PE

ENGINEERING ECONOMICS & LIFECYCLE COST DECISION-MAKING

2 CEH

PERTINENT

ENGINEERING

BuilderCE

PROFESSIONAL ENGINEERING CONTINUING EDUCATION

Engineering Economics

Lifecycle Cost Decision-Making

Self-Paced Course Study Guide



Engineering alternatives connect infrastructure performance with costs over time. Contextual illustration, not a documented project analysis.

COURSE	CREDIT / CATEGORY	INSTRUCTOR
ENG-008	2 CEH / PDH · Pertinent to Engineering Engineering Economics	Matthew Ward, MBA, CIA

Superior Learning, LLC d/b/a BuilderCE

Course overview

Engineering decisions almost always allocate scarce resources. A technically feasible design may still be a poor investment if it requires excessive maintenance, creates avoidable downtime, consumes substantially more energy, or forces premature replacement. Conversely, a higher first-cost alternative can be economically preferable when it produces reliable savings, longer service life, lower operating burden, or reduced exposure to disruption. Engineering economics provides a disciplined way to make those tradeoffs visible.

This course presents a practical framework for comparing engineering alternatives over time. It emphasizes present-value thinking, lifecycle cost, total cost of ownership, repair-versus-replacement analysis, sensitivity analysis, uncertainty, and transparent communication of assumptions. The methods apply to infrastructure, equipment, facilities, building systems, utilities, transportation assets, industrial processes, and other capital decisions where cost occurs at different points in time.

The course does not attempt to turn engineers into financial analysts. Its purpose is narrower and more useful: help engineers structure economic comparisons so that decision-makers can see what is being compared, what assumptions drive the result, which costs were included or excluded, and what conditions could change the preferred alternative. Economic analysis supports engineering judgment; it does not replace technical requirements, safety, reliability, code compliance, environmental obligations, or professional responsibility.

Learning Objectives

Upon successful completion, the learner should be able to:

- Explain why first cost alone may be an inadequate basis for an engineering decision.
- Apply present-value and lifecycle-cost concepts to compare engineering alternatives on a consistent basis.
- Distinguish capital cost, operating cost, maintenance cost, replacement cost, downtime cost, end-of-life cost, residual value, and total cost of ownership.
- Use repair-versus-replacement and incremental-cost thinking without allowing sunk costs to distort the decision.
- Use sensitivity and scenario analysis to test the effect of uncertain assumptions.
- Document and communicate economic assumptions, limitations, tradeoffs, and switching conditions supporting an engineering recommendation.

How to Use This Course

The examples are intentionally simplified so the economic logic is easy to inspect. Real projects may require more detailed tax treatment, financing structure, depreciation, probabilistic modeling, escalation indices, user costs, environmental externalities, or agency-specific discount-rate rules. When those considerations matter, the engineer should use the governing method and qualified financial, accounting, procurement, or legal support as appropriate. The core discipline remains the same: compare alternatives that deliver the required function, define the analysis boundary, place costs on a common time basis, test material assumptions, and document the reasoning.

Study plan and navigation

MODULE	MINUTES	FOCUS
1	20	Engineering Economic Decision Framework
2	25	Time Value of Money & Present-Value Analysis
3	30	Lifecycle Cost & Total Cost of Ownership
4	25	Repair-versus-Replace & Capital Alternatives
5	20	Sensitivity, Uncertainty & Defensible Recommendations

Planned instructional time: 120 minutes, exclusive of the final examination. Individual study time may vary.

How to complete this course

Read all five modules and study the worked calculations, diagrams and examples. No separate module acknowledgement is required. When you have finished reading, select Continue at the bottom of the BuilderCE lesson page to begin the 10-question final examination. If you are reading the PDF, return to that webpage first. A score of at least 70% is required to pass. Retakes are permitted.

Two-pump calculation · Published NIST model · Break-even calculation · Sources

MODULE 1 | 20 MINUTES

Engineering Economic Decision Framework

Engineering economics begins before the first formula is used. The most important analytical choices are often the definition of the problem, the alternatives being compared, the time horizon, and the cost boundary. A mathematically precise model can still mislead if those choices are inconsistent or incomplete.

1.1 Economics as Part of Engineering Judgment

Engineering practice requires balancing performance, cost, schedule, reliability, constructability, maintainability, resilience, environmental effects, and risk. Economic analysis converts some of those consequences into a common monetary framework so that alternatives can be compared. It is especially valuable when one option has a lower initial cost but higher future cost, or when a higher initial investment creates future savings.

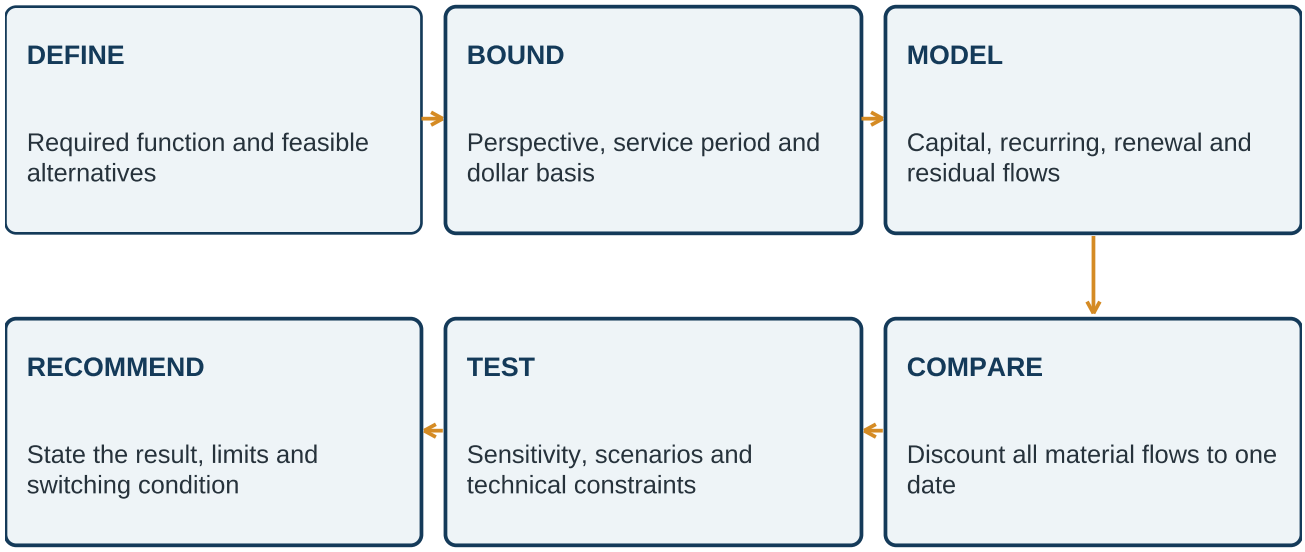
The economic question should be framed after the technical requirements are clear. If two alternatives do not satisfy the same essential function, comparing their lifecycle costs alone can be meaningless. A smaller pump that cannot meet required flow is not an economically superior alternative just because it costs less. A pavement strategy with a materially different service level cannot be treated as equivalent without acknowledging that difference. Economic comparison is most defensible when alternatives satisfy the same required outcome or when differences in performance are explicitly included in the decision.

The engineer therefore begins with three questions:

1. What function must the alternative deliver?
2. What constraints are non-negotiable?
3. Which consequences are decision-relevant from this point forward?

The third question is particularly important. Engineering projects accumulate history: prior studies, design spending, previous repairs, change orders, and sunk effort. Those past expenditures may explain

how the project reached its current condition, but money already spent cannot usually be recovered by choosing one future alternative over another. The economic comparison should focus on future cash flows that differ among the available choices.



Define the service and analysis boundary, model future cash flows, compare on one date, test uncertainty and state the decision.

1.2 Define Alternatives Before Estimating Costs

A common weakness in project evaluation is to develop one favored technical solution in detail and compare it against a poorly defined status quo. That produces apparent precision without a balanced comparison. Alternatives should be sufficiently defined that material cost and performance differences can be estimated on comparable assumptions.

