Analysis of Cost Estimation

Book : *Plant Design and Economics for Chemical Engineers*, M.S. Peters and K. D. Timmerhaus

Cost components in capital investment

Direct Costs

(1) Purchased equipment cost

- This is the basis on which most pre-design estimates of fixed capital investment are made
- Components of the fixed capital investment are all estimated as a fraction of the total purchased equipment cost
- It is , therefore, essential to have accurate equipment prices
- **Sizes and specifications** of equipment are usually obtained from **mass and energy balance calculations and process equipment design**
- Equipment costs are obtained from (1) **firm bids from suppliers, cost values from past purchases, (3) process equipment cost published in engineering journals and books**
- If costs from existing or old data is used, they must be corrected for two factors:

  (I) Inflation factor (or cost indexes) – considering time effect

  (II) Capacity factor (or scaling factor) – considering size effect

Estimating equipment cost by using Cost indexes

- The cost data available for a predesign estimate are valid only for the time it was developed
- Since prices change with time, a method was used to update the cost data applicable at a past date to costs that are representative of a later time
- **Cost index is an index value for a given time showing the cost at that time relative to a certain base time**

$$\textbf{Present cost} = \textbf{Original cost}\left(\frac{\textbf{index value at present}}{\textbf{index value at time original cost was obtained}}\right)$$

- Common indexes permit fairly accurate estimates if the period involved is less than 10 years

- Many different types of cost indexes are published regularly
  - Marshall and Swift equipment cost index
  - Chemical Engineering Plant cost index

Table 6-2 Cost indexes as annual averages

Year	Marshall and Swift installed-equipment indexes, 1926 = 100		*Eng. News-Record* construction index			Nelson-Farrar refinery construction index, 1946 = 100	*Chemical Engineering* plant cost index, 1957–1959 = 100
	All industries	Process industry	1913 = 100	1949 = 100	1967 = 100		
1987	814	830	4406	956	410	1121.5	324
1988	852	859.3	4519	980	421	1164.5	343
1989	895	905.6	4615	1001	430	1195.9	355
1990	915.1	929.3	4732	1026	441	1225.7	357.6
1991	930.6	949.9	4835	1049	450	1252.9	361.3
1992	943.1	957.9	4985	1081	464	1277.3	358.2
1993	964.2	971.4	5210	1130	485	1310.8	359.2
1994	993.4	992.8	5408	1173	504	1349.7	368.1
1995	1027.5	1029.0	5471	1187	509	1392.1	381.1
1996	1039.1	1048.5	5620	1219	523	1418.9	381.7
1997	1056.8	1063.7	5825	1264	542	1449.2	386.5
1998	1061.9	1077.1	5920	1284	551	1477.6	389.5
1999	1068.3	1081.9	6060	1315	564	1497.2	390.6
2000	1089.0	1097.7	6221	1350	579	1542.7	394.1
2001	1093.9	1106.9	6342	1376	591	1579.7	394.3
2002	1102.5‡	1116.9‡	6490‡	1408‡	604‡	1599.2‡	390.4†,§

All indexes are calculated from a base year

Indexes can be converted to another base year by

$$\textbf{Index value on new base} = \frac{\textbf{index value (old base) to be converted}}{\textbf{index value (old base) for new base year}} \text{X } 100$$

Estimating equipment cost by using scaling factor for sizes

- Often it is necessary to estimate the cost of an equipment for a particular size or capacity for which cost data is not available
- For such cases, estimates are made using the six-tenth (6/10 th) factor rule

$$\textbf{Cost of equipment } B = \textbf{Cost of equipment } A \left(\frac{\textbf{capacity of equipment } B}{\textbf{capacity of equipment } A} \right)^{0.6}$$

