1 Engineering Economic Decisions

After this chapter you will be able to:

1. state what engineering economy is, and explain why engineers are the people who do this work
2. explain the six steps of the rational decision-making process, and name the two steps that engineering economics supplies
3. recognize the five types of engineering economic decision, and the two features that define every investment project, time and uncertainty
4. state the four fundamental principles of engineering economy
5. distinguish the relevant figures from the irrelevant ones by keeping only the differences among alternatives
6. read one project year in the income statement, the balance sheet, and the cash flow statement, and explain why profit and cash differ

Lecture 2. This section is covered by Lecture 2.

Engineers make decisions about money every day. Which machine should the plant buy? Should a manual task be automated? Is a proposed project worth its cost? Should an aging machine be kept or replaced, and if replaced, when? Each of these has a technical side and an economic side, and the engineer is usually the person closest to both. This chapter introduces the kind of decision the course is about, the process used to make such a decision well, and the four principles that run through every method that follows.

Engineering economy. The use of economic methods to evaluate engineering alternatives; choosing among them using money as the common measure.

1.1 What Engineering Economy Is

Engineering economy is the use of economic methods to evaluate engineering alternatives. It is the financial and economic evaluation of projects, and more broadly the study of the financial factors that affect industrial activity. A one-line definition is worth keeping in mind: engineering economy is the practice of choosing among engineering alternatives using money as the common measuring stick.

Engineers are well placed to do this work because they understand the technology. They can best judge how long an asset such as a flotation cell, a haul truck, or an inspection robot will remain useful, and they can estimate how much a processing line will produce. Engineering economy connects this technical knowledge to the decision of whether a project should go ahead and which alternative should be chosen.

Business vs. non-business. In a business setting, alternatives are judged by a money criterion such as profit. In a non-business setting, criteria such as safety, public benefit, or environmental impact also matter.

In a business setting, decisions are usually justified by a money criterion such as profit. In a non-business setting, other criteria such as safety, public benefit, or environmental impact also matter. Either way, in a competitive environment engineers are expected to carry out the financial analysis of their own projects and to make decisions they can defend.

Reference. Chan S. Park, *Fundamentals of Engineering Economics*, 3rd ed., chapter-opening vignette.

1.2 *Why This Matters: An Opening Story*

The textbook opens with a familiar story. Mark Zuckerberg launched Facebook while he was a university student, first as a social network for one campus. It grew to more than two billion users, and by 2017 its value had risen to roughly $450 billion. There are many similar examples, such as Google, Dell, and Yahoo, each founded by motivated students.

What these ventures share is a combination of two things: capable people who generated sound ideas for investing capital, and the ability to carry those ideas out and obtain good results. A good idea alone is not enough; it must be justified and executed in economic terms. That combination of a sound idea and sound economic execution is the subject of this course.

Lecture 2. This section is covered by Lecture 2.

Rational decision process. The six steps from recognizing a problem to selecting the best alternative. Engineering economics supplies the criterion and the final choice.

1.3 *The Rational Decision-Making Process*

A good decision follows a clear process. The textbook describes six steps.

1. Recognize that a decision problem exists.

2. Define the goals or objectives.

3. Collect all relevant information.
4. Identify the set of feasible alternatives.
5. Select the decision criterion.
6. Select the best alternative according to that criterion.

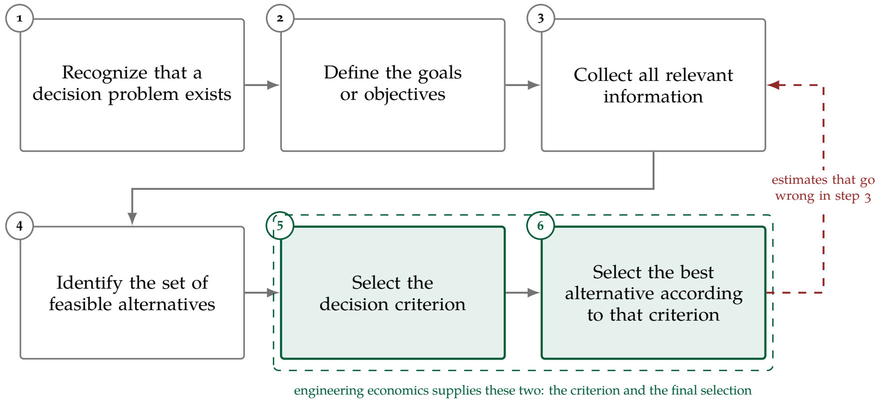

Figure 1.1. The six steps of the rational decision-making process. Engineering economics supplies the last two, the criterion and the final selection; the dashed arrow is not a seventh step but a reminder that a decision is only as good as the estimates gathered in step 3, which is where a realized cost or demand that departs from the estimate sends the analysis back.

