9 *Estimating Costs: From Engineering Data to Numbers*

After this chapter you will be able to:

1. classify a cost as direct or indirect, fixed or variable, and recurring or nonrecurring
2. state the AACE estimate class of a number, and the accuracy range that class can claim
3. compute a capacity-factored estimate with $C_2 = C_1(Q_2/Q_1)^n$, and derive the exponent n from two reference plants
4. escalate an old cost to today with a cost index ratio, $C_{\text{now}} = C_{\text{then}}(I_{\text{now}}/I_{\text{then}})$
5. size a project contingency, and distinguish it from management reserve
6. recognize why capital estimates are biased low, and name the countermeasures

Every chapter so far has consumed cost estimates as if they arrived by themselves. Chapter 5 discounted "a kit that costs 55,000 SAR"; chapter 7 solved for the rate hidden in given cash flows; even the public projects of chapter 8 began from a stated capital cost. This chapter asks where those numbers come from. The answer is a craft with its own vocabulary and its own error bars: costs are first *classified* (direct or indirect, fixed or variable, recurring or nonrecurring), then *estimated* by methods that trade effort for accuracy, from a ten-minute analogy to a full takeoff of drawings, then *escalated* to the date money will actually be spent, and finally cushioned with a *contingency* that reflects how little is yet known. The estimate classification system of AACE International organizes all of this: it ties the maturity of the engineering to the accuracy a cost number can defensibly claim, from a Class 5 order-of-magnitude screen to a Class 1 definitive estimate. An engineer who knows which class a number belongs to knows how hard to lean on it.

Scaling, classifying, and dating a cost.

Q1. A concentrator with capacity 1,000 t/d cost 100 million SAR to build. A proposed plant of the same type will have capacity 2,000 t/d. Is 200 million SAR a good first estimate of its cost?

Q2. Classify the electricity that drives a flotation cell's agitator motors: direct or indirect? Fixed or variable?

Q3. A vendor quoted 850,000 SAR for a slurry pump in 2019, when the relevant equipment cost index stood at 190. The index now stands at 247. What is the updated estimate?

Answers.

Q1. *No; it is too high.* Process-plant costs grow more slowly than capacity. With the six-tenths rule, $C_2 = 100 \times 2^{0.6} = 151.6$ million SAR. Doubling the capacity raises the cost by only about half, which is the economy of scale that makes large plants attractive.

Q2. *Direct* (it is traceable to the flotation operation) and *variable* (it rises and falls with the tonnage processed). The plant manager's salary is the mirror image: indirect and fixed. The two classifications answer different questions and should not be merged.

Q3. Scale by the index ratio: $850{,}000 \times (247/190) = 1{,}105{,}000$ SAR. The 2019 number is not wrong; it is a 2019 number. Prices move, and an estimate must be stated at the date the money will be spent.

Reference. Park, 3rd ed., Section 10.1 (pp. 426–435).

Direct cost. A cost traceable to one product, process, or work package: ore haulage, flotation reagents, the mill relining crew.

Indirect cost. A cost shared across the operation and allocated rather than traced: the assay laboratory, site administration, camp services. Also called overhead.

9.1 *Cost Concepts: A Vocabulary for Estimating*

Before any number is estimated, it must be classified, because different decisions call for different costs. Three pairings do most of the work.

Direct versus indirect. A direct cost can be traced to a single product or work package: the reagents consumed by the flotation circuit, the liner steel in the mill. An indirect cost (overhead) supports the whole operation and must be allocated: the assay laboratory, site administration, insurance. Estimators build direct costs from quantities and unit prices, then load indirects on top as percentages or allocations; audits of estimates often find their errors in the indirect layer, because nothing physical anchors it.

Fixed versus variable. Over a stated operating range, fixed costs do not move with output (salaried staff, leases, standby charges) while variable costs are proportional to it (reagents, grinding media, power per tonne). The split predicts how the *unit* cost behaves: fixed cost per tonne falls as tonnage rises, so the same plant is cheaper per tonne when it runs full. This is the cost side of the unit-profit calculations of Chapter 6.

Recurring versus nonrecurring. The first cost, commissioning, and closure are one-time events; operating and maintenance repeat every period. The cash flow diagram already encodes this distinction: nonrecurring costs are single arrows, recurring costs are series.

One more item belongs in the vocabulary now, although its full treatment waits for chapter 11: *working capital*, the money tied up in ore stockpiles, consumable inventories, spare parts, and unpaid invoices. It is spent near start-up like capital, but it is not consumed: it is recovered when the project winds down. Estimates that omit working capital understate the money the owner must actually mobilize.

