Cost Concepts and Design Economics

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The A380 Superjumbo's Breakeven Point

When Europe's Airbus Company approved the A380 program in 2000, it was estimated that only 250 of the giant, 555-seat aircraft needed to be sold to break even. The program was initially based on expected deliveries of 751 aircraft over its life cycle. Long delays and mounting costs, however, have dramatically changed the original breakeven figure. In 2005, this figure was updated to 270 aircraft. According to an article in the *Financial Times* (October 20, 2006, p. 18), Airbus would have to sell 420 aircraft to break even—a 68% increase over the original estimate. To date, only 262 firm orders for the aircraft have been received. The topic of breakeven analysis is an integral part of this chapter.

Costs Categories

- *Fixed cost*: unaffected by changes in activity level over a feasible range of operations for the capacity or capability available. Typical fixed costs include: insurance and taxes on facilities, general management and administrative salaries, license fees, and interest costs on borrowed capital.
- Any exception?

Costs Categories

- *Variable cost*: vary in total with the quantity of output (or similar measure of activity). Costs of material and labor used in a product or service are variable costs, because they vary in total with the number of output units, even though the costs per unit stay the same.
- *Incremental cost*: additional cost resulting from increasing output of a system by one (or more) units. Incremental cost is often associated with "go–no go" decisions that involve a limited change in output or activity level. For instance, the incremental cost per mile for driving an automobile may be $0.49.

Fixed and Variable Costs

In connection with surfacing a new highway, a contractor has a choice of two sites on which to set up the asphalt-mixing plant equipment. The contractor estimates that it will cost $2.75 per cubic yard mile (yd^3-mile) to haul the asphalt-paving material from the mixing plant to the job location. Factors relating to the two mixing sites are as follows (production costs at each site are the same):

Cost Factor	Site *A*	Site *B*
Average hauling distance	4 miles	3 miles
Monthly rental of site	$2,000	$7,000
Cost to set up and remove equipment	$15,000	$50,000
Hauling expense	$2.75/$yd^3$-mile	$2.75/$yd^3$-mile
Flagperson	Not required	$150/day

The job requires 50,000 cubic yards of mixed-asphalt-paving material. It is estimated that four months (17 weeks of five working days per week) will be required for the job. Compare the two sites in terms of their fixed, variable, and total costs. Assume that the cost of the return trip is negligible. Which is the better site? For the selected site, how many cubic yards of paving material does the contractor have to deliver before starting to make a profit if paid $12 per cubic yard delivered to the job location?

More ways to categorize costs

- *Direct*: can be measured and allocated to a specific output or work activity. The labor and material costs directly associated with a product, service, or construction activity are direct costs. For example, the materials needed to make a pair of scissors would be a direct cost.
- *Indirect*: difficult to attribute or allocate to a specific output or work activity (also *overhead* or *burden*). Normally, they are costs allocated through a selected formula (such as proportional to direct labor hours, direct labor dollars, or direct material dollars) to the outputs or work activities. For example, the costs of common tools, general supplies, and equipment maintenance in a plant are treated as indirect costs.

More ways to categorize costs

- *Standard cost*: cost per unit of output, established in advance of production or service delivery. They are developed from anticipated direct labor hours, materials, and overhead categories (with their established costs per unit). Because total overhead costs are associated with a certain level of production, this is an important condition that should be remembered when dealing with standard cost data.

We need to use common cost terminology.

- *Cash cost:* a cost that involves a payment of cash.
- *Book cost:* a cost that does not involve a cash transaction but is reflected in the accounting system. The most common example of book cost is the depreciation charged for the use of assets such as plant and equipment.
- *Sunk cost:* a cost that has occurred in the past and has no relevance to estimates of future costs and revenues related to an alternative course of action. For instance, sunk costs are non refundable cash outlays, such as earnest money on a house or money spent on a passport.

More common cost terminology

- *Opportunity cost*: the monetary advantage foregone due to limited resources. The cost of the best rejected opportunity. Consider a student who could earn $20,000 for working during a year, but chooses instead to go to school for a year and spend $5,000 to do so. The opportunity cost of going to school for that year is $25,000
- *Life-cycle cost*: the summation of all costs related to a product, structure, system, or service during its life span. The cumulative committed life-cycle cost curve increases rapidly during the acquisition phase. In general, approximately 80% of life-cycle costs are “locked in” at the end of this phase by the decisions made during requirements analysis and preliminary and detailed design. In contrast, as reflected by the cumulative life-cycle cost curve, only about20% of actual costs occur during the acquisition phase, with about 80% being incurred during the operation phase.