Figure 1.1 sets the six steps out in order; note where the dashed arrow returns, since a decision fails far more often on the estimates of step 3 than on the criterion of step 5.

Engineering economics mainly supplies the tools for the last two steps: the criterion and the final selection. But the quality of the decision depends on all six. If the wrong information is collected, or a good alternative is missed, even a correct criterion leads to a poor decision.

Pitfall: optimism bias. The estimates collected in step 3 tend to be systematically favorable: costs come in low and benefits high, and the error does not average out (Flyvbjerg, 2006). Treat a single in-house estimate as a hopeful draft, not a measurement. A later chapter treats this bias, and its correction, in full.

Example 1.1 — Which haul truck to acquire

A mining operation must move ore from the pit to the crusher. The six steps apply directly.

Solution.

Step	Process	Applied to the decision
1	Recognize the problem	Ore must move from pit to crusher
2	Define goals	Low cost per tonne; better safety
3	Collect information	Technical and financial data, both fleets
4	Identify alternatives	Conventional fleet vs. autonomous fleet
5	Select the criterion	Min. cost per tonne-km at acceptable risk
6	Select the best option	Choose the autonomous fleet

The same six steps apply to a wide range of decisions, from a single robot to a complex project worth billions of SAR. The structure of the process does not change; only the size of the numbers changes.

In practice. Step 3 is engineering work. Payload, cycle time, and fleet availability determine the cost per tonne-km, and no criterion in step 5 can repair estimates that go wrong in step 3.

Engineering economic decision. Any investment decision related to an engineering project. There are five types.

1.4 *Types of Strategic Engineering Economic Decisions*

An engineering economic decision is any investment decision related to an engineering project. Such decisions fall into five groups.

New product or expansion. Build a new lithium-refining line? Open a new mine to meet rising battery demand?

Equipment and process selection. Which separation technology? Which robot platform for pipeline inspection?

Cost reduction. Automate a manual sampling task? Deploy automated process control to cut energy use? Make a part in-house or buy it?

Equipment replacement. Replace an aging haul truck now, or later? Upgrade the control software instead?

Service and quality improvement. Invest to improve throughput, the mineral recovery rate, or the safety record?

Two defining features. *Time*: money is committed now and results appear later. *Uncertainty*: those results are not known in advance.

Two features define every investment project: *time* and *uncertainty*. Money is committed now, and the results appear later and are not known in advance. Large minerals and automation projects are hard precisely because they need a large amount of capital at the start, the outcomes appear only after a long time, and changing prices make future revenue hard to predict. The methods in this course are designed to deal with both of these features.

1.5 *The Four Fundamental Principles*

Four principles guide every analysis in this course. They are simple to state and worth memorizing.

1.5.1 *Principle 1: An earlier riyal is worth more than a later riyal*

Money has earning power. At 10% interest, 100 SAR today grows to 110 SAR in one year and to 121 SAR in two years (Figure 1.2). Because money can be invested to earn a return, receiving 100 SAR today is not the same as receiving 100 SAR next year. This single idea, the time value of money, is the subject of Chapter 2 and of every method built on it.

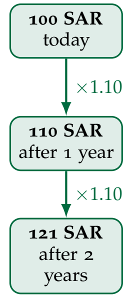

Figure 1.2. At 10%, money today grows period by period. This is the time value of money.

1.5.2 *Principle 2: Only the differences among alternatives matter*

When two alternatives share an item, that item cannot change which one is better. Consider inspecting a pipeline network with a robot or with a manual crew. Annual figures are in SAR.

Option	**Permit fees**	**Site access**	**Capital outlay**	**Annual operating**	**Salvage (yr 5)**
Robot	12,000	8,000	400,000	60,000	90,000
Manual crew	12,000	8,000	0	280,000	0

Table 1.1. Robot vs. manual pipeline inspection. The permit fees and site access (gray) are identical for both options, so they cannot affect the choice.

