, there are often initial operations and extensive warranty requirements, which increases general conditions.
- EPC can be faster than DB, resulting in lower escalation to mid-point costs.

Helpful References

AACE (Association for the Advancement of Cost Engineering International) (2020) “Cost Estimate Classification System”. Recommended Practice No. 17R-97.

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