Illustrative Example

TBWS, 2nd Ed.

Page 182, Problem 5.1

Step 1 – Read Problem

In 1994, our company bought a heat exchanger (heat transfer area = 50 m^2) for a cooling water application at moderate temperatures and pressures for $6,500. In 1997, we bought an exchanger (heat transfer area = 120 m^2) for a similar application for $11,000. What is your best estimate of the cost of a similar heat exchanger with a heat transfer area of 90 m^2 for use today (assume mid-2001 prices apply)?

Why are we doing this example?

Illustrate some fundamental concepts.

Cross-check vendor quotes.

Step 2 – Digest Information

In 1994, our company bought a heat exchanger (heat transfer area = 50 m^2) for a cooling water application at moderate temperatures and pressures for $6,500.

In 1997, we bought an exchanger (heat transfer area = 120 m^2) for a similar application for $11,000.

What is your best estimate of the cost of a similar heat exchanger with a heat transfer area of 90 m^2 for use today (assume mid-2001 prices apply)?

Step 3 – Organize Data & Clarify Objective

Unit No.	Size m^2	MOC	P bar	t yr	C_P \$1000
1	50	similar	moderate	1994	6.50
2	120	similar	moderate	1997	11.00
3	90	similar	moderate	2000.5	?

MOC = Material of Construction
P = Operating Pressure
1 bar = 100,000 Pa ≈ 1 atm
t = time
C_P = Purchase Cost
\$1000 = 1 k\$

Required accuracy of estimate: Not quantified. "your best estimate" stated. We shall assume within ±5%.

Significant figures: The prior purchase costs are stated to 2 significant figures. The sizes of prior heat exchangers are stated to 1-2. We shall carry 3-4 figures to handle rounding.

Step 3 – Perform a "Back of the Envelope" Calculation

Why do we do this step?

It provides a rough check for later calculations that potentially are more accurate, but also more susceptible to gross errors.

Remember:

> **The first principle is that you must not fool yourself— and you are the easiest person to fool.**

Richard P. Feynman
1974 Commencement Address
California Institute of Technology

Step 3 (continued) –

Average inflation rate during past 60 years is about 3%.

Inflation during past five years was below average.

For Unit 2, let's adjust the 1997 cost to a mid-2001 by ~10%.

This gives ~$12,000 for Unit 2 in mid-2001.

Unit 2 has a heat transfer area of 120 m^2. This is close to the desired size of 90 m^2.

Let's just use a proportional relationship of cost to area (i.e., *ignore economy of scale*).

$$C_P \approx \$12{,}000\ (90/120) \approx \underline{\underline{\$9{,}000}}$$

Note: So far we have done all of this calculation without a calculator and without looking anything up!

Step 4 – Perform a *refined* "Back of the Envelope" Calculation (i.e., Use a Calculator!)

Why do we do this step?

In addition to refining our preliminary answer, we gain insights that improve our ability to check later calculations.

Remember:

> **The first principle is that you must not fool yourself— and you are the easiest person to fool.**

Richard P. Feynman
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Step 4 (continued) –

Use from the prior step, a value of ~$12,000 for Unit 2 in mid-2001.

Before, we ignored the *economy of scale*. We used a proportionality equation:

$$\cancel{C_{P2} / C_{P1} = (A_2 / A_1)^1}$$

C_{P2} **= purchase cost of Unit 1**

C_{P1} **= purchase cost of Unit 1**

A_2 **= size of Unit 1**

A_1 **= size of Unit 1**

Step 4 (continued) –

Let's consider the *economy of scale* using a simple exponential equation:

Memorize!

$$\boxed{C_{P2} / C_{P1} = (A_2 / A_1)^n}$$

n **= cost exponent**

We utilize a *rule of thumb*:

Memorize!

$$\boxed{n \approx 0.6}$$

$$C_P \approx \$12{,}000\ (90/120)^{0.6} \approx \underline{\underline{\$10{,}100}}$$

This estimate is quite possibly good enough for many decisions for spending money.

Note: So far we have done all of this calculation without looking anything up!

Step 5 – Reflect on Results

First Estimate:

Type:	**Back of Envelope**
Inflation:	**guesstimate**
Size:	**proportional cost exponent = 1 no economy of scale**
Result:	**$9,000**

Second Estimate:

Type:	**Back of Envelope with Calculator**
Inflation:	**guesstimate**
Size:	**0.6 cost exponent (rule of thumb)**
Result:	**$10,100**

These results seem consistent. Why?

The scale ratio is relatively small (0.75).

The scale ratio is less than 1.
We are scaling *down*, not up.