The permit fees and the site-access charges are the same for both options, so they are irrelevant to the choice. The analysis should compare only what differs: the capital outlay, the annual operating cost, and the salvage value.

Insight. Items that are identical across alternatives cannot change the ranking, so they can be removed from the analysis. This is why a good comparison lists only the differences. It is also why a large shared cost, such as a purchase price that is the same for both options, is often not relevant to the decision.

Pitfall: sunk-cost attachment. Principle 2 removes money already spent from every comparison, yet people keep paying attention to it: a large past outlay feels like a reason to continue. The audit problems at the end of this chapter practice catching this error; a later chapter examines why the attachment persists.

Marginal cost / revenue. Marginal cost is the cost of one more unit; marginal revenue is the revenue from one more unit.

1.5.3 Principle 3: Marginal revenue must exceed marginal cost

In practice. Marginal cost is rarely flat in a plant. Beyond the efficient operating point, energy per tonne and wear rates rise, and knowing where that point sits is engineering knowledge; without it this principle cannot be applied.

Producing one more tonne of refined concentrate is worthwhile only if the extra revenue from it exceeds the extra cost of producing it. This principle is used to decide how much to produce, when to stop expanding capacity, and which orders are worth accepting.

1.5.4 Principle 4: Additional risk requires additional expected return

Risk premium. The extra expected return demanded for taking on more risk.

Investors accept more risk only if they expect a higher return in exchange.

Table 1.2. Risk and expected return for three project types. As risk rises, the expected return demanded rises with it.

Where to place project capital	Risk	Expected return
Government sukuk or cash reserve	Low / none	3%
Upgrade to an established plant	Moderate	9%
New autonomous-mining venture	High	22%

The same logic applies to engineering projects: a riskier robotics venture must promise a higher return to be justified.

Reference. Park, 3rd ed., Section 1.2, discusses how projects appear in a firm's financial statements.

1.6 Projects and the Firm's Financial Statements

A project does not live on its own. Once approved, it becomes part of a firm, and the firm reports its position to owners, lenders, and regulators through three standard financial statements. An engineer who proposes a project should know where that project will appear in each of them, because the people who approve the capital read these statements first.

Income statement. The report of a period's revenues and expenses. The bottom line is net income, also called profit.

The *income statement* answers: did the firm earn a profit this period? It lists the revenues earned during the period and subtracts the expenses incurred to earn them. A project appears here through the revenue it adds, the operating costs it adds, the depreciation of its equipment, and the interest on any money borrowed to build it.

Balance sheet. A snapshot of what the firm owns (assets) and owes (liabilities) at one date. The difference is the owners' equity, and the two sides always balance.

Cash flow statement. The report of actual cash received and paid during a period, grouped into operating, investing, and financing activities.

The *balance sheet* answers: what does the firm own and owe right now? It is a snapshot at one date, not a story over a period. A project appears here as an asset (the equipment, at cost less accumulated depreciation), as a liability (the unpaid balance of any loan that financed it), and in the owners' equity (the profit the project has added and the firm has kept).

The *cash flow statement* answers: where did the cash actually go? It records only cash, in three groups: *operating* (cash from running the business), *investing* (cash spent on or received from long-lived assets), and *financing* (cash raised from or returned to lenders and owners). This statement is the closest relative of the cash flow diagram of chapter 2: both track money as it actually moves.

Example 1.2 — One project year in three statements

Najd Copper commissions a crusher upgrade at the start of the year. The upgrade costs 900,000 SAR, paid immediately: 600,000 SAR is borrowed from a bank at 5%, and 300,000 SAR comes from the firm's own cash. During the year the upgrade adds 520,000 SAR of revenue and 180,000 SAR of operating cost. The equipment is depreciated straight-line over ten years (90,000 SAR per year), and at year end the firm pays 30,000 SAR of interest ($0.05 \times 600{,}000$) and repays 120,000 SAR of principal. Show where the project's first year appears in each of the three statements. (Income taxes are set aside here; they are the subject of the chapter on depreciation and income taxes.)

Solution.

Income statement (the year's profit).