Depending on the decision, alternatives may include:

- repair the existing asset;
- rehabilitate or modernize it;
- replace it with a like-for-like system;
- replace it with a higher-efficiency or higher-capacity system;
- lease or contract for a service rather than own the asset;
- phase the investment;
- defer the investment and continue current operations; or
- take no action when the status quo is a legitimate option.

Including a status-quo or do-nothing alternative is not the same as assuming that doing nothing has zero cost. The existing asset may require escalating maintenance, emergency repairs, energy, temporary measures, inspections, lost production, or eventual replacement. The status quo should be modeled honestly rather than treated as a free baseline.

Alternatives should also be screened for technical feasibility before expensive economic modeling. If an option violates a code requirement, fails capacity needs, or cannot satisfy a required reliability target, it should not be presented as economically preferred. The model should compare feasible choices, not use economics to excuse technical inadequacy.

1.3 Relevant Costs, Incremental Costs, and Sunk Costs

A relevant cost is a future cost that changes because of the decision. An incremental cost is the difference in future cost between alternatives. These concepts keep the model focused on what the decision can influence.

Consider a facility that spent $40,000 last year rebuilding a motor. The motor now has another serious failure. The decision is whether to spend $25,000 on another repair or install a new $95,000 unit. The prior $40,000 is emotionally important, but it is usually a sunk cost for the current decision. It has already been spent under either future path. Adding it only to the replacement alternative, or using it as a reason to continue repairing, distorts the comparison.

Opportunity cost is different. It represents the value of a resource committed to one use instead of another. An owner occupying a piece of equipment for a low-value purpose may give up the ability to use it for a higher-value project. Opportunity cost may be difficult to estimate, but it is economically real when alternatives compete for constrained resources.

Transfer payments and internal allocations require care. An internal labor charge may matter for budgeting even if it does not change total organizational cash flow. The correct treatment depends on the perspective of the analysis. A project manager deciding between contractors may appropriately use charged labor rates; a corporate capital-allocation analysis may need to distinguish cash outlays from accounting allocations. The analysis should state the perspective rather than mixing perspectives unintentionally.

1.4 Cost Categories Engineers Commonly Miss

First cost is visible and usually documented. Future cost is more likely to be omitted because it is spread across departments, budgets, and years. Relevant categories can include:

- planning, design, permitting, and procurement;
- purchase price and installation;
- commissioning and startup;
- energy and utilities;
- consumables;
- routine preventive maintenance;
- corrective maintenance;
- inspection and testing;
- software licenses and service contracts;
- labor to operate or support the asset;
- downtime, temporary systems, rentals, or lost service;
- periodic overhaul or major repair;
- component replacement;
- code-driven upgrades or required renewals;
- decommissioning, removal, environmental remediation, and disposal; and
- salvage or residual value at the end of the study period.

Not every category belongs in every analysis. The objective is not to create the longest possible cost list. It is to include costs that are material to the decision and treat alternatives consistently. A small item that is essentially identical under every alternative does not improve the comparison. A cost that is uncertain but potentially decision-changing deserves explicit treatment rather than omission.

1.5 Choose the Perspective and Boundary

The same project can have different economic consequences depending on whose costs are being measured. A transportation agency may focus on agency construction and maintenance cost. A broader analysis may also include user delay, vehicle operating cost, or safety effects. A facility owner may consider purchase, energy, maintenance, and downtime. A contractor may focus on equipment ownership and operating cost. A public-sector analysis may have specific rules governing societal costs and benefits.

The analysis should therefore state:

- whose costs are included;
- the study period;
- the start date or base year;
- the physical and organizational boundary;

- whether costs are stated in real or nominal dollars;
- the discount rate or source of the rate;
- treatment of taxes, financing, escalation, and residual value; and
- material exclusions.

A clearly defined boundary is a professional safeguard. It allows another reviewer to understand why a cost appears in the model and why another cost does not. It also reduces the temptation to selectively include categories that favor a preferred alternative.

1.6 Decision Criteria and the First-Cost Trap

Lowest first cost and lowest lifecycle cost are not the same criterion. Neither is automatically correct in every decision. If a project has a one-year temporary purpose, a highly durable premium alternative may not create value. If an asset is expected to operate for decades, ignoring operating and replacement costs can be a major error.

A first-cost comparison is most defensible when future costs are insignificant, effectively identical across alternatives, or outside the decision's meaningful horizon. Lifecycle analysis becomes more important when alternatives differ materially in service life, energy use, maintenance burden, replacement frequency, downtime, or residual value.

Payback period is another familiar but incomplete criterion. Payback asks how long it takes for cumulative savings to recover the initial premium. It is easy to understand, but simple payback ignores the time value of money and ignores cash flows after the payback point. It can be a useful screening metric, but it should not substitute for a present-value lifecycle comparison when long-term differences matter.

Internal rate of return, benefit-cost ratio, equivalent annual cost, and net present value are other economic measures. This course focuses primarily on present value and lifecycle cost because they map directly to the approved scope and are widely applicable. The important practice is consistency: do not switch criteria opportunistically after seeing which metric makes a favored alternative look best.

Module 1 Applied Check

A municipality is comparing two standby-generator packages. Package A costs $210,000 and has a recommended overhaul every 8 years. Package B costs $245,000 but uses a standardized engine platform already supported by the municipality and is expected to require less specialized maintenance. A first-cost recommendation would choose A immediately. A defensible economic evaluation would first confirm equivalent performance, define a common study period, estimate maintenance and overhaul timing, consider support and downtime implications, and then compare the alternatives on a consistent present-value basis.

The key lesson is that economic quality begins with model structure. If the alternatives, boundary, and relevant costs are not defensible, more decimal places will not fix the analysis.

1.7 Functional Equivalence and Decision Quality

Economic comparison becomes unreliable when alternatives are not functionally equivalent. Functional equivalence does not require identical design. It requires that the alternatives satisfy the performance that actually matters to the owner. That can include capacity, reliability, pressure, temperature control, ride quality, redundancy, service availability, safety factor, emissions, maintainability, resilience, or other defined outcomes.

An engineer should therefore separate minimum requirements from desirable attributes. Minimum requirements are screening constraints. An alternative that fails them is not saved by a favorable lifecycle cost. Desirable attributes may be valued qualitatively or, when a credible monetary relationship exists, incorporated into the economic model.

For example, two cooling systems may both meet peak load, but one may provide N+1 redundancy while the other does not. If redundancy is a project requirement, the second option is not an equivalent

alternative. If redundancy is optional, its cost and operational benefit should be discussed explicitly rather than hidden inside the model.

Another example is pavement rehabilitation. Two treatments may have different service lives and traffic-disruption profiles. They can still be compared economically if the model accounts for repeat treatments and the selected perspective properly recognizes material disruption costs. Simply comparing bid prices per lane-mile would not represent equivalent future service.

This discipline prevents a subtle form of bias: allowing the cheaper alternative to provide less service while calling the difference “economic efficiency.” The economic model should not silently redefine the engineering requirement.

Baseline Alternative: Model the Future That Would Actually Occur

Every comparison needs a baseline, but the baseline should reflect a realistic future path. If an aging asset must eventually be replaced, “keep existing forever” is not a credible baseline. A more realistic baseline may be “continue maintaining for five years, then replace,” or “perform minimum code-required repairs and reassess in three years.”

The baseline should also include unavoidable costs. If the owner must perform a $100,000 environmental cleanup regardless of which alternative is selected, that cost can often be excluded from the incremental comparison because it does not affect the ranking. If one alternative changes the cleanup scope, however, the difference becomes relevant.

Cost Estimate Quality and Model Purpose

The required accuracy of cost inputs should match the decision stage. A concept-stage screening analysis may appropriately use parametric estimates, recent bid history, vendor budget quotes, or order-of-magnitude maintenance allowances. A final capital-authorization recommendation may require detailed installed-cost estimates, firm quotations, utility-rate analysis, and validated maintenance histories.