Step 6 – Adjust for Inflation
(use literature values)

Unit No.	Size m^2	MOC	P bar	t yr	*CEPCI*	C_P \$1000
1	50	similar	moderate	1994	368	6.50
2	120	similar	moderate	1997	387	11.00
3	90	similar	moderate	2000.5	397	?

CEPCI = Chemical Engineering Plant Cost Index
(TBWS, 2nd Ed., page 154, Table 5.4)

Memorize!

$$C_{P,\,t2} \,/\, C_{P,\,t1} = I_{t2} \,/\, I_{t1}$$

Unit No.	Size m^2	MOC	P bar	t yr	*CEPCI*	C_P \$1000
1a	50	similar	moderate	2000.5	397	7.01
2a	120	similar	moderate	2000.5	397	11.28
3	90	similar	moderate	2000.5	397	?

CEPCI = Chemical Engineering Plant Cost Index
(TBWS, 2nd Ed., page 154, Table 5.4)

"a" in Unit No. refers to time-adjusted value for purchase cost of unit

Step 7 – Adjust for Size
(use literature values)

Refer to TBWS, page 148, Table 5.3

For heat exchangers, *n* = 0.59

Unit No.	Size m^2	MOC	*P* bar	*t* yr	*CEPCI*	C_P \$1000
1ab	90	similar	moderate	2000.5	397	9.91
2ab	90	similar	moderate	2000.5	397	9.52
3	90	similar	moderate	2000.5	397	9.7

MOC = Material of Construction
P = Operating Pressure
1 bar = 100,000 Pa ≈ 1 atm
t = time
CEPCI = Chemical Engineering Plant Cost Index
(TBWS, 2nd Ed., page 154, Table 5.4)
C_P = Purchase Cost
\$1000 = 1 k\$

"a" in Unit No. refers to time-adjusted value for purchase cost of unit.
"b" in Unit No. refers to size-adjusted value for purchase cost of unit.

n = cost exponent = 0.59 (TBWS, 2nd Ed., page 149, Table 5.3)

Required accuracy of estimate: Not quantified. "your best estimate" stated. We assume within ±5% is satisfactory.

Significant figures: The prior purchase costs are stated to 2 significant figures. The sizes or prior heat exchangers are stated to 1-2 significant figures. We carry 3-4 figures and round to 2 at end.

Step 8 – Reflect on Results Again

Second Estimate:

Type: Back of Envelope with Calculator

Inflation: guesstimate

Size: 0.6 cost exponent (rule of thumb)

Result: $10,100

Third Estimate:

Type: Elementary literature correlation

Inflation: CEPCI

Size: 0.59 cost exponent

Result: $9,700

No evidence of gross error.

Third estimate is just a refinement.

Step 9 – Determine our own "*n*"!

$$\boxed{C_{P2} / C_{P1} = (A_2 / A_1)^n}$$

$$n = \frac{\log(C_{P2} / C_{P1})}{\log(A_2 / A_1)}$$

Substitute time-adjusted values for purchase costs.

$$n = \frac{\log(11.28 / 7.01)}{\log(120 / 50)}$$

$$n = 0.543$$

This value is reasonably close to textbook value of 0.59 for heat exchanger shell and tube carbon steel. No evidence of gross error.

Step 10 – Make "Best" Estimate

$$\boxed{C_{P2} / C_{P1} = (A_2 / A_1)^n}$$

$$C_{P3} / 7.01 = (90 / 50)^{0.543}$$

$$C_{P3} = 9.65 \text{ k\$} = \underline{\underline{\$9{,}700}}$$

This value is reasonably close to "back of the envelope" result of $9,700. No evidence of gross error.

Step 10 (continued) –

Note: With no rounding in calculations, find:

$$C_{P3} \; = \; \underline{\underline{\$9{,}651.1137}}$$

Would this value really be better than $9,700?

How accurate are the inflation index values?
How accurate is the inflation index methodology?
How accurate are the equipment sizes?
How "similar" were the prior heat exchanger units?

In what situation would it help someone to make a sounder decision for spending money?

If the decision is so critical, then go out and get formal price quotes from vendors.

Step 11 – Generalize Approach

We can apply this approach to other pieces of equipment, combinations of equipment, and even entire processing plants.

We just need prior data for similar items.

These data include purchase cost, purchase date, and characteristic size.

Cost engineers can compile lots and lots of data for purchase costs for many equipment types, sizes, materials of construction, pressure ratings.

Cost engineers can regress all the data to develop broad correlations and then make available in the engineering literature.

We can utilize these correlations in user-friendly computer software.

Step 12 – Summarize Concepts

Economy of Scale

Six-tenths Rule

Refining Six-tenths Rule

Inflation Index

Significant Figures

"Back of the Envelope" Calculation

Don't fool yourself!