Fixed cost. A cost that does not change with output over the relevant range: permits, salaried staff, standby power charges.

Variable cost. A cost proportional to output: reagents, grinding media, energy per tonne, tonnage royalties.

Recurring / nonrecurring. Recurring costs repeat every period (operating and maintenance); nonrecurring costs happen once (first cost, commissioning, closure).

Working capital. Money tied up in inventories, spares, and receivables to keep the plant running. It is invested near start-up and recovered at the end of the project.

Example 9.1 — Unit cost at a flotation concentrator

A copper concentrator has fixed costs of 24 million SAR per year (staff, leases, standby charges) and variable costs of 85 SAR per tonne milled (power, reagents, grinding media). Compute the total cost per tonne at 300,000 t/yr and at 500,000 t/yr, and explain the difference.

Solution.

At 300,000 t/yr, the fixed cost spreads over fewer tonnes:

$$\text{unit cost} = 85 + \frac{24{,}000{,}000}{300{,}000} = 85 + 80 = \boxed{165\text{ SAR/t}}.$$

At 500,000 t/yr:

$$\text{unit cost} = 85 + \frac{24{,}000{,}000}{500{,}000} = 85 + 48 = \boxed{133\text{ SAR/t}}.$$

The variable 85 SAR/t is untouched by throughput; only the fixed layer dilutes. The 32 SAR/t difference is why utilization dominates unit-cost discussions, and why a cost estimate must always state the tonnage it assumes. A single ''cost per tonne'' without its throughput is not an estimate; it is a point on an unstated curve.

Insight. Classification is not bookkeeping pedantry; it decides which costs matter for which decision. A shutdown decision compares price against *variable* cost, because the fixed costs run either way in the short term. A capacity decision needs the whole curve. And an incremental decision, the kind Chapters 5 and 7 formalized, needs only the costs that *differ* between alternatives. The most common estimating error in student work is hauling a fixed cost into a comparison it cannot affect.

Reference. AACE International, Recommended Practice 18R-97, *Cost Estimate Classification System* (rev. 2020). Matrix values verified against the published document in July 2026.

Estimate class. A label (Class 5 down to Class 1) tying an estimate's claimed accuracy to the maturity of the project definition behind it.

9.2 *Estimate Classes: How Good Is This Number?*

An estimate is not simply right or wrong; it has a pedigree. AACE International's Recommended Practice 18R-97 classifies process-industry cost estimates into five classes, determined by one primary characteristic: **the maturity of the project definition deliverables**, the flowsheets, diagrams, and equipment lists that exist when the estimate is made. The accuracy an estimate can claim follows from that maturity, not from the estimator's confidence. Table 9.1 summarizes the matrix.

Class	Definition maturity (% complete)	End usage; methodology	Expected accuracy (80% confidence)
5	0% to 2%	Concept screening; capacity factoring, parametric, analogy	−20% to −50% low; +30% to +100% high
4	1% to 15%	Study or feasibility; equipment-factored or parametric models	−15% to −30% low; +20% to +50% high
3	10% to 40%	Budget authorization; semi-detailed unit costs	−10% to −20% low; +10% to +30% high
2	30% to 75%	Control or bid/tender; detailed unit cost, forced takeoff	−5% to −15% low; +5% to +20% high
1	65% to 100%	Check estimate or bid/tender; detailed unit cost with takeoff	−3% to −10% low; +3% to +15% high

Table 9.1. The AACE 18R-97 cost estimate classification matrix for the process industries (summarized). The maturity of the project definition is the sole determinant of the class; usage, method, and accuracy follow from it.

Read the matrix from left to right. A **Class 5** estimate exists before engineering does: definition is 0–2% complete, the method is capacity factoring, parametric models, judgment, or analogy, and the honest accuracy band stretches from −50% to +100% in unfavorable cases, the band loosely quoted as "order of magnitude, ±50%." It exists to screen concepts, never to authorize budgets. A **Class 3** estimate, built on 10–40% definition with semi-detailed unit costs, is the usual basis for budget authorization. A **Class 1** definitive estimate, with engineering nearly complete and a detailed takeoff of quantities, narrows to roughly −10% to +15% at the widest. Three cautions from the practice itself: the ranges are quoted at an 80% confidence interval and assume an unbiased estimate with appropriate contingency already included; systemic risks (new technology, remote sites, hot markets) can stretch the high end to two or three times the tabulated values; and the class is set by the deliverables that exist, not by the precision a spreadsheet displays.

Figure 9.1 plots the five accuracy bands one above the other; note that every band is wider on the high side than on the low side, so an estimate is far more likely to be overrun than underspent.