Engineers should avoid a common mismatch: presenting early-stage cost estimates with late-stage precision. If installed cost is uncertain by +/-20%, a lifecycle result reported to the nearest dollar is not more accurate because the spreadsheet calculates it that way.

Cost-Input Documentation Checklist

Useful documentation for each material cost input includes:

- estimate basis and date;
- source organization or dataset;
- whether tax, freight, escalation, contingency, design, and installation are included;
- quantity and unit assumptions;
- confidence range where relevant; and
- the responsible estimator or reviewer.

Incremental Analysis: Remove Costs That Cannot Change the Decision

When alternatives share a large block of identical cost, the engineer can often simplify the model by comparing only the incremental differences. Suppose both alternatives require the same $2 million building shell, permitting cost, and site utilities. If those costs are truly identical, they do not affect which mechanical system is economically preferred.

Incremental modeling reduces clutter and directs attention to decision-driving cash flows. However, a summary should still make clear that common costs were intentionally excluded from the comparative model. Otherwise a reader may incorrectly believe the analysis forgot them.

Decision Record: Make the Recommendation Reconstructable

A good economic analysis becomes part of the engineering decision record. Months or years later, someone should be able to understand why the selected alternative appeared reasonable with the information available at the time. That record is especially important when market prices, operating conditions, or project scope later change.

The record should not pretend that the model predicted the future perfectly. It should demonstrate that the decision was structured, assumptions were visible, and material uncertainties were considered. That is a much more defensible standard than hindsight accuracy.

Decision-Quality Checkpoint

Before relying on an economic comparison, confirm that:

- alternatives satisfy the required function or differences are made explicit;
- the study period matches the service decision;
- common costs are excluded only when they truly cannot affect ranking;
- estimate precision matches the maturity of the project; and
- a reviewer can trace the material assumptions to a source or stated judgment.

Applied Mini-Case: Water Storage Coating

A utility is choosing between a standard coating system with a 12-year expected service interval and a premium coating with a 20-year expected interval. The premium coating costs 35% more initially. If the analysis stops at coating material price, the standard system looks attractive. If the tank requires expensive draining, temporary service, surface preparation, containment, and inspection each time it is recoated, the renewal interval may dominate lifecycle cost.

The engineer should compare the complete recoating event, not only coating material. The relevant service requirement is continued tank protection over the study period. A 30-year analysis may require two future recoating events for the standard system and only one for the premium system. The timing of those events matters because later costs are discounted.

The economic recommendation should also address uncertainty: if the premium coating achieves only 15 years rather than 20, does it remain preferred? That question is more decision-relevant than arguing over a single predicted service life.

MODULE 2 | 25 MINUTES

Time Value of Money & Present-Value Concepts

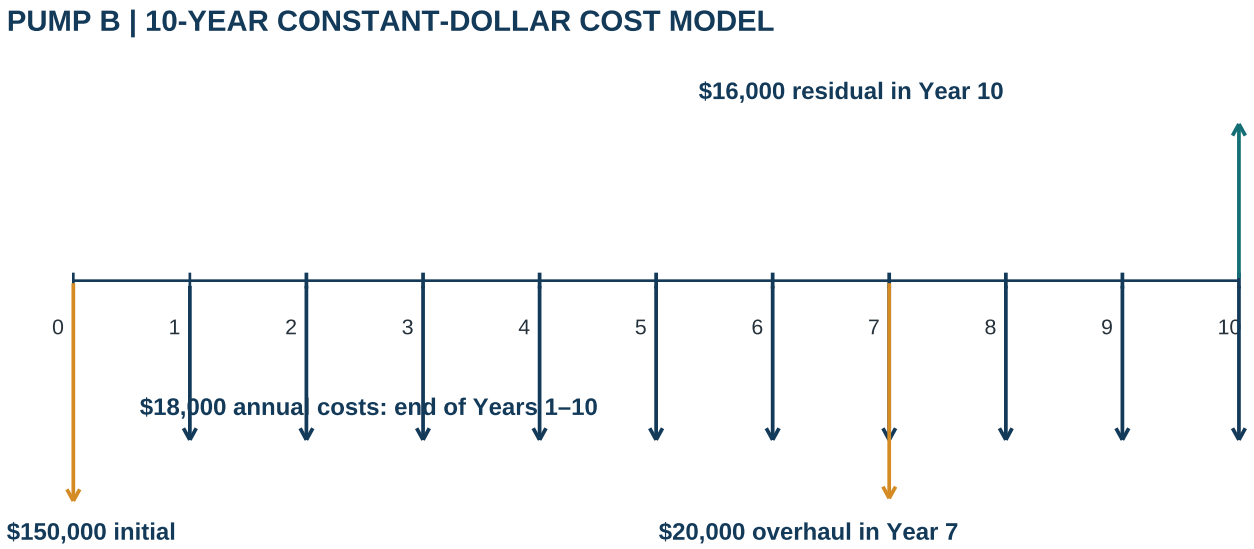
Money has a time dimension. A dollar spent today and a dollar spent ten years from now are not economically equivalent because funds available today can be used elsewhere, future purchasing power changes, and decision-makers generally require compensation for waiting and risk. Present-value analysis places cash flows occurring at different times onto a common date so that alternatives can be compared consistently.

2.1 The Decision Date and Cash-Flow Timing

The most common comparison date is the present, often called Year 0. Initial capital cost is usually placed at Year 0. Future operating, maintenance, repair, and replacement costs occur in later years. Residual value may be recognized at the end of the study period.

Timing assumptions matter. An annual maintenance cost assumed at the end of each year has a slightly different present value from the same cost incurred at the beginning of each year. On many preliminary engineering studies the difference may be immaterial, but the convention should be stated and applied consistently.

A useful first step is to draw the cash-flow timeline before calculating anything. The timeline forces the analyst to identify when large costs occur, whether repeated costs are uniform or escalating, and whether a replacement falls inside or outside the analysis period.



Original Pump B inputs on a ten-year timeline. Costs occur at Year 0 and year-end; the terminal residual is a credit.

2.2 Future Value and Present Value

If P is a present amount, i is the discount or interest rate per period, and n is the number of periods, the future value F is:

$$F = P(1 + i)^n$$

Rearranging gives the present value of a future amount:

$$P = F / (1 + i)^n$$

The quantity 1/(1+i)^n is the present-value factor. As n increases, a fixed future amount usually has a smaller present value when i is positive.

Example: a major overhaul is expected to cost $80,000 in Year 6. At a 4% annual discount rate, its present value is approximately:

$$P = 80{,}000 / (1.04)^6 = \$63{,}225$$

The analysis does not claim that the contractor will accept $63,225 in Year 6. The present value is an equivalent economic amount at the decision date used for comparison.

This distinction is important when communicating results. Present value is an analytical equivalence, not a forecast of the nominal check that will be written later.

2.3 Uniform Annual Costs

Many engineering assets have recurring annual costs: energy, inspections, service agreements, preventive maintenance, licensing, or operator labor. A uniform annual series A occurring at the end of each year for n years can be converted to present value using:

$$P = A[(1 - (1 + i)^{-n}) / i]$$

For example, an annual service contract of $12,000 for 10 years at a 4% discount rate has a present value of approximately $97,331. If a competing asset requires only $8,000 per year for the same period, the present-value difference in service cost is about $32,444.

Recurring costs often appear small when viewed one year at a time. Present-value analysis shows their cumulative economic significance without simply adding undiscounted dollars from different years.

2.4 Uneven Cash Flows

Real projects rarely have perfectly uniform costs. One year may require an inspection; another may require a major shutdown; a component may be replaced in Year 9; energy prices may escalate; and a residual value may remain at the end of the study period.

The general approach is straightforward: estimate each material cash flow in the year it occurs, discount it to the common date, and sum the present values. A spreadsheet makes the calculation easier, but the engineer should still be able to inspect the model logic. Hidden formulas, hard-coded values, unexplained escalation, or inconsistent timing conventions make a model difficult to review.