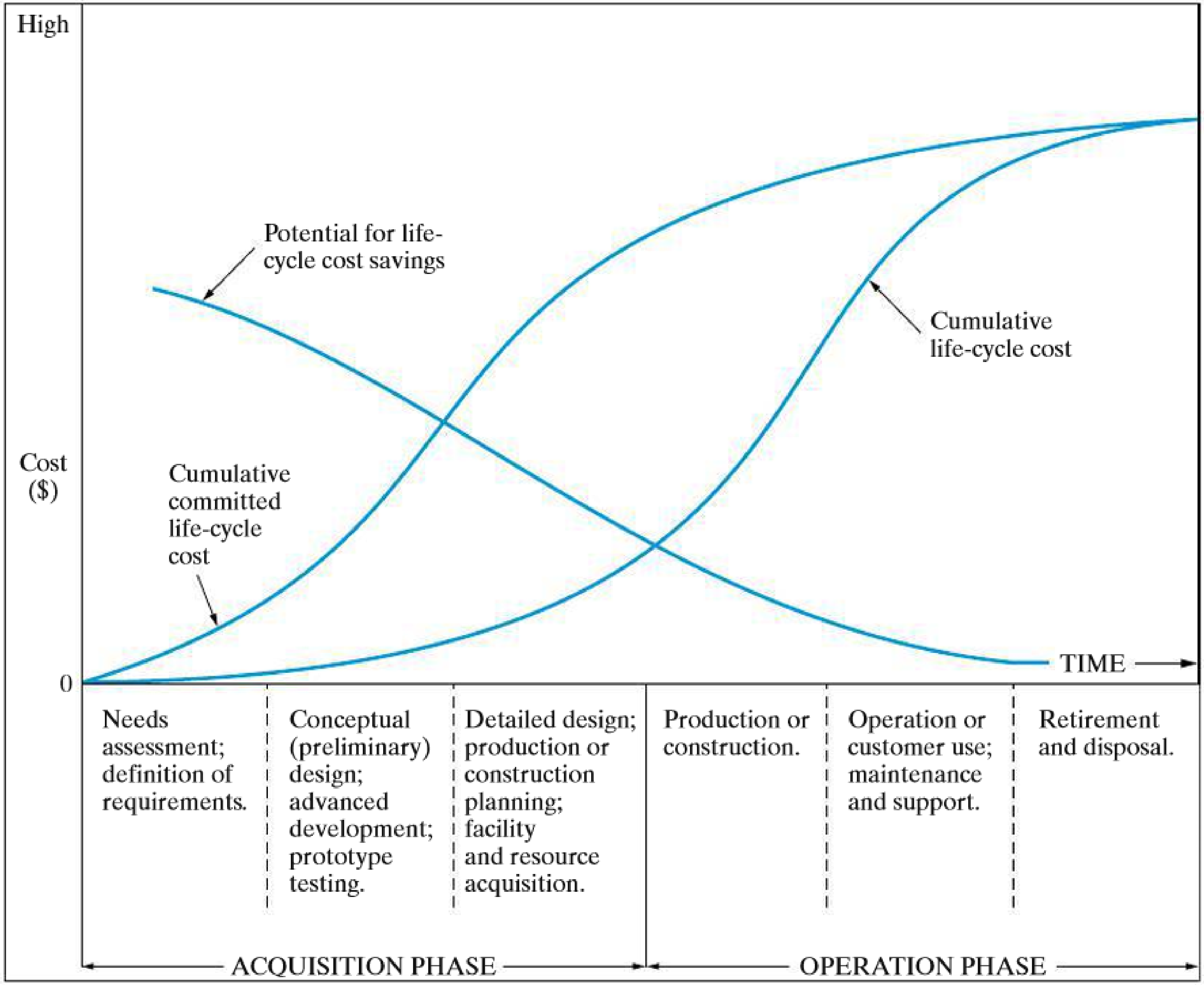


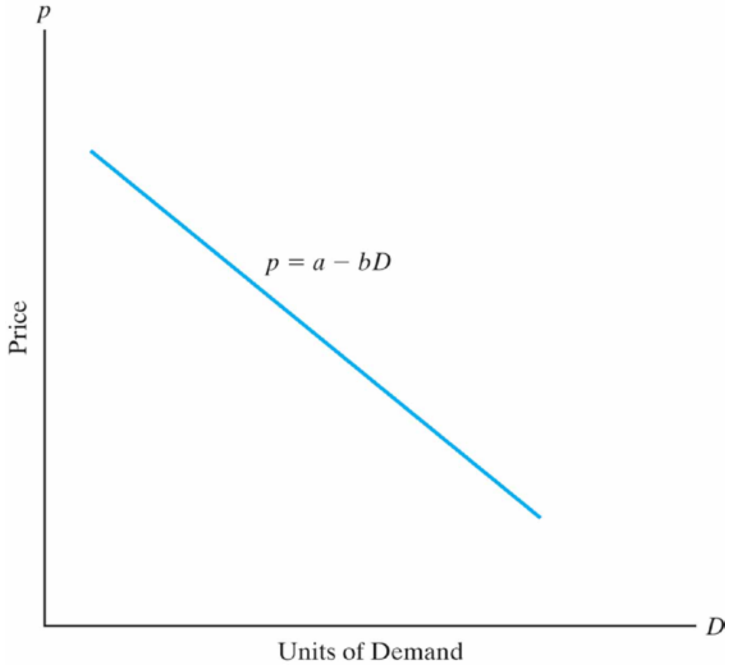
Figure 2-1 Phases of the Life Cycle and Their Relative Cost

The general price-demand relationship

Perfect competition and *Monopoly*

With conditions of perfect competition assumed, it is easier to formulate general economic laws. Why?

The demand for a product or service is directly related to its price according to $p=a-bD$ where p is price, D is demand, and a and