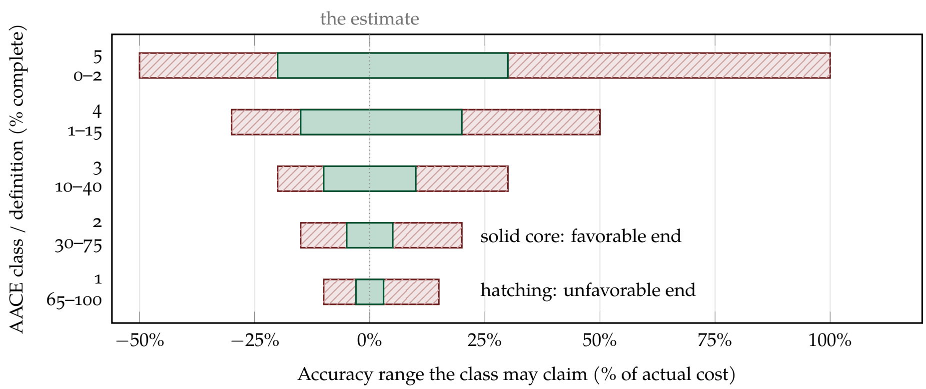

Figure 9.1. The estimate-accuracy funnel of Table 9.1. Each row is one AACE class: the solid core is the favorable end of the class's range, the hatched wings run out to the unfavorable end. Accuracy is bought with engineering, not with arithmetic care — the band narrows only as the project definition on the left matures. All ranges are 80% confidence intervals that already assume appropriate contingency.

Insight. The matrix ties money to engineering with a chain: deliverables determine class, class determines method, method determines accuracy. Spending on engineering is therefore what *buys* accuracy; no amount of arithmetic care can turn a Class 5 basis into a Class 3 number. This is why stage-gate capital processes release funds in steps: each gate pays for the engineering that narrows the next estimate.

In practice. The classification is judged from concrete deliverables: are the process flow diagrams issued? are piping and instrumentation diagrams complete? is there an engineered equipment list? An engineer who can name which deliverables exist can assign the correct class to any estimate presented, and can challenge one that claims Class 3 accuracy on Class 5 paper.

9.3 *Estimation Methods: From Analogy to Takeoff*

The five classes correspond to a ladder of methods. This section climbs it.

Analogy. The fastest estimate is a neighbor's actual cost: "the last concentrator of this type cost 180 million SAR." Adjust for scope, site, and date, and state the source. Analogy is honest Class 5 work, and it anchors every later method, because parametric models are only organized collections of analogies.

Estimate by analogy. Take the known cost of a similar completed project and adjust for differences in scope, site, and date.

Capacity factoring: the six-tenths rule. When the new plant differs from the reference mainly in size, scale the cost with a power law:

Capacity factoring. $C_2 = C_1(Q_2/Q_1)^n$: scale a known plant cost C_1 at capacity Q_1 to a new capacity Q_2 with a process-specific exponent n, commonly near 0.6.

$$C_2 = C_1 \left(\frac{Q_2}{Q_1} \right)^n , \tag{9.1}$$

where C_1 is the known cost of a plant of capacity Q_1, and Q_2 is the new capacity. Across many process plants the exponent n clusters near 0.6, hence the name; because $n < 1$, cost grows more slowly than capacity, which is the economy of scale. The exponent is an empirical, equipment- and process-specific quantity, typically between 0.5 and 0.85, and the rule should not be stretched across more than about a tenfold capacity range or across a change of technology.

In practice. The exponent is geometry and physics before it is statistics. Vessel cost follows surface area (metal) while capacity follows volume, and area grows as volume to the two-thirds power, so tanks and columns scale near 0.6–0.7. Machines that must be duplicated rather than enlarged, such as parallel flotation cells or modular trains, scale closer to 0.9–1.0. Choosing n is a judgment about *how* the plant gets bigger, not a constant to memorize.

Example 9.2 — Scaling up a flotation plant

A flotation concentrator treating 200,000 t/yr was recently built for 180 million SAR. A geometrically similar plant is proposed for 500,000 t/yr. (a) Estimate its cost with the six-tenths rule. (b) Compare with linear scaling, and with $n = 0.9$, the exponent a vendor suggests because the larger plant would use parallel identical trains. (c) State the class of this estimate.

Solution.