Revenue and expenses that belong to the year:

$$
\begin{aligned}
\text{Revenue} &= 520{,}000 \\
\text{Operating cost} &= -180{,}000 \\
\text{Depreciation} &= -90{,}000 \\
\text{Interest} &= -30{,}000 \\
\text{Net income} &= \boxed{220{,}000\ \text{SAR}}
\end{aligned}
$$

Note that the 900,000 SAR purchase does not appear as an expense. Only this year's share of it, the 90,000 SAR depreciation, does.

Cash flow statement (the year's cash).

Only actual cash moves:

$$\begin{aligned}
\text{Operating: } & 520{,}000 - 180{,}000 - 30{,}000 = +310{,}000 \\
\text{Investing: } & -900{,}000 \\
\text{Financing: } & +600{,}000 - 120{,}000 = +480{,}000 \\
\text{Net change in cash: } & \boxed{-110{,}000 \text{ SAR}}
\end{aligned}$$

Depreciation appears nowhere here, because no cash leaves the firm when equipment ages. Equivalently, operating cash is net income plus depreciation: $220{,}000 + 90{,}000 = 310{,}000$ SAR.

Balance sheet (the position at year end).

Changes caused by the project:

$$\begin{aligned}
\text{Assets: } & \text{equipment } 900{,}000 - 90{,}000 = +810{,}000;\ \text{cash } -110{,}000 \\
& \Rightarrow \text{ total assets } +700{,}000 \\
\text{Liabilities: } & \text{loan } 600{,}000 - 120{,}000 = +480{,}000 \\
\text{Equity: } & \text{retained earnings } +220{,}000
\end{aligned}$$

The two sides agree: $480{,}000 + 220{,}000 = \boxed{700{,}000 \text{ SAR}}$. The balance sheet balances, which is a built-in arithmetic check.

Insight. Profit and cash are different numbers telling different truths. The project earned 220,000 SAR of profit in a year in which the firm's cash *fell* by 110,000 SAR, and both statements are correct. The wedge between them is timing: the purchase is paid at once but expensed over ten years. Engineering economy works with the cash flows, because cash is what earns interest; the statements then report the result to outsiders in their own language.

Reference. Flyvbjerg (2006), *Project Management Journal*, 37(3), 5–15. An open-access copy is on arXiv (arXiv:1302.3642).

1.7 *Case Study from the Literature*

The pitfalls flagged in this chapter's margins are not anecdotes. They have been measured, on decades of real projects, and the measurements bear directly on step 3 of the decision process and on Principle 4. The case below works through the published numbers.

Example 1.3 — Case study: cost overruns in transportation megaprojects

Flyvbjerg (2006) summarized the first large statistical studies of forecast accuracy in transportation infrastructure. Across the samples, the average cost overrun in constant prices was 44.7% for rail projects (standard deviation 38.4), 33.8% for bridges and tunnels (62.4), and 20.4% for roads (29.9), and over the 70-year period for which data exist the accuracy of cost forecasts has not improved. Demand forecasts err too, in a direction that flatters rail: actual rail passenger traffic averaged 51.4% *below* forecast, with 84% of rail projects wrong by more than $\pm 20\%$, while actual road traffic averaged 9.5% *above* forecast. Based on these distributions, the United Kingdom's Department for Transport adopted "uplifts": percentages added to a submitted budget so that the result holds at a stated confidence level. For roads the uplift is 15% at the 50% level and 32% at the 80% level; for rail it is 40% and 57%. The paper's amounts are in pounds sterling, and this example keeps that currency.

(a) Apply the road uplifts to the paper's own example, a road budget of £100 million. (b) Apply the rail uplifts to a metro budget of £300 million. (c) A rail promoter forecasts revenue of 1.20 per unit of forecast cost. Using the average outcomes above, estimate the realized revenue-to-cost ratio.

Solution.

(*a*) *Road budgets.*

An uplift is a multiplication by one plus the percentage:

$$100 \times 1.15 = \boxed{\text{£115 million}} \quad \text{(50\% confidence)},$$
$$100 \times 1.32 = \boxed{\text{£132 million}} \quad \text{(80\% confidence)}.$$

These are the paper's own figures: a funder who wants an 80% chance of staying within budget should hold £132 million against a £100 million submission.