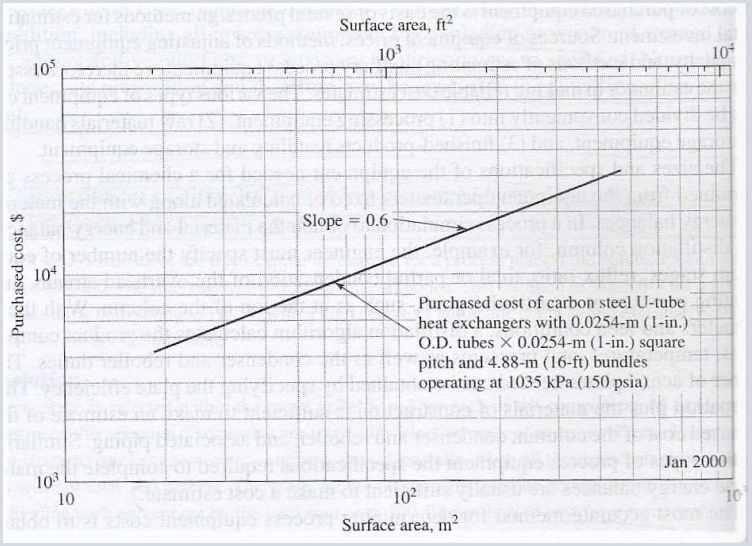

Table 6-4 Typical exponents for equipment cost as a function of capacity

Equipment	Size range	Exponent
Blender, double cone rotary, carbon steel (c.s.)	1.4–7.1 m^3 (50–250 ft^3)	0.49
Blower, centrifugal	0.5–4.7 m^3/s (10^3–10^4 ft^3/min)	0.59
Centrifuge, solid bowl, c.s.	7.5–75 kW (10–10^2 hp) drive	0.67
Crystallizer, vacuum batch, c.s.	15–200 m^3 (500–7000 ft^3)	0.37
Compressor, reciprocating, air-cooled, two-stage, 1035-kPa discharge	0.005–0.19 m^3 (10–400 ft^3/min)	0.69
Compressor, rotary, single-stage, sliding vane, 1035-kPa discharge	0.05–0.5 m^3/s (10^2–10^3 ft^3/min)	0.79
Dryer, drum, single vacuum	1–10 m^2 (10–10^2 ft^2)	0.76
Dryer, drum, single atmospheric	1–10 m^2 (10–10^2 ft^2)	0.40
Evaporator (installed), horizontal tank	10–1000 m^2 (10^2–10^4 ft^2)	0.54
Fan, centrifugal	0.5–5 m^3/s (10^3–10^4 ft^3/min)	0.44
Fan, centrifugal	10–35 m^3/s (2×10^4–7×10^4 ft^3/min)	1.17
Heat exchanger, shell-and-tube, floating head, c.s.	10–40 m^2 (100–400 ft^2)	0.60
Heat exchanger, shell-and-tube, fixed sheet, c.s.	10–40 m^2 (100–400 ft^2)	0.44
Kettle, cast-iron, jacketed	1–3 m^3 (250–800 gal)	0.27
Kettle, glass-lined, jacketed	0.8–3 m^3 (200–800 gal)	0.31
Motor, squirrel cage, induction, 440-V, explosion-proof	4–15 kW (5–20 hp)	0.69
Motor, squirrel cage, induction, 440-V, explosion-proof	15–150 kW (20–200 hp)	0.99
Pump, reciprocating, horizontal cast-iron (includes motor)	1×10^{-4}–6×10^{-3} m^3/s (2–100 gpm)	0.34
Pump, centrifugal, horizontal, cast steel (includes motor)	4–40 m^3/s·kPa (10^4–10^5 gpm·psi)	0.33
Reactor, glass-lined, jacketed (without drive)	0.2–2.2 m^3 (50–600 gal)	0.54
Reactor, stainless steel, 2070-kPa	0.4–4.0 m^3 (10^2–10^3 gal)	0.56
Separator, centrifugal, c.s.	1.5–7 m^3 (50–250 ft^3)	0.49
Tank, flat head, c.s.	0.4–40 m^3 (10^2–10^4 gal)	0.57
Tank, c.s., glass-lined	0.4–4.0 m^3 (10^2–10^3 gal)	0.49
Tower, c.s.	5×10^2–10^6 kg (10^3–2×10^6 lb)	0.62
Tray, bubble cap, c.s.	1–3 m (3–10 ft) diameter	1.20
Tray, sieve, c.s.	1–3 m (3–10 ft) diameter	0.86