(*a*) *Six-tenths.* The capacity ratio is $500/200 = 2.5$:

$$C_2 = 180\,(2.5)^{0.6} = 180\,(1.7329) = \boxed{311.9 \text{ million SAR}}.$$

(b) *Other exponents.* Linear scaling ($n = 1$) gives $180 \times 2.5 = 450$ million SAR; $n = 0.9$ gives $180\,(2.5)^{0.9} = 180\,(2.2811) = 410.6$ million SAR. The spread from 311.9 to 450 million SAR, a range of 44%, is produced entirely by the choice of exponent, which is why that choice must be defended from the flowsheet: if the big plant is one larger vessel line, 0.6 is defensible; if it is two and a half copies of the small one, the vendor's 0.9 is closer to the truth.
(c) *Class.* Capacity factoring on a single reference plant with no engineering deliverables is **Class 5**: concept screening, honest accuracy no better than about -30% to $+50\%$ even in a favorable case. Decision sentence: carry 312 million SAR as a screening figure with its class attached, and do not let it be adopted as a budget.

Example 9.3 — Estimating the exponent from two plants

Two recently built concentrators of the same type cost 140 million SAR at 150,000 t/yr and 260 million SAR at 400,000 t/yr. (a) Estimate the process-specific exponent n. (b) Use it to estimate the cost of a 250,000 t/yr plant.

Solution.

(a) Solve Equation (9.1) for n:

$$n = \frac{\ln(C_2/C_1)}{\ln(Q_2/Q_1)} = \frac{\ln(260/140)}{\ln(400{,}000/150{,}000)} = \frac{\ln 1.8571}{\ln 2.6667} = \frac{0.6190}{0.9808} = \boxed{0.63}.$$

(b) Scale from the 150,000 t/yr reference:

$$C = 140\left(\frac{250}{150}\right)^{0.63} = 140\,(1.3804) = \boxed{193.3 \text{ million SAR}}.$$

Two data points fix an exponent exactly and validate nothing; with three or more reference plants, a regression of $\ln C$ on $\ln Q$ gives n as the slope and shows the scatter, which is the honest accuracy of the method. Interpolating between the two references, as here, is safer than extrapolating beyond them.

Parametric estimate. Cost from statistical relationships on design parameters: SAR per tonne of daily capacity, per square meter, per meter of depth.

Parametric and unit-rate estimating. Between factoring and takeoff sits the workhorse of feasibility studies: multiply engineered quantities by historical

Detailed takeoff. Quantities measured line by line from issued drawings, each priced with current rates; the Class 2/1 method.

Cost index. A dimensionless series tracking the price of a defined basket of equipment, materials, and labor over time. The ratio of index values converts a cost between dates.

In practice. Know what is in the basket. A plant cost index weights vessels, piping, and construction labor; a mining index weights steel, tires, and diesel. Escalating a mill quote with a consumer index, or a Saudi project with a basket priced in another market's labor, silently changes the estimate. The index is an engineering choice, not a clerical one.

unit rates, SAR per square meter of liner, per cubic meter of embankment, per tonne of installed steel, or regress cost on design parameters across past projects. The quality of a parametric estimate is the quality of its database: rates must come from comparable projects, comparable sites, and a stated year.

Detailed takeoff. At Classes 2 and 1, quantities are measured from issued drawings, priced line by line with current quotations, and summed. The method is expensive, which is the point of the ladder: takeoff effort is spent only after cheaper methods have kept the concept alive through its gates.

9.4 Escalation: Bringing Old Numbers to Today

Reference costs come from the past; the money will be spent in the future. A *cost index* bridges the dates. An index is a dimensionless series tracking the price of a defined basket, plant equipment, construction labor, structural steel, and a cost moves between dates by the ratio of the index values:

$$C_{\text{now}} = C_{\text{then}} \times \frac{I_{\text{now}}}{I_{\text{then}}}. \tag{9.2}$$

This is the mechanics of chapter 4 at work: a cost index is an inflation measure for a specialized basket, and Equation (9.2) is the same actual-to-actual conversion used there, with the plant-cost index standing in for the CPI. Construction baskets often move faster than consumer prices, so using general inflation to update an equipment quote usually *under*-escalates it.

Example 9.4 — Escalating a 2019 quote

A ball mill was quoted at 8.4 million SAR in 2019, when the applicable mineral-processing plant cost index stood at 204. The index now stands at 278. (a) Update the quote to today. (b) The mill will actually be purchased two years from now; if the index is expected to keep rising at about 3% per year, extend the estimate to the purchase date.

Solution.

(a) Apply the index ratio:

$$C_{\text{now}} = 8.4 \times \frac{278}{204} = 8.4\,(1.3627) = \boxed{11.45 \text{ million SAR}}.$$

The quote did not age badly; it simply aged. A 2019 number spent as if it were current would be about 36% short. (b) Extend two years at 3% per year, the same compounding as any rate in Chapter 2:

$$C_{+2} = 11.45\,(1.03)^2 = 11.45\,(1.0609) = \boxed{12.15 \text{ million SAR}}.$$

Please keep the two operations distinct in written work: the index ratio converts between *observed* dates; the 3% extension is a *forecast*, and it should be labeled as one. A vendor requote, when available, beats both.