(*b*) ***Rail budgets.***

Rail requires larger uplifts because its overrun distribution is worse:

$$300 \times 1.40 = \boxed{\text{£420 million}}, \qquad 300 \times 1.57 = \boxed{\text{£471 million}}.$$

At the same 80% confidence, rail needs 57% added where a road needs 32%.

(*c*) ***The combined effect on rail.***

On average, realized cost is 1.447 times the forecast, and realized rail demand, and with it revenue, is $1 - 0.514 = 0.486$ of the forecast. The realized ratio is therefore

$$1.20 \times \frac{0.486}{1.447} = 1.20 \times 0.336 = \boxed{0.40}.$$

A project presented as returning 1.20 units of revenue per unit of cost delivers, at the historical averages, about 0.40: the cost error and the demand error compound, because one inflates the denominator while the other deflates the numerator.

Flyvbjerg concluded that errors of this size and persistence cannot be explained by honest technical difficulty alone. He attributed them to *optimism bias* (planners believe their own favorable estimates) and *strategic misrepresentation* (proposals are shaded to win approval), and argued for *reference class forecasting*: place the new project inside the outcome distribution of comparable past projects and budget from that distribution, as the uplift tables do. The American Planning Association endorsed the method in 2005 (Flyvbjerg, 2006). For this course the lesson attaches to step 3 of the decision process: the quality of a decision is capped by the quality of its estimates, and an estimate audited against outside data beats a confident inside view.

In practice. The uplift percentages are not engineering knowledge; they are a statistical patch applied when engineering knowledge is reported with bias. A firm whose estimates are demonstrably unbiased needs smaller uplifts, which makes honest estimating a source of competitive advantage.

1.8 *Chapter Summary*

- An **engineering economic decision** is any investment decision related to an engineering project.
- There are **five types**: new product or expansion; equipment and process selec-

tion; cost reduction; replacement; service and quality improvement.

- **Time** and **uncertainty** are the defining features of any investment project.
- The **rational decision process** has six steps; engineering economics supplies the criterion and the final choice.
- The **four principles**: an earlier riyal is worth more than a later riyal; only differences among alternatives matter; marginal revenue must exceed marginal cost; additional risk is not taken without additional expected return.
- An approved project appears in the firm's **three financial statements**: its profit in the income statement, its assets, loan, and retained earnings in the balance sheet, and its actual cash in the cash flow statement. Profit and cash differ, and the difference is timing.

1.9 *Exercises*

These problems exercise the six-step decision process, the five types of engineering economic decision, and the four principles, with most turning on separating the figures that differ between alternatives from those that do not.

Exercise 1.1. Two haul-truck options carry *identical* permit fees and site-access charges, but differ in capital outlay, operating cost, and salvage value. According to the principles of engineering economy, which figures are relevant to the choice?

(A) all five, since each is a real cost
(B) only the figures that *differ* between the options
(C) only the permit fees and site-access charges
(D) none — the cheaper truck is always best

Exercise 1.2. A refinery is deciding how many tonnes of concentrate to produce. It should keep increasing output as long as:

(A) total revenue is positive
(B) the marginal revenue of one more tonne exceeds its marginal cost
(C) the average cost per tonne is falling
(D) the salvage value is positive

Exercise 1.3. A campus delivery robot is expected to reduce costs over several years. The team should base its purchase decision on:

(A) the full purchase price, since it is the largest number
(B) the savings in year 1 only
(C) the total savings, ignoring when they occur
(D) the savings that differ from the next-best option

Exercise 1.4. True or False. With a positive interest rate, receiving 100 SAR today is economically equivalent to receiving 100 SAR one year from now.

Exercise 1.5. True or False. "Earning power" and "purchasing power" are two distinct reasons money has a time value, and inflation relates to purchasing power.

Exam-style problems

The remaining problems follow the format of the course's major exams: a scenario, lettered parts with point values, and full work expected. Show the reasoning for every part, box each final number with its units, and end with a decision sentence.