For a stream of individual cash flows C_t, lifecycle present value can be written conceptually as:

$$\mathrm{PV} = \Sigma\ [\mathrm{C_t}\ /\ (1 + \mathrm{i})\hat{}\mathrm{t}]$$

where positive and negative signs should be used consistently. Some organizations model all costs as positive and compare the lowest total cost. Others use expenditures as negative cash flows and benefits as positive cash flows. Either approach can work if the convention is clear.

2.5 Discount Rate: What It Represents

The discount rate determines how future amounts are weighted relative to present amounts. A higher discount rate reduces the present value of distant future costs and savings more aggressively. That can materially affect comparisons between a low-first-cost/high-operating-cost option and a high-first-cost/low-operating-cost option.

The engineer should not invent a discount rate simply because a familiar percentage seems reasonable. The appropriate rate may be specified by the owner, agency, corporate capital policy, funding program, or governing guidance. Federal analyses may use rates prescribed by OMB Circular A-94 or program-specific methods. Private organizations may use a hurdle rate, weighted cost of capital, or other policy rate. For a professional engineering analysis, the source and basis of the selected rate should be documented.

The model should also distinguish discount rate from inflation. A discount rate can reflect the time value of resources and required return; inflation describes changes in the general price level. Specific cost categories such as energy, labor, or materials may escalate differently from general inflation.

2.6 Real and Nominal Dollars

A consistent model can be prepared in constant dollars or current dollars.

Real or constant-dollar analysis expresses future costs in the purchasing power of a base year, excluding general inflation. A real discount rate is used.

Nominal or current-dollar analysis includes expected inflation or escalation in future cash flows. A nominal discount rate is used.

The two approaches can produce equivalent results when assumptions are internally consistent. Problems arise when they are mixed. Discounting inflated nominal cash flows at a real rate generally overstates present value. Discounting constant-dollar cash flows at a nominal rate generally understates present value.

The relationship is:

$$(1 + \text{nominal rate}) = (1 + \text{real rate})(1 + \text{inflation rate})$$

For modest rates, people sometimes approximate nominal rate as real rate plus inflation. The exact multiplicative relationship is better practice when converting between the two.

CONSTANT DOLLARS	CURRENT DOLLARS
Exclude general inflation from future amounts	Include general inflation in future amounts
Use a real discount rate	Use a nominal discount rate
Specific real escalation may still apply	Avoid adding inflation twice to escalated prices

2.7 Worked Example: Two Pump Alternatives

An owner must choose between two pumps that meet the same hydraulic duty. The study period is 10 years and the analysis uses constant dollars with a 4% real discount rate.

Pump A

- Installed cost: $120,000 at Year 0
- Annual energy and routine maintenance: $24,000 per year
- Major overhaul: $30,000 in Year 6
- Residual value: $10,000 at Year 10

Pump B

- Installed cost: $150,000 at Year 0
- Annual energy and routine maintenance: $18,000 per year
- Major overhaul: $20,000 in Year 7
- Residual value: $16,000 at Year 10

The installed-cost difference is $30,000, so first-cost analysis favors Pump A. Present-value analysis asks whether Pump B's lower annual costs and different overhaul/residual profile offset that premium.

At 4%, the present value factor for a 10-year uniform annual series is approximately 8.1109.

$$\text{Pump A annual-cost PV} = 24{,}000 \times 8.1109 = \$194{,}662$$

$$\text{Pump B annual-cost PV} = 18{,}000 \times 8.1109 = \$145{,}996$$

Overhaul PVs:

$$\text{Pump A overhaul PV} = 30{,}000/(1.04)\text{^}6 = \$23{,}709$$

$$\text{Pump B overhaul PV} = 20{,}000/(1.04)\text{^}7 = \$15{,}199$$

Residual values reduce total lifecycle cost:

$$\text{Pump A residual PV} = 10{,}000/(1.04)\text{^}10 = \$6{,}756$$

$$\text{Pump B residual PV} = 16{,}000/(1.04)\text{^}10 = \$10{,}810$$

Approximate lifecycle present cost:

$$\text{Pump A} = 120{,}000 + 194{,}662 + 23{,}709 - 6{,}756 = \$331{,}615$$

$$\text{Pump B} = 150{,}000 + 145{,}996 + 15{,}199 - 10{,}810 = \$300{,}385$$

Despite the higher first cost, Pump B has an approximately $31,000 lower lifecycle present cost under the stated assumptions.

> **Interpretation.** Using unrounded factors, Pump A is $331,615 and Pump B is $300,385 in present cost, rounded to whole dollars. Pump B's advantage is $31,230. A lower calculated cost supports the recommendation only after equivalent duty, reliability and other constraints are verified.

The engineer should not stop with the arithmetic. The recommendation should also ask whether the energy estimate is credible, whether both pumps truly have comparable reliability and capacity, whether the overhaul timing is supported, and whether the 10-year study period is appropriate. If the economic preference disappears under modest changes in those assumptions, that uncertainty should be communicated.

2.8 Different Service Lives and Common Comparison Periods

Alternatives sometimes have different lives. Comparing a 10-year option directly with a 20-year option using only one cycle of each can bias the analysis. Possible approaches include using a common study period and modeling replacements, using equivalent annual cost, or applying an owner-prescribed method.

The important principle is that alternatives should be compared over equivalent service requirements. If an asset must provide service for 20 years, a 10-year alternative may need a replacement in the model. Ignoring that replacement effectively gives the short-lived alternative free service after Year 10.

Residual value can also be used when an asset has remaining service life at the end of the study period. The method for estimating residual or salvage value should be documented and applied consistently.

Module 2 Applied Check

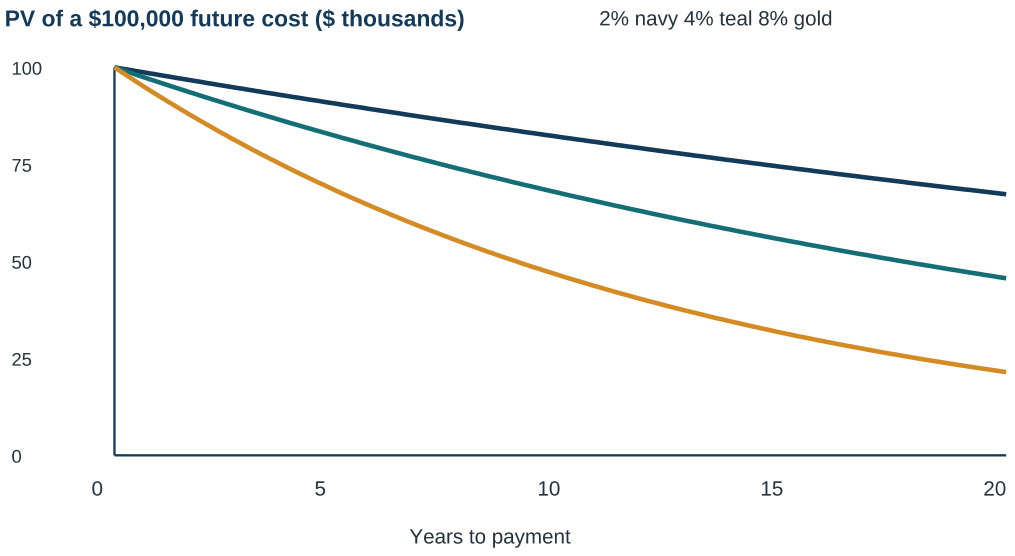
If an alternative looks attractive only because its major replacement occurs one year after the selected study period, reconsider the boundary. Study-period selection should reflect the decision rather than manipulate it.

2.9 Discount-Rate Effects and Economic Interpretation

Discount rate is not merely a spreadsheet input. It can change the ranking of alternatives when one option requires a large investment now in exchange for savings far in the future. Engineers should understand the directional effect even when the rate is prescribed by policy.

Consider two options. Option A costs $100,000 now and $50,000 in Year 10. Option B costs $135,000 now and nothing in Year 10. At a very low discount rate, avoiding the Year-10 cost has substantial present value, so B may be attractive. At a higher rate, the distant $50,000 is weighted less heavily, making A more competitive.

This does not mean analysts should select a rate to create a desired outcome. It means that decisions with long-dated savings can be rate-sensitive and should be tested accordingly.