Escalation and capacity factoring combine multiplicatively, so their order does not matter: to estimate a new plant from an old reference of different size, multiply the reference cost by the index ratio and by the capacity ratio raised to n. The exercises practice the combination.

9.5 *Contingency and Management Reserve*

No list of line items is ever complete at estimating time. *Contingency* is the allowance added for costs that experience says will occur but that cannot yet be named: quantities that grow when drawings are finished, fittings no one listed, rework. Two properties follow from that definition and are tested in the exercises. First, contingency is **expected spending**: on a well-run project it is consumed, not returned, so removing it does not save money, it only mis-states the estimate. Second, contingency is sized by *ignorance*, so it shrinks with the estimate class: the less engineering exists, the more must be carried.

Practice splits the allowance in two. *Process contingency* covers technology maturity and is applied section by section: guidance following AACE practice carries roughly 30–70% of a section's cost for a concept proven only at bench scale, 20–35% for a small pilot plant, 5–20% when full-sized modules have operated, and 0–10% for commercial technology. *Project contingency* covers estimate incompleteness for the whole plant: for budget-type (Class 4 or 5) estimates, roughly 15–30% of the base cost including process contingency. Beyond both sits the *management reserve* (owner's contingency): money the owner holds *outside* the estimate for risks outside the estimate's scope, such as scope changes or delayed start-up. The boundary matters in audits: the project manager owns and spends

Reference. Process and project contingency guidance as summarized in the NETL cost estimation methodology (DOE/NETL-2011/1455), following AACE practice; see the case study in Section 9.7.

Contingency. An allowance for costs that experience says will occur but cannot yet be itemized. It is expected spending, inside the estimate, not a margin of safety on top of it.

Management reserve. Funds held by the owner, outside the estimate, for risks beyond the estimate's scope, such as scope changes. Also called owner's contingency.

contingency; only the owner releases reserve.

Insight. Contingency is where estimating meets probability. The accuracy ranges of Table 9.1 are quoted assuming contingency is already included and sized so the estimate is a roughly 50/50 number, equally likely to overrun as underrun. An estimate stripped of contingency is not leaner; it is a number whose odds of being enough have quietly fallen well below half. chapter 14 shows the modern version of this statement, where the estimate is a distribution and contingency is read from a chosen percentile.

Example 9.5— Building a total plant cost with contingency

A bio-oxidation gold plant has a bare erected cost (equipment, materials, and construction labor) of 240 million SAR, of which the novel bio-oxidation section accounts for 40 million SAR; the section has run only at pilot scale. Engineering and construction-management services are priced at 9% of the bare erected cost. The estimator applies 25% process contingency to the pilot-stage section and 20% project contingency to the whole base. Compute the total plant cost, and state what the owner should hold as management reserve policy.

Solution.

Step 1: services.
$0.09 \times 240 = 21.6$ million SAR.

Step 2: process contingency.
Applied only to the immature section: $0.25 \times 40 = 10.0$ million SAR.

Step 3: project contingency on the loaded base.

$$\text{base} = 240 + 21.6 + 10.0 = 271.6, \qquad 0.20 \times 271.6 = 54.32 \text{ million SAR.}$$

Step 4: total plant cost.

$$\text{TPC} = 271.6 + 54.32 = \boxed{325.92 \text{ million SAR}}.$$

About 64 million SAR, one fifth of the total, is contingency of one kind or the other: that is a statement about how little is known at Class 4, not about waste. Management reserve is set on top by owner policy (often a percentage of TPC informed by risk analysis) and is *not* added to the estimate; it is held, separately governed, for scope-level surprises. Decision sentence: we carry 325.92 million SAR as the Class 4 total plant cost, and we resist any request to "find savings" by deleting step 2 or step 3, because those steps are expected spending.

9.6 Estimate Bias: A Pointer

The methods of this chapter assume the estimator wants the right answer. Large-project statistics say something more uncomfortable: capital estimates are biased low, systematically, across countries and decades. Part of the cause is honest optimism about one's own project; part is strategic, because low estimates win approvals. The classification system already contains the countermeasure hints: quote the class, quote the range, keep contingency intact, and benchmark against reference projects rather than against intentions, an approach known as reference-class forecasting. chapter 20 takes up these biases, and the governance designs that blunt them, in full.