b are constants that depend on the particular product or service.



Total revenue depends on price and demand.

Total revenue is the product of the selling price per unit, *p*, and the number of units sold, *D* (eq. 2-4).

$$TR = pD = (a - bD)D = aD - bD^2$$

$$\text{for} \quad 0 \leq D \leq \frac{a}{b} \quad \text{and} \quad a > 0, \quad b > 0$$

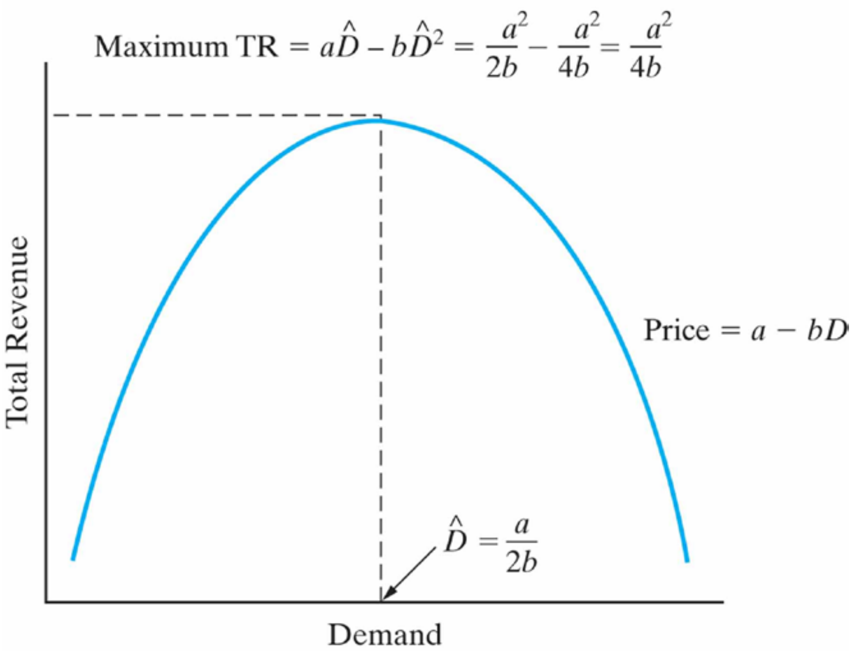
Calculus can help determine the demand that maximizes revenue.