- The 6/10 th rule though popular, is a simplification
- Actual values of cost capacity exponent vary from < 0.3 to > 1
- The equipment capacity range should not be more than 10 fold
- Also, equipment should be of same material of construction, temperature, pressure operating range

(2) Purchased equipment delivery cost

- Purchased equipment prices are usually fob (free on board) – purchaser pays the freight.
- Delivery allowance is usually 10% of purchased equipment cost

(3) Purchased equipment installation

- Involves cost for labour, platform, foundation, support, equipment insulation, piping insulation etc
- Varies from 25-55% of delivered purchased equipment cost or 6-14% of FCI

(4) Instrumentation and Control

- Includes instrument costs, installation labour costs, expenses for auxilliary equipment and material
- Varies from 8-50% of delivered purchased equipment cost
- For solid-fluid chemical processing plants, it is usually 26% of delivered purchased equipment cost or 5% of TCI

(5) Piping

- Cost covers valves, fittings, pipes, supports, labour etc
- Can be as high as 80% of delivered purchased equipment cost or 20 % of FCI

Type of process plant	% of purchased equipment cost			% of FCI
	Material	Labour	Total	
Solid	9	7	16	4
Solid-fluid	17	14	31	7
Fluid	38	30	68	13

(6) Electrical systems

- Includes power wiring, lighting, transformation, instrument and control wiring
- Installed cost varies from 15-30% of delivered purchased equipment cost or 4-8% of FCI

(7) Buildings

- Includes expenses for material, suppliers, labour, erection, plumbing, heating, lighting, ventilation

	% of purchased equipment cost			% of fixed capital investment		
	New plant at new site	New unit at existing site	Expansion at existing site	New plant at new site	New unit at existing site	Expansion at existing site
Solid	**68**	**25**	**15**	**18**	**7**	**4**
Solid-fluid	**47**	**29**	**7**	**12**	**7**	**2**
Fluid	**45**	**5-18**	**6**	**10**	**2-4**	**2**

(8) Yard improvements

- Includes fencing, gardening, roads, sidewalks, railway sidings, landscaping etc
- Cost varies from 10-20% of purchased equipment cost or 2-5 % of FCI

(9) Service facilities

- Includes utilities for supplying steam, water, power, compressed air and fuel
- Also includes cost for waste disposal, fire protection, safety installations
- Total cost varies from 30-80% of purchased equipment cost or 8-20 % of FCI with an average of 14%

(10) Land

- Last costs range between 4-8 % of purchased equipment cost or 1-2 % of TCI
- Not included as a part of FCI as land cannot be depreciated (by law)
- It is a one time investment at the beginning of plant construction

Indirect costs

(11) Engineering and Supervision

- Includes utilities for supplying steam, water, power, compressed air and fuel
- Also includes cost for waste disposal, fire protection, safety installations
- Total cost varies from 30-80% of purchased equipment cost or 8-20 % of FCI with an average of 14%

(12) Legal expenses

- Results largely from land purchases, equipment purchase, construction contract, compliance with govt, environmental and safety norms
- It is usually 1-3% of FCI

(13) Construction expenses

- Includes temporary construction and operation, construction tools and rentals, home office personnel located at construction site, travel and living, taxes, insurance
- Construction expenses average around 8-10% of FCI

(14) Contractor's fee

- Estimated to be 2-8 % of direct plant cost or 1.5-6 % of FCI

(15) Contingencies

- Money for unexpected events and changes that increases the cost of the project
- Events such as storms, floods, accidents, strikes, design changes, errors in estimation are also included
- Ranges from 5-15 % of FCI with an average value of 8%

Methods for estimating capital investment

- Several methods exist for estimating the capital investment
- Among the methods mentioned below, each method requires less detailed information and less preparation time and has lower degree of accuracy

Method A: *Detailed Item Estimate*

- Requires details about each item in the capital investment list
- Complete drawings and specifications required for equipment and material needs
- Prices obtained from current cost data or quotations from vendors
- Installation costs estimated from accurate labour rates, efficiencies, employee-hour calculations
- Method is very time consuming
- Mostly used by contractor's bidding from finished drawings and specifications
- Accuracy of $\pm$ 5% is expected from this method