9.7 Case Study from the Literature

Everything in this chapter appears, assembled and in production use, in the cost estimation methodology that the U.S. National Energy Technology Laboratory (NETL) applies to its techno-economic baseline studies of power plants. The document, openly published, states its estimate class and accuracy, defines a stack of capital-cost levels, and prescribes both contingencies by technology maturity. All amounts in this methodology are in U.S. dollars, the currency used in the source.

Reference. NETL, *Quality Guidelines for Energy System Studies: Cost Estimation Methodology for NETL Assessments of Power Plant Performance*, DOE/NETL-2011/1455 (April 2011). Figures read from the published document in July 2026.

The methodology declares its pedigree in the terms of Section 9.2: most NETL studies are **AACE Class 4** estimates, intended for feasibility-study use, with an expected accuracy of about −15%/+30%. Capital is built up through five defined levels: the bare erected cost (BEC: equipment, facilities, construction labor); the engineering, procurement, and construction cost (EPCC: BEC plus contractor services, estimated at 8–10% of BEC); the total plant cost (TPC: EPCC plus process and project contingencies); the total overnight cost (TOC: TPC plus owner's costs such as preproduction, inventories, financing fees, and land); and the total as-spent capital (TASC), which spreads TOC over the multi-year construction schedule with escalation and interest. Process contingency follows the maturity ladder quoted in Section 9.5; project contingency for these Class 4/5 estimates is 15–30% of the base; and capital escalation during construction is taken at 3.6% per year, the long-run average of a published plant cost index, connecting directly to Section 9.4.

Example 9.6 — Case study: an NETL-style capital build-up

Apply the NETL methodology to a coal-gasification power plant study with a bare erected cost of 1,000 million USD, of which the CO_2-capture section (BEC 300 million USD) is technology whose full-sized modules have operated but which is not yet fully commercial. Use EPC services at 9% of BEC, process contingency of 15% on the capture section, project contingency of 20% of the base, and NETL's owner's-cost factors: preproduction 2% of TPC, inventory capital 0.5% of TPC, financing costs 2.7% of TPC, other owner's costs 15% of TPC, and land 0.9 million USD. The plant is a five-year, high-risk build with a TASC/TOC multiplier of 1.140. Compute TPC, TOC, and TASC.

Solution.

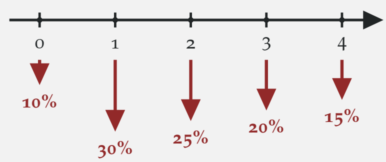

Figure 9.2. The NETL five-year expenditure profile: the total overnight cost is spent 10/30/25/20/15% over years 0–4, and TASC adds escalation and interest to these as-spent amounts.

Step 1: EPCC.

$1{,}000 + 0.09 \times 1{,}000 = 1{,}090$ million USD.

Step 2: contingencies and TPC.

Process contingency touches only the capture section: $0.15 \times 300 = 45$. The base is then $1{,}090 + 45 = 1{,}135$, and project contingency adds $0.20 \times 1{,}135 =$

227:

$$\text{TPC} = 1{,}135 + 227 = \boxed{1{,}362 \text{ million USD}}.$$

Step 3: owner's costs and TOC.

Preproduction $0.02 \times 1{,}362 = 27.24$; inventory $0.005 \times 1{,}362 = 6.81$; financing $0.027 \times 1{,}362 = 36.77$; other owner's costs $0.15 \times 1{,}362 = 204.30$; land 0.90:

$$\text{TOC} = 1{,}362 + 27.24 + 6.81 + 36.77 + 204.30 + 0.90 = \boxed{1{,}638.02 \text{ million USD}}.$$

Step 4: TASC.

Spending is spread over five years (Figure 9.2), and the published multiplier for a high-risk, five-year build converts overnight to as-spent money:

$$\text{TASC} = 1{,}638.02 \times 1.140 = \boxed{1{,}867 \text{ million USD}}.$$

Please note the anatomy: from 1,000 of directly estimable cost, the disciplined build-up reaches 1,867, and every step is a named, defensible allowance rather than padding. The 272 million USD of combined contingency is expected spending at Class 4 definition; the owner's-cost block is real money a naive estimate would omit entirely; and the overnight-to-as-spent step exists because construction money is spent over years, the same time-value logic as every chapter of this book.

What does the source itself emphasize? That these are Class 4, −15%/+30% numbers meant for comparing technologies on a common basis, not for authorizing budgets; that contingency ranges come from AACE recommended practice tied to technology maturity; and that all results are reported with their dollar-year and financing assumptions attached. The document also standardizes what its estimates *exclude* (unusual site conditions, transmission beyond the fence line), a reminder that a cost estimate is defined as much by its stated boundary as by its total.