Computed present value of a future $100,000 cost at 2%, 4% and 8%; higher positive rates reduce its present weight.

Present Worth Versus Annual Worth

Present worth expresses the economic consequence at one reference date. Annual worth, sometimes called equivalent annual value or equivalent annual cost, spreads present worth into an equivalent uniform annual amount. The two methods can rank alternatives consistently when applied correctly.

Annual worth is particularly useful when decision-makers think in annual budgets or when alternatives have unequal lives and are assumed to be repeatable. Present worth is often more intuitive for a capital authorization because it gives the total present economic burden over the study period.

The capital-recovery factor converts present value P to equivalent annual amount A:

$$A = P[i(1+i)^n / ((1+i)^n - 1)]$$

The reciprocal converts a uniform annual series to present value.

The method chosen should be documented. An analysis should not present present worth for one option and undiscounted annual average for another.

Midyear, Beginning-of-Year, and End-of-Year Conventions

Cash-flow timing can be simplified using conventions. Recurring operating costs are commonly assumed at year-end. Capital cost is usually at Year 0. Some analyses use midyear convention for costs that occur continuously throughout the year.

The convention matters more when rates are high, periods are long, or large cash flows occur near period boundaries. For many preliminary comparisons, the difference between midyear and year-end treatment of modest recurring costs will not change the decision. The professional objective is consistency and transparency, not unnecessary complexity.

Escalation of Specific Costs

General inflation and specific escalation are not always the same. Electricity, natural gas, labor, specialty chemicals, asphalt, steel, insurance, and proprietary service contracts can follow different price paths.

A model in nominal dollars may escalate categories separately when reliable forecasts or policy assumptions exist. A constant-dollar analysis may omit general inflation while still modeling a real escalation or decline for a specific commodity if its expected movement differs materially from general inflation.

The engineer should avoid double counting. If nominal energy prices already include inflation and escalation, adding a second inflation factor to the same cash flow exaggerates future cost.

Worked Example: Discounting a Replacement Cycle

A piece of monitoring equipment costs $65,000 today and must be replaced every four years. The owner needs the service for 12 years. Ignoring residual value, replacements occur at Years 4 and 8; a third full purchase at Year 12 is not needed if the study ends at that point.

At a 5% discount rate:

- Year 0 purchase PV = $65,000
- Year 4 replacement PV = 65,000/(1.05)^4 = approximately $53,476
- Year 8 replacement PV = 65,000/(1.05)^8 = approximately $43,995

Total present acquisition cost is approximately $162,470, before operating or maintenance costs. The total is calculated before rounding the individual present values.

Simply multiplying $65,000 by three would produce $195,000 of undiscounted spending. Both numbers can be useful for different purposes, but only the present-value figure puts the three purchases on a common economic date.

Equal-Period Comparison and Residual Life

Suppose Alternative X lasts 10 years and Alternative Y lasts 15 years, while the owner requires service for 20 years. X may require replacement at Year 10. Y may require replacement at Year 15, leaving 10 years of unused life on the second unit at the Year-20 boundary. A residual-value method can recognize that remaining value.

Alternatively, an equivalent annual cost method can compare the annualized economic burden of each alternative if replacement cycles are reasonably repeatable. The choice of method should be consistent with owner policy and the decision context.

A misleading shortcut is to compare the cost of one 10-year unit with one 15-year unit and ignore what happens after each reaches end of life. That compares different amounts of service.

Discounting Benefits and Cost Avoidance

Present-value logic applies to savings and benefits as well as costs. If a premium system avoids $20,000 of annual energy cost, the avoided cost is a positive economic benefit relative to the baseline. It can be modeled either as reduced cost in the premium alternative or as a separate savings stream. Avoid double counting by using only one representation.

Similarly, avoiding a $300,000 replacement in Year 12 has a present value less than $300,000 today. Economic analysis should value avoided future spending at the time it would otherwise occur.

Rate Sensitivity Example

Assume an efficiency upgrade costs an extra $180,000 today and saves $28,000 per year for 12 years. At a 2% discount rate, the present value of savings is approximately $296,000. At 6%, it is approximately $235,000. At 10%, it is approximately $191,000.

The upgrade remains economically positive across those illustrative rates, but the margin changes substantially. If the annual savings were only $22,000, the economic conclusion could become rate-sensitive. Reporting that sensitivity provides more useful information than implying the rate has no effect.

2.10 Common Present-Value Modeling Errors

Present-value models often fail in predictable ways. One is wrong timing: a replacement that occurs in Year 8 is entered in Year 7 or Year 9 because spreadsheet columns are mislabeled. Another is double escalation: a future cost is escalated to nominal dollars and then multiplied again by an inflation factor embedded in another formula. A third is mixed dollar basis: constant-dollar maintenance is combined with nominal energy forecasts and discounted at one rate without reconciliation.

A fourth error is misplaced residual value. Residual value belongs at the end of the study period and reduces net lifecycle cost. It should not be subtracted at Year 0 unless it represents an immediate sale or trade-in. A fifth is replacement-cycle omission, where a shorter-lived alternative is modeled for only one cycle even though the required service period is longer.

A sixth error is formula inconsistency across alternatives. One sheet may discount annual costs using an annuity formula while another discounts each year individually with different escalation. Either method can be valid, but the assumptions must be equivalent. When possible, use one model structure with alternative-specific inputs rather than separate spreadsheets that can drift apart.

A seventh error is hard-coded discount factors. If the discount rate is changed during sensitivity analysis, hard-coded factors may not update. Centralize key assumptions and make formulas traceable.

A simple model audit can verify the Year-0 cost, one recurring-cost calculation, one future replacement, and one residual-value calculation by hand. If those checkpoints reconcile, confidence in the spreadsheet improves. Engineers do not need to manually recalculate every cell, but they should validate enough of the model to know that the formulas implement the intended economic logic.

Spreadsheet Structure That Supports Review

A transparent workbook often separates four layers:

1. Inputs: study period, discount rate, escalation assumptions, service lives, quantities, unit costs, and timing.
2. Cash-flow schedule: one row or block for each cost category by year.
3. Present-value calculation: discount factors and discounted cash flows.
4. Summary and sensitivity: total lifecycle cost, incremental difference, key scenarios, and switching values.

This separation makes it easier to see whether a change in the summary comes from a real input change or from an accidental formula edit.

Sign Conventions and Reconciliation

Some models represent costs as positive amounts and then select the alternative with the lower total. Others represent costs as negative cash flows and benefits as positive. Both conventions are acceptable. Mixing conventions is not.

A useful reconciliation compares total undiscounted cost with total discounted cost. For a positive discount rate and future positive costs, discounted future cost should generally be lower than the undiscounted sum, excluding unusual sign patterns. If the discounted total is unexpectedly larger, review the formula and escalation assumptions.

The model should also reconcile the number of replacements and major maintenance events to the service-life logic. If a 30-year study of a 10-year component shows only one unit, something is missing unless residual treatment or a different replacement assumption explains it.

MODULE 3 | 30 MINUTES

Lifecycle Cost & Total Cost of Ownership

Lifecycle cost analysis expands the comparison from purchase price to the full set of material costs associated with acquiring, owning, operating, maintaining, renewing, and disposing of an asset over a defined period. NIST Handbook 135, ASTM E917, and ISO 15686-5 each emphasize the importance of defining the study period and comparing relevant costs of alternatives that provide the required function.

3.1 Lifecycle Cost Structure

A useful conceptual expression is:

$$\text{LCC} = \text{Initial Cost} + \text{PV(Operations)} + \text{PV(Maintenance)} + \text{PV(Repairs)} + \text{PV(Replacements)} + \text{PV(End-of-Life Costs)} - \text{PV(Residual Value)}$$

Additional categories can be included when they are decision-relevant. The equation is not a mandatory template; it is a reminder that future cost must be placed on a common basis.

Lifecycle analysis is especially valuable for assets whose ownership cost is distributed across many years. Pumps, chillers, lighting systems, pavement structures, treatment equipment, fleet equipment, controls, electrical systems, bridges, roofs, and industrial machinery can all have substantial operating or renewal costs relative to first cost.