Method B: *Unit Cost Estimate*

- Requires detailed estimates of purchased price obtained either from quotations or index-corrected cost records and published data
- Equipment installation labour is evaluated as a fraction of the delivered-equipment cost.
- Costs for concrete, steel, pipe, electricals, instrumentation, insulation, etc., are obtained by take-offs from the drawings and applying unit costs to the material and labour needs. Unit cost is also applied to engineering employee-hours, number of drawings, and specifications.
- Also included is a factor for construction expense, contractor's fee, and contingency (estimated from previously completed projects)
- Method gives $\pm$ 10-20% accuracy

$$C_n = \left[\sum(E + E_L) + \sum\left(f_x M_x + f_y M'_L\right) + \sum f_e H_e + \sum f_d d_n\right] f_F$$

where C_n = new capital investment

E : delivered equipment cost

E_L : delivered equipment labour cost

f_x : specific material unit cost

M_x : specific material quantity

f_y : specific material labour cost per employee-h

M_L ' : labour employee hours for a specific material

f_e : unit cost for engineering

H_e : engineering employee hours

f_d : unit cost per drawing or specification

d_n : no. of drawings or specifications

f_F : construction or field expense factor (always > 1)

Method C: *Percentage of Delivered Equipment Cost*

- Requires determination of the delivered equipment cost
- All direct and indirect costs are estimated as a % of this value
- Method gives $\pm$ 20-30% accuracy

$$C_n = \sum(E + f_1E + f_2E + f_3E + \cdots + f_nE) = E\sum(1 + f_1 + f_2 + f_3 + \cdots + f_n)$$

where C_n = new capital investment E : delivered equipment cost

f_1, f_2, f_3 : multiplying factors for piping, electrical, indirect costs etc (factors depend on process involved, design, complexity, required materials, plant location etc)

Project Identifier:	Fraction of delivered equipment		
	Solid-processing plant	Solid-fluid processing plant	Fluid-processing plant
Direct costs			
Purchased equipment			
Delivery, percent of purchased equipment			
Subtotal: delivered equipment			
Purchased equipment installation	0.45	0.39	0.47
Instrumentation and controls (installed)	0.18	0.26	0.36
Piping (installed)	0.16	0.31	0.68
Electrical systems (installed)	0.10	0.10	0.11
Buildings (including services)	0.25	0.29	0.18
Yard improvements	0.15	0.12	0.10
Service facilities (installed)	0.40	0.55	0.70
Total direct cost			

Project Identifier:	Fraction of delivered equipment		
	Solid-processing plant	Solid-fluid processing plant	Fluid-processing plant
Indirect costs			
Engineering and supervision	0.33	0.32	0.33
Construction expenses	0.39	0.34	0.41
Legal expenses	0.04	0.04	0.04
Contractor's fee	0.17	0.19	0.22
Contingency	0.35	0.37	0.44
Total indirect cost			
Fixed capital investment			
Working capital	0.70	0.75	0.89

Method D: *Lang Factors for Approximation of Capital Investment*

- The cost of a process plant may be obtained by multiplying the equipment cost by some factor (depending on type of process) to approximate the fixed or total capital investment

Type of plant	Lang factors			
	Fixed capital investment		Total capital investment	
Solid	3.9 (Old)	4.0	4.6 (Old)	4.7
Solid -fluid	4.1 (Old)	4.3	4.9 (Old)	5.0
Fluid	4.8 (Old)	5.0	5.7 (Old)	6.0

TCI = Lang Factor X Equipment cost

Greater accuracy can be achieved by not using one but a number of factors

$$C_n = f_I\,[E'(1 + f_F + f_P + f_M) + E_i + A]$$

where C_n = new capital investment
f_I : indirect cost factor, usually >1 (usually 1.4)
f_P : cost factor for piping materials
E_i : cost of equipment already installed
E' : purchased equipment cost on fob basis
f_F : cost factor for field labour
f_M : cost factor for miscellaneous items
A : incremental costs of corrosion resistant alloy materials

$$\log f_F = 0.635 - 0.154 log(0.001E') - 0.992\left(\frac{e}{E'}\right) + 0.506\left(\frac{f_v}{E'}\right)$$

$$\log f_P = -0.266 - 0.014 log(0.001E') - 0.156\left(\frac{e}{E'}\right) + 0.556\left(\frac{P}{E'}\right)$$

$$\log f_M = 0.344 - 0.033 log(0.001E') + 1.194\left(\frac{t}{E'}\right)$$

e : total heat exchanger cost (less incremental cost of alloy)
f_v : total cost of field fabricated vessels (- incremental cost of alloy)
P : total pump + driver cost (- incremental cost of alloy)
t : total cost of tower shells (- incremental cost of alloy)