Refer to section 2.2.5

$$\frac{dTR}{dD} = a - 2bD = 0$$

Solving, the optimal demand is (eq. 2-6)

$$\hat{D} = \frac{a}{2b}$$



We can also find the maximum profit…

Refer to section 2.2.6

$C_T = C_F + C_V$ but by assumption total $C_V = c_v.D$

Profit = Revenue- Cost

$= (aD-bD^2)-(C_F + C_V)$

$= (aD-bD^2)-(C_F + c_v.D) = aD - bD^2 - C_F + c_v.D$

$$\text{Profit} = -bD^2 + (a - c_v)D - C_F$$
$$0 \leq D \leq \frac{a}{b} \quad \text{and} \quad a > 0, b > 0$$

Differentiating, we can find the value of D that maximizes profit (eq. 2-10).

$$D^* = \frac{a - c_v}{2b}$$

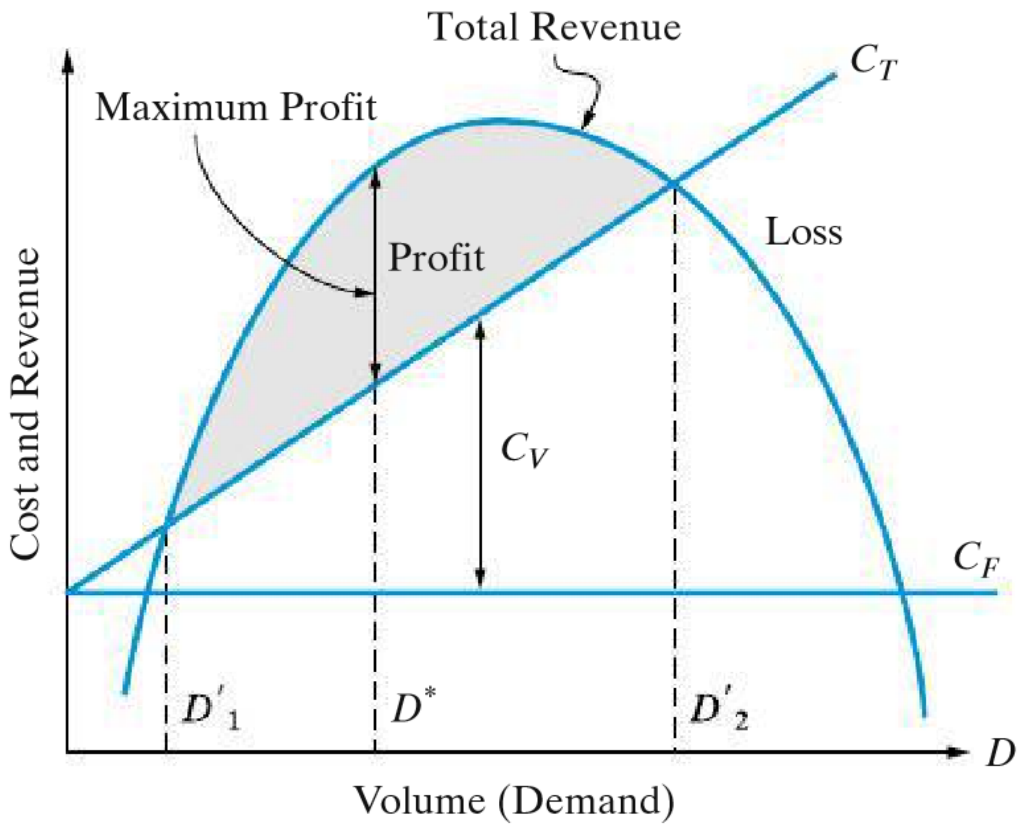


Figure 2-4 Combined Cost and Revenue Functions, and Breakeven Points, as Functions of Volume, and Their Effect on Typical Profit

And we can find revenue/cost breakeven.

See Section 2.2.6

Breakeven is found when **total revenue = total cost**. Solving, we find the demand at which this occurs (eq. 2-12) by solving the quadratic equation.

$$D' = \frac{-(a - c_v) \pm \sqrt{(a - c_v)^2 - 4(-b)(-C_F)}}{2(-b)}$$

Pause and solve

Acme Manufacturing is a major player in the lawn sprinkler business. Their high-end sprinkler is used commercially, and is quite popular with golf course greens keepers. In producing these sprinklers Acme's fixed cost (C_F) is $55,000 per month with a variable cost (c_v) of $15.50 per unit. The selling price for these high-end sprinklers is described by the equation p=$87.50 – 0.02($D$).

a) What is the optimal volume of sprinklers? Does Acme make a profit at that volume?
b) What is the range of profitable demand?

Example 2-4

Optimal Demand When Demand Is a Function of Price

A company produces an electronic timing switch that is used in consumer and commercial products. The fixed cost (C_F) is \$73,000 per month, and the variable cost (c_v) is \$83 per unit. The selling price per unit is $p = \$180 - 0.02(D)$, based on Equation (2-1). For this situation,

(a) determine the optimal volume for this product and confirm that a profit occurs (instead of a loss) at this demand.