3.2 Acquisition and Implementation Costs

Initial cost may include more than purchase price. Depending on the alternative, relevant acquisition costs can include design, engineering, procurement, permitting, mobilization, demolition, site work, installation, commissioning, training, spares, startup support, and temporary operations during transition.

Two equipment quotes may appear comparable until one requires a new foundation, electrical upgrade, controls integration, additional ventilation, or extended shutdown. Those enabling costs belong to the decision if they differ between alternatives.

Conversely, shared costs that are identical for all alternatives may be omitted from the comparative model if doing so does not change the ranking. The model should make that simplification visible so reviewers understand that the category was considered rather than forgotten.

3.3 Operations and Energy

Operating cost often dominates the lifecycle of continuously used equipment. Small differences in efficiency can compound across thousands of operating hours. The economic estimate should be based on realistic duty cycle, load profile, utilization, energy tariff, demand charges where applicable, and expected operating pattern.

A common modeling error is to multiply nameplate power by 8,760 hours without considering actual load, cycling, seasonal operation, redundancy, standby status, or process demand. Another error is to use a single utility rate when the tariff has time-of-use or demand components that materially affect the result.

Engineers should distinguish physical performance assumptions from economic assumptions. For example, expected kilowatt-hours are primarily a technical estimate; the future cost per kilowatt-hour is an economic assumption. Keeping that distinction clear makes sensitivity analysis more useful.

3.4 Maintenance, Repair, and Renewal

Maintenance cost is not simply an annual allowance. Different alternatives can have different maintenance strategies, labor skill requirements, parts availability, inspection frequency, lubrication needs, calibration requirements, vendor-service dependence, and overhaul intervals.

Major repair and renewal events should be modeled in the year they are expected. If an asset requires a $70,000 overhaul every five years, treating that as a flat $14,000 annual cost can be acceptable for some screening analyses but can distort present value when timing matters. Explicit cash-flow timing is preferable when major events are material.

Renewal assumptions should be supported by manufacturer data, owner history, condition assessment, reliability records, industry guidance, or engineering judgment. A highly precise cost model built on an unsupported service-life assumption is not a high-quality analysis.

3.5 Downtime and Service Disruption

Downtime can be economically important and difficult to estimate. A failed pump may reduce production, require rental equipment, cause overtime, interrupt public service, or force a temporary bypass. A bridge rehabilitation strategy may create user delay. A failed HVAC system may affect tenant operations or require temporary cooling.

Downtime should not be assigned an exaggerated dollar value merely to favor a reliability alternative. The analyst should identify the mechanism by which downtime produces cost and estimate only the portion relevant to the decision. Useful categories can include:

- lost production or throughput;
- temporary equipment rental;
- emergency mobilization;
- overtime labor;
- customer or user disruption when included by the governing perspective;
- liquidated damages or contractual exposure when realistically attributable; and
- accelerated wear or quality loss caused by abnormal operation.

When downtime cost is uncertain, sensitivity or scenario analysis is often better than hiding the assumption inside a single point estimate.

3.6 Replacement, Residual Value, and End of Life

Assets with shorter lives may require one or more replacements within the study period. Replacement cost should include removal and reinstallation consequences where material. A component replaced in Year 12 may also have residual value at Year 20 if its expected life extends beyond the study period.

Residual value is sometimes approximated using remaining-life fraction, expected resale, scrap value, or owner-specific methodology. No single method is appropriate for every asset. What matters is that the treatment is reasonable, documented, and consistent.

End-of-life cost may include demolition, decommissioning, disposal, hazardous-material handling, site restoration, data migration, or transition to replacement systems. Some assets have positive salvage value; others have net disposal cost.

3.7 Total Cost of Ownership and Lifecycle Cost

The terms total cost of ownership and lifecycle cost are often used similarly, but organizations may define them differently. Total cost of ownership commonly emphasizes the full cost incurred by the owner in acquiring and using an asset. Lifecycle cost is frequently associated with a formal present-value method over a defined study period.

Rather than arguing over terminology, the engineer should define the model boundary. A reviewer needs to know which costs are included, when they occur, and how they are discounted. A label without a boundary is not a methodology.

3.8 Identifying Omitted Costs

One of the best quality checks is to ask where each alternative creates work or resource consumption outside the capital project budget. Maintenance may be paid by operations. Energy may come from a utility budget. spare parts may come from stores. Inspection may be performed by in-house staff. Downtime may appear as lost production rather than a maintenance invoice.

A structured lifecycle-cost interview can ask:

- What must be purchased or constructed initially?
- What must happen every day, month, or year to operate the alternative?
- What planned maintenance is required?
- What fails or wears out, and when?
- What specialized labor, tools, licenses, consumables, or vendor services are required?
- What happens when the asset is unavailable?
- What major renewal or replacement occurs within the study period?
- What happens at the end of the study period?
- Does the asset retain usable life or salvage value?

The objective is completeness at a decision-relevant level, not false precision.

3.9 Worked Example: Lighting Retrofit Alternatives

A facility is comparing two lighting-retrofit packages for a large operating area. Both meet required illumination and controls standards. The study period is 15 years and the real discount rate is 3%.

Option A - Standard LED

- Installed cost: $420,000
- Annual energy cost: $96,000
- Annual maintenance: $10,000
- Driver/fixture renewal in Year 9: $90,000
- Residual value at Year 15: $20,000

Option B - High-efficiency networked LED

- Installed cost: $540,000
- Annual energy cost: $70,000
- Annual maintenance: $7,000
- Controls service/software: $6,000 per year
- Renewal in Year 11: $75,000
- Residual value at Year 15: $35,000

Option B has a $120,000 higher first cost. Its recurring annual cost is $83,000 ($70,000 energy + $7,000 maintenance + $6,000 service), compared with $106,000 for Option A. The recurring annual savings are $23,000.

At 3%, the present-value factor for a 15-year uniform series is approximately 11.9379. The PV of recurring-cost savings is approximately $274,572.

The later renewal and higher residual value also favor Option B. Even before calculating every component, the recurring savings are large enough to justify a detailed lifecycle comparison rather than rejecting Option B on first cost.

A complete model would discount the renewal and residual cash flows, confirm whether the networked controls service is truly required for the full period, verify energy savings using realistic operating hours and control sequences, and test whether service-life assumptions are credible.

This example demonstrates why lifecycle cost is not simply “first cost plus maintenance.” Energy, software/service obligations, renewal timing, and residual value can materially change the economic result.

3.10 Lifecycle Cost Quality Controls

A lifecycle-cost model should be reviewable. Useful quality controls include:

- a clearly labeled assumptions sheet;
- one source or rationale for each material input;
- consistent year and dollar basis;
- formulas that reference input cells rather than hidden hard-coded constants;
- separate technical quantities from unit-cost assumptions;
- reconciliation of total undiscounted cash flow to the present-value model;
- visible treatment of residual value and replacements;
- scenario and sensitivity checks; and
- independent review of the highest-impact assumptions.

The largest risk in lifecycle cost is often not arithmetic error. It is an incomplete or optimistic assumption that appears objective because it sits inside a spreadsheet.

Module 3 Key Principle

A lifecycle-cost model is strongest when another qualified reviewer can reconstruct the boundary, timing, and assumptions without relying on undocumented institutional memory.

3.11 Building a Lifecycle Cost Model from Engineering Data

A lifecycle model is strongest when cost inputs are connected to physical drivers. Instead of entering “maintenance = $25,000/year” as an unsupported allowance, the engineer can model expected maintenance tasks, frequency, labor hours, parts, and service contracts. Instead of entering “energy = $90,000/year,” the model can link operating hours, load, efficiency, and utility rates.

Driver-based modeling improves sensitivity analysis because the analyst can change the underlying cause rather than an opaque total.

For a pump, annual energy cost may be estimated conceptually from:

- power draw under expected duty;

- annual operating hours;
- motor and drive efficiency;
- electricity rate structure; and
- expected control strategy.