Exercise 1.6. Choosing a haul-truck fleet at Najd Copper. Najd Copper must select one haul-truck fleet for a five-year pit contract. Before the comparison began, the firm spent 180,000 SAR on a route survey whose results apply equally to both fleets. Both fleets also require the same pit-access permit of 25,000 SAR per year. The remaining figures, in SAR, are:

	First cost (year 0)	Operating per year	Salvage (year 5)
Fleet D (diesel)	2,400,000	620,000	400,000
Fleet E (electric)	3,100,000	470,000	650,000

(a) (*6 pts*) State which figures are relevant to the choice and which are not, naming the principle that removes each irrelevant one. (b) (*8 pts*) Using only the relevant figures, and ignoring the timing of the flows for the moment, compute the five-year net advantage of Fleet E over Fleet D. (c) (*6 pts*) The extra capital for Fleet E is paid at year 0, while its operating savings arrive in years 1–5 and its extra salvage at year 5. Using Principle 1, state whether the answer in (b) overstates or understates the advantage of Fleet E, and give the reason.

Exercise 1.7. Expanding output at Wadi Phosphate. Wadi Phosphate sells concentrate at a market price of 380 SAR per tonne, and its output does not affect the price. The beneficiation line can be expanded in three blocks of 10,000 tonnes per year each. Because each block pushes the plant further past its efficient operating point, the blocks differ in cost: block 1 adds 2,900,000 SAR per year of cost, block 2 adds 3,400,000 SAR per year, and block 3 adds 4,100,000 SAR per year. (a) (*6 pts*) Compute the marginal cost per tonne of each block. (b) (*8 pts*) Decide which blocks to add and compute the extra annual profit at that output. (c) (*6 pts*) A manager argues: "the average cost across all three blocks is $10{,}400{,}000/30{,}000 = 346.67$ SAR per tonne, which is below the 380 SAR price, so all three blocks should be added." Identify the error and compute the annual profit given up if all three blocks are added.

Assessing outside recommendations

Engineers are often handed a finished analysis: a vendor proposal, a consultant memo, or the output of an AI assistant. Auditing someone else's work is a different skill from producing your own, because the arithmetic is usually correct and the flaw sits in the method. For each problem below, (a) decide whether to accept the recommendation, (b) identify each error or omission precisely, and (c) produce the corrected number.

Exercise 1.8. A consultant's memo on sampling automation. Wadi Lithium must decide whether to keep its manual brine-sampling crew or buy an inspection robot. Last year the firm spent 240,000 SAR on a pilot trial of the robot. A consultant submits the memo below.

> *Robot option: purchase 520,000, plus the 240,000 pilot program already invested in this technology, gives 760,000 of capital. Operating cost is 60,000 per year for five years, or 300,000, less a 90,000 salvage credit. Five-year total:* $760{,}000 + 300{,}000 - 90{,}000 = 970{,}000$ *SAR. Manual crew: 195,000 per year for five years, or 975,000 SAR. The totals are essentially equal, and the robot carries more implementation risk. Recommendation: retain the manual crew.*

(a) (*4 pts*) Should the firm accept the recommendation? (b) (*8 pts*) Identify each error in the memo precisely. (c) (*8 pts*) Correct the comparison and state the resulting recommendation. (Follow the memo in ignoring the timing of the flows.)

Exercise 1.9. An AI assistant places surplus capital. Najd Copper holds 2,000,000 SAR that it will not need until a mill rebuild in three years. Two placements are considered: a government sukuk paying a certain 4% compounded annually, or a minority stake in an autonomous-drilling venture that will be bought out in three years, paying 2,600,000 SAR if the technology is adopted (probability 0.5) and 1,600,000 SAR if it is not (probability 0.5). An AI assistant wrote:

> *Expected venture payout* $= 0.5(2{,}600{,}000) + 0.5(1{,}600{,}000) = 2{,}100{,}000$ *SAR. Expected gain* $= 2{,}100{,}000 - 2{,}000{,}000 = +100{,}000$ *SAR, and the favorable case gains 600,000 SAR. The venture is profitable in expectation. Recommendation: invest in the venture.*

(a) (*4 pts*) Should the firm accept the recommendation? (b) (*8 pts*) Identify each error in the assistant's reasoning. (c) (*8 pts*) Produce the corrected comparison and state the resulting recommendation.

References

Flyvbjerg, B. (2006). From Nobel Prize to Project Management: Getting Risks Right. *Project Management Journal*, 37(3), 5–15. Open-access copy: `https://arxiv.org/abs/1302.3642`

Park, C. S. (2012). *Fundamentals of Engineering Economics*, 3rd ed. Pearson.