(b) find the volumes at which breakeven occurs; that is, what is the range of profitable demand? Solve by hand and by spreadsheet.

(a) $D^* = \dfrac{a - c_v}{2b} = \dfrac{\$180 - \$83}{2(0.02)} = 2{,}425$ units per month [from Equation (2-10)].

Is $(a - c_v) > 0$?

$$(\$180 - \$83) = \$97, \quad \text{which is greater than 0.}$$

And is (total revenue − total cost) > 0 for $D^* = 2{,}425$ units per month?

$$[\$180(2{,}425) - 0.02(2{,}425)^2] - [\$73{,}000 + \$83(2{,}425)] = \$44{,}612$$

A demand of $D^* = 2{,}425$ units per month results in a maximum profit of \$44,612 per month. Notice that the second derivative is negative (−0.04).

(b) Total revenue = total cost (breakeven point)

$$-bD^2 + (a - c_v)D - C_F = 0 \qquad \text{[from Equation (2-11)]}$$

$$-0.02D^2 + (\$180 - \$83)D - \$73{,}000 = 0$$

$$-0.02D^2 + 97D - 73{,}000 = 0$$

And, from Equation (2-12),

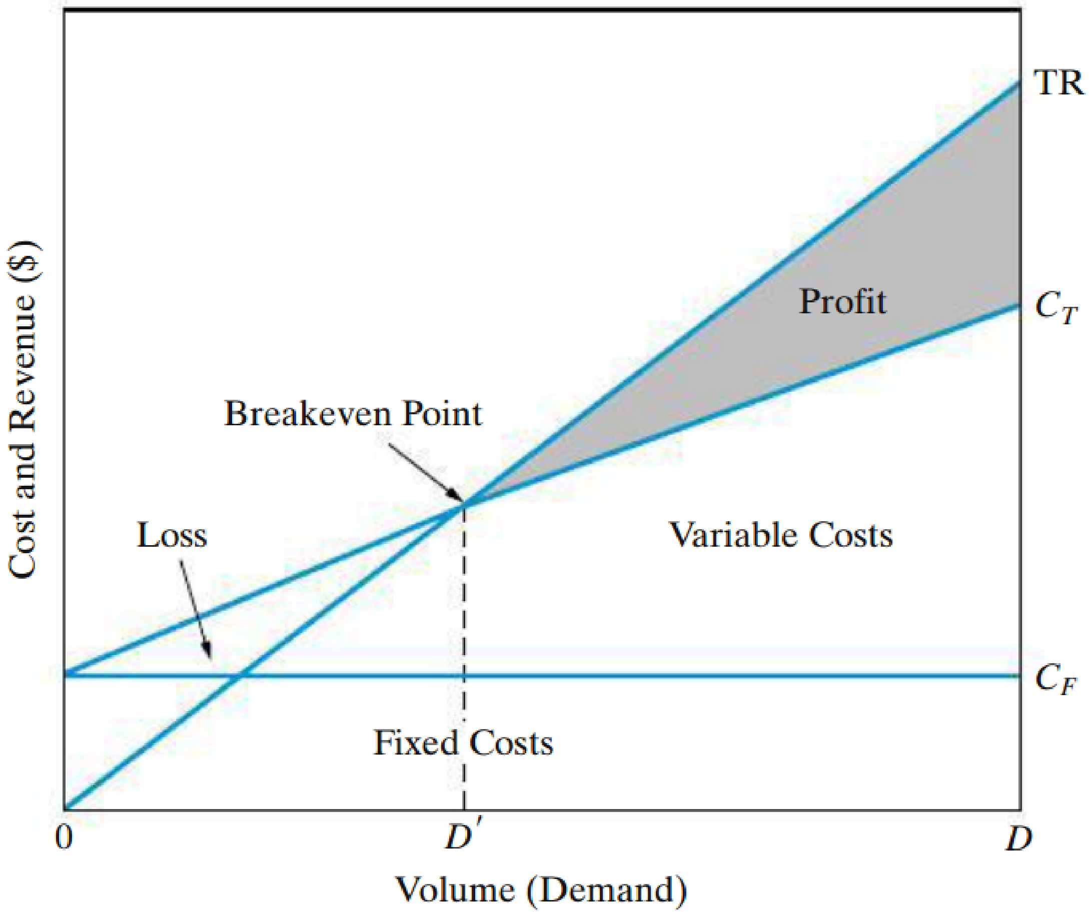
$$D' = \frac{-97 \pm [(97)^2 - 4(-0.02)(-73{,}000)]^{0.5}}{2(-0.02)}$$

$$D'_1 = \frac{-97 + 59.74}{-0.04} = 932 \text{ units per month}$$

$$D'_2 = \frac{-97 - 59.74}{-0.04} = 3{,}918 \text{ units per month.}$$

Thus, the range of profitable demand is 932–3,918 units per month.