For pavement, lifecycle cost may be driven by treatment interval, lane quantity, unit treatment cost, traffic-control requirements, and user-delay assumptions if the selected perspective includes user costs.

For a roof, cost may be driven by installed area, membrane system, inspection program, repair frequency, replacement interval, and interior-damage exposure.

Maintenance Data: Use History Carefully

Historical maintenance cost can be valuable, but it should be normalized before being projected. One unusually expensive emergency may not represent expected annual cost; conversely, several years with deferred maintenance may understate future need.

Useful questions include:

- Did operating conditions change during the historical period?
- Was maintenance performed proactively or deferred?
- Are labor rates and parts availability changing?
- Does the replacement alternative use different technology or service support?
- Are historical costs missing internal labor or downtime?

A simple average is not automatically a forecast.

Energy and Utility Modeling

Energy cost can dominate lifecycle economics for continuously operating systems. Yet energy savings are often overstated because analysts use full-load efficiency differences for equipment that spends most of its life at part load.

A better analysis uses the expected operating profile. For variable-flow systems, controls strategy may matter as much as nameplate efficiency. For lighting, occupancy and daylight controls may reduce hours. For HVAC, weather and load diversity affect annual consumption.

Economic analysis should use the best available engineering energy estimate and then test the economic assumptions around price and utilization. This separation keeps the model auditable.

Downtime: From Technical Event to Economic Consequence

Downtime should be modeled through an explicit causal chain. For an industrial pump:

failure -> lost pumping capacity -> production constraint -> lost throughput or temporary pumping -> measurable cost.

For a public facility chiller:

failure -> loss of cooling -> temporary rental or curtailed occupancy -> rental, mobilization, overtime, or other measurable consequence.

If the causal chain is weak, a large downtime dollar value may not be credible. When exact cost is unavailable, scenario ranges can show the decision impact without pretending to know more than the evidence supports.

User Costs and Broader Perspectives

Infrastructure decisions sometimes include costs borne by users rather than the asset owner. Highway construction may create delay and vehicle operating costs. Water outages may affect customers. Transit disruptions may impose travel-time penalties.

Whether such costs belong in the analysis depends on the defined perspective and governing method. FHWA lifecycle-cost practices, for example, distinguish agency costs from user costs and provide

methods for pavement-alternative analysis. An internal facility investment may appropriately exclude societal costs that are outside the owner's decision framework.

The key is not that every model should include user costs. The key is that the perspective should determine inclusion rather than convenience.

Residual Value Methods

Residual value can be estimated several ways. A straight-line remaining-life approach assumes value is proportional to unused service life. Market or salvage value may be more appropriate for equipment with a resale market. For infrastructure, residual value may reflect remaining service potential rather than actual sale value.

Suppose a $200,000 component has a 20-year economic life and is installed 15 years before the end of the study period. A simple remaining-life approach would recognize 5/20, or 25%, of an appropriate replacement-cost basis as residual value, subject to owner methodology. That amount is then discounted from the study-period end back to the decision date.

Residual value should not be used to manufacture value for assets with no realistic remaining utility. Likewise, ignoring substantial remaining life can unfairly penalize a longer-lived alternative.

Inflation, Escalation, and Cost Indices

Long-horizon lifecycle models may use construction cost indices, producer price indices, utility forecasts, or owner escalation assumptions. The analyst should document the source date and avoid applying a general index to categories that are already quoted in future dollars.

Cost indices are especially useful when normalizing historical costs to a common base year. A five-year-old overhaul cost should not necessarily be used at face value if labor and materials have changed significantly.

Contingency and Uncertainty

Including contingency in lifecycle estimates can be appropriate, but it should be handled thoughtfully. Applying the same percentage contingency to every future cash flow may imply a level of risk structure that does not exist. Some organizations prefer expected-value estimates; others carry explicit contingency for uncertain capital items and use sensitivity ranges for operating assumptions.

The analysis should follow owner policy where available. The important point is to avoid hiding uncertainty inside an unexplained percentage.

Lifecycle Cost Versus Budget Cash Flow

Lifecycle present value answers an economic comparison question. It does not replace the annual budget forecast. An alternative with lower lifecycle cost may require a large capital appropriation now and a major renewal in Year 8. Decision-makers may need both:

- lifecycle present cost to understand economic value; and
- annual nominal cash-flow forecast to understand affordability and funding timing.

Confusing those two views can create avoidable conflict. The engineering recommendation should identify when the economically preferred option has a more difficult funding profile.

Applied Mini-Case: Bridge Deck Rehabilitation

A bridge owner is evaluating two deck rehabilitation strategies. Strategy A has lower construction cost but is expected to require another major intervention in 12 years. Strategy B costs 40% more now but is expected to extend the next major intervention to Year 20. Both satisfy current structural and ride-quality requirements.

A complete economic comparison may include:

- initial construction and traffic-control cost;
- inspection and routine maintenance differences;

- future rehabilitation timing;
- user delay if included by agency policy;
- residual service value at the study-period end; and
- uncertainty in treatment life.

If the study period is only 10 years, the model will miss the major economic difference entirely. If the study period is 30 years, the model captures at least one renewal cycle for both strategies. The appropriate period should follow the decision and agency method, not the result the analyst wants.

Sensitivity to treatment life is critical. If Strategy B lasts only 15 years, is the premium still justified? If Strategy A performs for 16 years rather than 12, does the ranking change? Those switching conditions are often more valuable to asset managers than a single base-case total.

3.12 Worked Total-Cost-of-Ownership Example: Standby Power Systems

A data-processing facility needs a new standby generator system. Two packages satisfy the electrical load and required transfer performance.

Package A has a lower first cost and uses a common engine platform. Installed cost is $620,000. Annual inspection, exercise, fuel testing, and preventive maintenance are expected to average $18,000. A major overhaul is expected in Year 10 at $110,000. The system is expected to retain $45,000 of residual value at Year 15.

Package B costs $715,000 installed. It uses a higher-efficiency engine and integrated monitoring package. Annual preventive maintenance and monitoring service are expected to average $15,000. The manufacturer expects the major overhaul in Year 12 at $95,000. Residual value at Year 15 is estimated at $65,000.

Because standby generators run relatively few hours, fuel efficiency alone may not justify the first-cost premium. The model should identify which categories actually differ. If both alternatives consume similar test fuel and provide the same reliability, the annual operating-cost difference may be small. The timing of overhaul and residual value may matter more.

The analysis should also ask whether the integrated monitoring subscription creates a recurring cost not included in the original quote, whether remote monitoring reduces inspection labor, and whether the owner already has staff and parts for Package A. Those organizational effects can be economically relevant when they produce real future differences.

This example illustrates why total cost of ownership is not a fixed checklist. The decision-relevant costs depend on how the asset will be used. A continuously operated generator would require much more attention to fuel efficiency. A standby unit may be driven more by maintenance, supportability, overhaul timing, and reliability requirements.

Boundary Discipline in TCO Models

TCO models can become bloated when every conceivable organizational cost is included. A disciplined model asks whether a cost is both caused by the alternative and material to the decision. If the facility will employ the same electrician regardless of which generator is selected, allocating the electrician's entire salary to one alternative is not appropriate. If one package requires a dedicated vendor service contract that the other does not, that incremental cost is relevant.

Similarly, corporate overhead, insurance, security, or administrative allocations may be useful for full-cost accounting but irrelevant to a technical alternative comparison if they do not change. State the perspective and purpose of the model so the cost boundary is understandable.

Lifecycle Model Maintenance

Lifecycle analyses can become stale quickly when procurement prices, energy rates, or project scope change. Before a major authorization decision, refresh material inputs and confirm that the selected alternatives still reflect the design. A model prepared at 30% design may not be appropriate for final procurement without update.

Version the model and record the date of major inputs. If the preferred alternative changes after updated bids, the decision record should show why. That is not a failure of the original analysis; it is evidence that the model is being used as a living decision tool rather than a static justification document.