Method F: *Investment cost per unit capacity*

- This method uses the data available for **fixed-capital investment required for various processes and the annual production capacity**
- The FCI is divided by the typical plant capacity to get the **per unit investment cost**
- An order-of-magnitude estimate of the FCI for a given process can then be obtained by **multiplying the appropriate investment cost per unit of capacity by the annual production capacity** of the proposed plant.
- The necessary correction for change of costs with time can be made with the use of cost indexes.

Method G: *Turnover ratio*

- This is an order of magnitude method using turnover ratio for estimation

$$\textbf{Turnover Ratio} = \frac{\textbf{Gross Annual Sales}}{\textbf{Fixed capital investment}}$$

- Gross annual sales = Annual Production Rate X Average selling price of commodities
- Turnover ratios can range from 0.2 to 4
- For chemical industries, value of 0.5 can be used as a rule of thumb

Method F: *Investment cost per unit capacity*

Product or process	Process	Typical plant size	Fixed-capital investment, million $	Power factor x^1 for specified process plant
		10^3 kg/yr (10^3 ton/yr)		
Acetic acid	CH_3OH and CO—catalytic	9×10^3 (10)	8	0.68
Acetone	Propylene-copper chloride catalyst	9×10^4 (100)	33	0.45
Ammonia	Steam reforming	9×10^4 (100)	29	0.53
Ammonium nitrate	Ammonia and nitric acid	9×10^4 (100)	6	0.65
Butanol	Propylene, CO, and H_2O—catalytic	4.5×10^4 (50)	48	0.40
Chlorine	Electrolysis of NaCl	4.5×10^4 (50)	33	0.45
Ethylene	Refinery gases	4.5×10^4 (50)	16	0.83
Ethylene oxide	Ethylene—catalytic	4.5×10^4 (50)	59	0.78
Formaldehyde (37%)	Methanol—catalytic	9×10^3 (10)	19	0.55
Glycol	Ethylene and chlorine	4.5×10^3 (5)	18	0.75
Hydrofluoric acid	Hydrogen fluoride and H_2O	9×10^3 (10)	10	0.68
Methanol	CO_2, natural gas, and steam	5.5×10^4 (60)	15	0.60
Nitric acid (high-strength)	Ammonia—catalytic	9×10^4 (100)	8	0.60
Phosphoric acid	Calcium phosphate and H_2SO_4	4.5×10^3 (5)	4	0.60
Polyethylene (high-density)	Ethylene—catalytic	4.5×10^3 (5)	19	0.65
Propylene	Refinery gases	9×10^3 (10)	4	0.70
Sulfuric acid	Sulfur—contact catalytic	9×10^4 (100)	4	0.65
Urea	Ammonia and CO_2	5.5×10^4 (60)	10	0.70
		10^3 m^3/day (10^3 bbl/day)		
Alkylation (H_2SO_4)	Catalytic	1.6 (10)	23	0.60
Coking (delayed)	Thermal	1.6 (10)	31	0.38
Coking (fluid)	Thermal	1.6 (10)	19	0.42
Cracking (fluid)	Catalytic	1.6 (10)	19	0.70
Cracking	Thermal	1.6 (10)	6	0.70
Distillation (atm.)	65% vaporized	16 (100)	38	0.90
Distillation (vac.)	65% vaporized	16 (100)	23	0.70
Hydrotreating	Catalytic desulfurization	1.6 (10)	3.5	0.65
Reforming	Catalytic	1.6 (10)	34	0.60
Polymerization	Catalytic	1.6 (10)	6	0.58