9.8 Chapter Summary

- Costs are classified before they are estimated: **direct** (traceable) versus **indirect** (allocated), **fixed** (constant over the range) versus **variable** (proportional to output), **recurring** versus **nonrecurring**. Unit cost falls with throughput because only the fixed layer dilutes. **Working capital** is mobilized at start-up and recovered at the end; chapter 11 gives it full treatment.

- The **AACE 18R-97 classes** tie claimed accuracy to the maturity of project definition: Class 5 (concept screening, roughly -50% to $+100\%$ at worst) through Class 1 (definitive, roughly -10% to $+15\%$ at worst), with ranges quoted at 80% confidence and contingency included. Engineering effort, not arithmetic care, is what moves an estimate up a class.

- The methods ladder matches the classes: **analogy** and **capacity factoring** $C_2 = C_1(Q_2/Q_1)^n$ (the six-tenths rule, $n \approx 0.6$, process-specific, valid over limited ranges) at Class 5; **parametric and unit-rate** estimates at Classes 4–3; **detailed takeoff** at Classes 2–1. The exponent can be estimated from reference plants as $n = \ln(C_2/C_1)/\ln(Q_2/Q_1)$.

- **Escalation** moves costs between dates by the ratio of a **cost index**: $C_{\text{now}} = C_{\text{then}}(I_{\text{now}}/I_{\text{then}})$, the specialized-basket version of chapter 4. Match the basket to the work, and label any forecast extension as a forecast.

- **Contingency is expected spending**, sized by what is not yet known: process contingency by technology maturity (up to 30–70% for bench-scale concepts), project contingency of roughly 15–30% for Class 4/5 estimates. **Management reserve** is owner-held money outside the estimate. Deleting contingency does not save money; it falsifies the estimate.

- Capital estimates are systematically **biased low**, by optimism and by strategy; the countermeasures are stated classes, stated ranges, intact contingency, and reference-class benchmarks (chapter 20).

- The NETL methodology shows the full stack in practice: BEC $\rightarrow$ EPCC $\rightarrow$ TPC (contingencies) $\rightarrow$ TOC (owner's costs) $\rightarrow$ TASC (time-spread spending), declared as AACE Class 4 with $-15\%/+30\%$ accuracy.

9.9 Exercises

These problems move from classifying costs along the direct/indirect and fixed/variable axes to scaling and escalating reference costs, building an estimate with contingency, and judging what accuracy class a number can honestly claim.

Classifying costs

Exercise 9.1. Classify each cost at a phosphate beneficiation plant along both axes, direct/indirect and fixed/variable: (i) flotation reagents; (ii) the plant manager's salary; (iii) grinding media consumed per tonne; (iv) the assay laboratory; (v) a royalty of 2 SAR per tonne of concentrate; (vi) the standby charge for the grid connection.

Capacity factoring

Exercise 9.2. A crushing station rated at 1,200 t/h cost 60 million SAR. Estimate the cost of a similar station rated at 2,000 t/h using the six-tenths rule, and state the estimate's class.

Exercise 9.3. Two dense-media separation plants cost 80 million SAR at 100,000 t/yr and 130 million SAR at 250,000 t/yr. (a) Estimate the scaling exponent. (b) Estimate the cost of a 180,000 t/yr plant. (c) Why is part (b) more trustworthy than an extrapolation to 600,000 t/yr with the same exponent?

Escalation with cost indices

Exercise 9.4. A slurry pump package was quoted at 3.2 million SAR in 2019, when the relevant index stood at 178. The index now stands at 241. Update the quote, and state one reason the updated figure could still be wrong in either direction.

Exercise 9.5. A 150,000 t/yr reference concentrator cost 90 million SAR in 2020, when the plant cost index stood at 192; the index now stands at 268. Estimate the cost, today, of a 300,000 t/yr plant of the same type with exponent $n = 0.65$. Show that the order of the two corrections does not matter.

Contingency

Exercise 9.6. A lithium-carbonate plant has a bare erected cost of 150 million SAR, of which a novel direct-extraction section (30 million SAR) exists only as bench-scale data. Engineering services are 10% of the bare erected cost. Apply 40% process contingency to the novel section and 25% project contingency to the loaded base, and compute the total plant cost. Then state, in one sentence each, what the two contingencies are for.

Exercise 9.7. A feasibility team has process flow diagrams for the main systems, a preliminary engineered equipment list, and definition it assesses at about 10% complete. Which AACE class is its estimate, and which accuracy range may it defensibly quote?