When price is constant



Example 2-5

Breakeven Point When Price Is Independent of Demand

An engineering consulting firm measures its output in a standard service hour unit, which is a function of the personnel grade levels in the professional staff. The variable cost (c_v) is $62 per standard service hour. The charge-out rate [i.e., selling price (p)] is $85.56 per hour. The maximum output of the firm is 160,000 hours per year, and its fixed cost (C_F) is $2,024,000 per year. For this firm,

(a) what is the breakeven point in standard service hours and in percentage of total capacity?

(b) what is the percentage reduction in the breakeven point (sensitivity) if fixed costs are reduced 10%; if variable cost per hour is reduced 10%; and if the selling price per unit is increased by 10%?

Solution

(a)

$$\text{Total revenue} = \text{total cost} \qquad \text{(breakeven point)}$$

$$pD' = C_F + c_v D'$$

$$D' = \frac{C_F}{(p - c_v)}, \tag{2-13}$$

and

$$D' = \frac{\$2{,}024{,}000}{(\$85.56 - \$62)} = 85{,}908 \text{ hours per year}$$

$$D' = \frac{85{,}908}{160{,}000} = 0.537,$$

or 53.7% of capacity.

Cost-driven design optimization

- Engineers must consider cost in the design of products, processes and services. “Cost-driven design optimization” is critical in today’s competitive business environment.
- In our brief examination we examine discrete and continuous problems that consider a single primary cost driver.
- Two main tasks are involved in cost-driven design optimization:
  - Determine the optimal value for a certain alternative’s design variable.
  - Select the best alternative, each with its own unique value for the design variable.
- Cost models are developed around the design variable, X.

Optimizing a design with respect to cost is a four-step process.

1. Identify the design variable that is the primary cost driver.
2. Express the cost model in terms of the design variable.
3. For continuous cost functions, differentiate to find the optimal value. For discrete functions, calculate cost over a range of values of the design variable.
4. Solve the equation in step 3 for a continuous function. For discrete, the optimum value has the minimum cost value found in step 3.

Here is a simplified cost function.

Refer to Section 2.3

$$\text{Cost} = aX + \frac{b}{X} + k$$

where,

a is a parameter that represents the directly varying cost(s),

b is a parameter that represents the indirectly varying cost(s),

k is a parameter that represents the fixed cost(s), and

X represents the design variable in question.

“Present economy studies” can ignore the time value of money.

- Alternatives are being compared over one year or less.
- When revenues and other economic benefits vary among alternatives, choose the alternative that maximizes overall profitability of defect-free output.
- When revenues and other economic benefits are not present or are constant among alternatives, choose the alternative that minimizes total cost per defect-free unit.

How Fast Should the Airplane Fly?

The cost of operating a jet-powered commercial (passenger-carrying) airplane varies as the three-halves (3/2) power of its velocity; specifically, $C_O = knv^{3/2}$, where n is the trip length in miles, k is a constant of proportionality, and v is velocity in miles per hour. It is known that at 400 miles per hour, the *average* cost of operation is $300 per mile. The company that owns the aircraft wants to minimize the cost of operation, but that cost must be balanced against the cost of the passengers' time (C_C), which has been set at $300,000 per hour.

(a) At what velocity should the trip be planned to minimize the total cost, which is the sum of the cost of operating the airplane and the cost of passengers' time?

(b) How do you know that your answer for the problem in Part (a) minimizes the total cost?

Pause and solve !?!

As energy costs continue to rise, power efficiency is increasingly important. Acme Chemical is evaluating two different electric motors to drive a mixing motor and needs to perform a present economy study. The motor will produce 75 hp and will be operated eight hours per day, 365 days for one year (maintenance will be performed on second shift—assume no down time during operation), after which time the motor will have no value. Select the most economical motor. Assume Acme's electric power costs $0.16 per kWh. 1 hp = 0.746 kW.

	Motor A	Motor B
Purchase price	$3,200	$3,900
Annual maintenance cost	$250	$450
Efficiency	75%	85%