(A) Class 5; −50% to +100%.
(B) Class 4; about −15% to −30% on the low side and +20% to +50% on the high side.
(C) Class 3; −10% to +30%, suitable for budget authorization.
(D) Class 2; −5% to +20%, suitable for tender checks.

Working capital (a preview)

Exercise 9.8. A concentrator project requires 12 million SAR of working capital (consumables, spares, and concentrate awaiting payment) at start-up, fully recovered when the plant closes after 8 years. At a MARR of 10%, what is the net present-worth effect of the working capital, and why is it not zero even though every SAR comes back?

Exam-style problems

The following problems are written in the format of a major exam: a scenario, lettered parts with point values, and full work expected. Name the estimating method and its class before computing, write each formula before substituting, box each final answer with its units, and end with a decision sentence.

Exercise 9.9. Screening estimate for the Wadi Lithium concentrator. A design team must produce a screening estimate for a 400,000 t/yr lithium concentrator.

The best reference is a 250,000 t/yr plant of the same type completed in 2021 for 210 million SAR, when the plant cost index stood at 214; the index now stands at 270. Use a scaling exponent of 0.6 and a project contingency of 20%. (a) (*8 pts*) Escalate the reference cost to today. (b) (*10 pts*) Scale the escalated cost to the new capacity. (c) (*6 pts*) Add the project contingency, state the AACE class of the resulting figure, and state what it may and may not be used for.

Exercise 9.10. Unit-rate estimate for a tailings storage facility. A tailings facility needs 2.4 million m^3 of compacted embankment fill and 850,000 m^2 of geomembrane liner. Recent regional unit rates are 34 SAR/m^3 for placed fill and 62 SAR/m^2 for supplied-and-installed liner. Indirect costs (supervision, survey, quality assurance) are priced at 18% of the direct cost, and project contingency at 15% of the direct-plus-indirect base. (a) (*8 pts*) Compute the direct cost of each element and the total direct cost. (b) (*6 pts*) Add indirect costs. (c) (*6 pts*) Add contingency, and state which AACE class this method typically supports and why.

Assessing outside recommendations

The two problems below present finished analyses produced by others. In each, the arithmetic is correct; the flaw is in the method. For each problem, (a) decide whether to accept the recommendation, (b) identify each error or omission precisely, and (c) produce the corrected numbers.

Exercise 9.11. An AI assistant treats contingency as savings. A review of a mine-water treatment project produced this memo from an AI assistant. The project's Class 4 capital estimate is 320 million SAR, which includes 54 million SAR of process and project contingency; savings are 44 million SAR per year for 10 years; the MARR is 10%.

> *At the MARR, the savings are worth* $44\,(P/A, 10\%, 10) = 44\,(6.1446) = 270.36$ *million SAR. Against the estimate of 320 million SAR the project fails. However, the estimate contains 54 million SAR of contingency, which is not a real cost, merely a buffer. On the true cost of 266 million SAR, the present worth is* $270.36 - 266 = +4.36$ *million SAR. Recommendation: approve; instruct the project team not to spend the contingency.*

(a) (*4 pts*) Should the firm accept the recommendation? (b) (*8 pts*) Identify the error precisely. (c) (*8 pts*) Produce the corrected screening and recommendation.

Exercise 9.12. A vendor scales cost linearly with capacity. A water-treatment vendor's proposal letter reads:

> *Our standard 1,000 m*^{3}*/day package plant is priced at 18 million SAR, fully installed. Your site requires 3,000 m*^{3}*/day, three times the capacity, and we quote accordingly:* $3 \times 18 = 54$ *million SAR. Pricing is exactly proportional to capacity, which guarantees fairness at any size.*

A junior engineer has recommended accepting the quote as the budget for a single integrated 3,000 m^3/day plant. (a) (*4 pts*) Should the recommendation be accepted? (b) (*8 pts*) Identify the flaw in using this quote as the budget figure. (c) (*8 pts*) Produce the corrected screening estimate and state the proper use of both numbers.

References

AACE International (2020). *Cost Estimate Classification System—As Applied in Engineering, Procurement, and Construction for the Process Industries*, Recommended Practice No. 18R-97 (rev. August 7, 2020). `https://web.aacei.org/docs/default-source/toc/toc_18r-97.pdf`

National Energy Technology Laboratory (2011). *Quality Guidelines for Energy System Studies: Cost Estimation Methodology for NETL Assessments of Power Plant Performance*, DOE/NETL-2011/1455. `https://www.netl.doe.gov/projects/files/QGESSCostEstimationMethodologyforNETLAssessmentsofPowerPlantPerformance_043011.pdf`

Park, C. S. (2012). *Fundamentals of Engineering Economics* (3rd ed.). Pearson. Section 10.1.