Reading a published lifecycle-cost model

NIST Handbook 135 uses an HVAC example to show how initial investment, annual costs, a fan replacement and a terminal residual value are placed on one time basis. The 2025 edition supersedes the 2022 edition. The reproduced input values below remain a published teaching example; they are not current project prices or discount factors to copy into a new analysis.

TIMING	PUBLISHED CASH FLOW	HOW TO READ IT
Base date	Initial investment: $103,000	Already at present value
End of Years 1–20	Electricity: $30,000/year; OM&R: $7,000/year	Recurring series; electricity uses the example's energy-adjusted factor
End of Year 12	Fan replacement: $12,000	One future cost, discounted once
End of Year 20	Residual value: $3,500	Terminal credit reduces lifecycle cost

COST ITEM	BASE AMOUNT	PUBLISHED FACTOR	PRESENT COST
Initial investment	$103,000	Already in PV	$103,000
Fan replacement	$12,000	$SPV_{12} = 0.701$	$8,412
Residual value	−$3,500	$SPV_{20} = 0.554$	−$1,939
Electricity	$30,000/year	FEMP $UPV^*_{20} = 14.32$	$429,600
OM&R	$7,000/year	$UPV_{20} = 14.877$	$104,139
Total lifecycle cost			$643,212

Adapted into editable tables from NIST HB 135e2025, Figure 5-1 and Table 5-2, printed pp. 71–72. OM&R means operation, maintenance and repair. These are the publication's rounded factors and totals. The starred electricity factor includes the example's energy-price treatment; it is not the ordinary uniform-series factor.

Check the model in order: identify the cash-flow date, select the factor appropriate to the cost category, apply the sign convention, then reconcile the total. Here $103,000 + $8,412 − $1,939 + $429,600 + $104,139 = $643,212. A residual credit reduces cost at the study-period end; it is not a Year-0 discount on the purchase.

For an actual federal facility analysis, follow the applicable FEMP methodology and annual supplement rather than reusing these historical example factors. For other owners, document the required method, rate, dollar basis and source. A method can be useful instruction without becoming a universal legal requirement for every engineering project.

NIST Handbook 135 2025 — source example

MODULE 4 | 25 MINUTES

Repair, Replace & Capital-Alternative Decisions

Repair-versus-replacement decisions are among the most common applications of engineering economics. They also attract cognitive bias because owners remember prior spending, fear admitting that a repair program has failed, or focus on the immediate capital request rather than future consequences.

4.1 Start From the Decision Date

The economic comparison begins today. Prior purchase price and previous repair spending are generally sunk. They may inform condition, reliability, or maintenance trends, but they do not become recoverable by choosing one future path over another.

The relevant questions are forward-looking:

- What will it cost to repair now?
- How much service life will the repair reasonably restore?
- What future maintenance and failure risk remain after repair?
- What will replacement cost now?
- What future operating, maintenance, and renewal consequences follow replacement?
- What downtime or transition cost is associated with each path?
- What capacity, efficiency, or compliance differences matter?

This is incremental analysis: compare the future differences created by the current choice.

STEP	REPAIR-VERSUS-REPLACE CONTROL
Start now	Exclude sunk costs; identify feasible options
Use the same horizon	Model repair followed by later replacement if service is still required
Include the future	Energy, maintenance, failure, downtime and residual effects
Check constraints	Capacity, reliability, safety, outage timing and affordability
Communicate limits	Separate economic preference from feasible implementation

4.2 Remaining Life Is Not the Same as Age

A 20-year-old asset may have substantial remaining life if condition is good and loading has been moderate. A younger asset may be near economic end of life because of corrosion, obsolescence, unsupported controls, capacity limitation, or repeated failure.

Remaining life should be informed by condition assessment, inspection, failure history, degradation mechanism, manufacturer support, code requirements, and operating context. Economic models should not use arbitrary service-life numbers detached from engineering evidence.

Repair life extension deserves the same scrutiny. A $40,000 repair that is expected to provide 8 years of reliable service is economically different from a repair that merely postpones replacement for 18 months. The engineering judgment behind the life extension should be visible.

4.3 Reliability and Expected Failure Cost

Some alternatives have similar scheduled maintenance cost but different failure exposure. Where failure probability and consequence can be reasonably estimated, expected cost can be used cautiously:

$$\text{Expected failure cost} = \text{Probability of failure} \times \text{Consequence cost}$$

For example, if a retained asset has an estimated 10% annual probability of a failure that would create an average $60,000 emergency and downtime consequence, the simple expected annual failure cost is $6,000. That number does not mean a $6,000 invoice will occur each year. It is an economic expectation useful for comparing alternatives.

Probability estimates should not be invented to make a model appear quantitative. If failure likelihood is highly uncertain, scenarios may be more defensible: low, expected, and high failure-frequency cases.

Reliability also affects nonfinancial risk. An emergency water-supply pump, life-safety system, or critical process asset may have technical reliability requirements that dominate the economic comparison. Economic analysis should identify that constraint rather than monetize every consequence.

4.4 Capacity, Obsolescence, and Avoided Future Work

Replacement may create economic value beyond reduced maintenance. A new asset may provide capacity needed for planned growth, eliminate unsupported controls, standardize spare parts, improve energy efficiency, reduce operator burden, or avoid a separate upgrade project.

Those benefits should be included only when they are reasonably attributable to the alternative. Avoided future cost is legitimate when the future work is otherwise expected. It is not legitimate to credit an alternative with speculative benefits that are unlikely to occur.

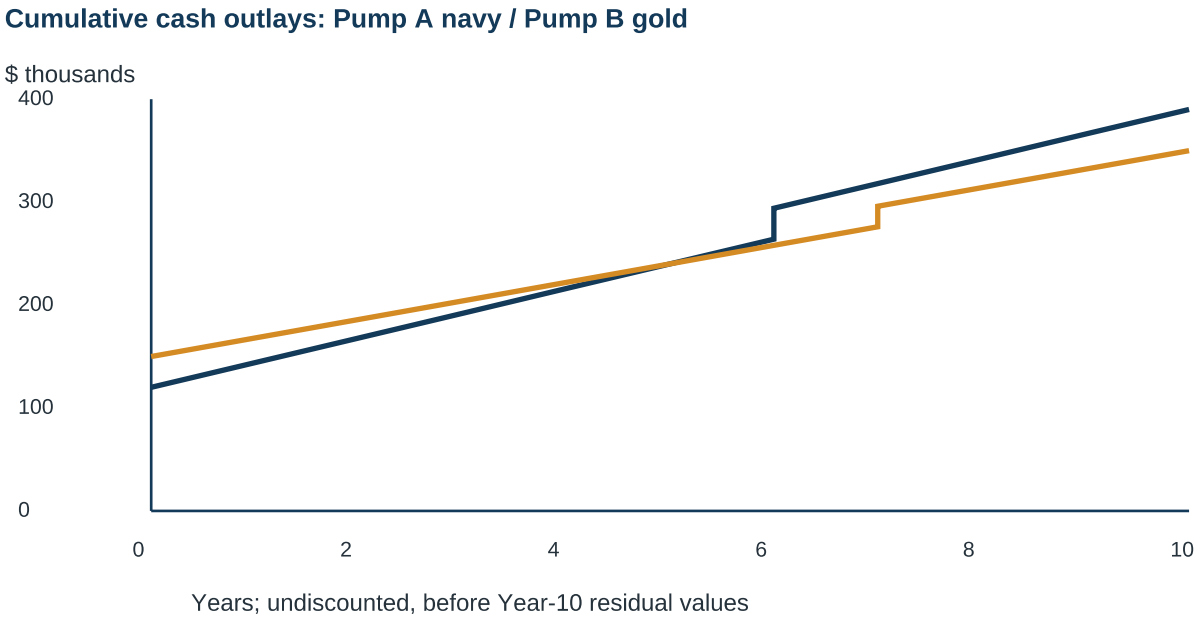
Similarly, a repair alternative should not be burdened with every possible future failure scenario while replacement is modeled optimistically. Symmetry matters.

4.5 Break-Even and Crossover Thinking

Break-even analysis asks what level of a key variable makes two alternatives economically equal. That variable might be annual energy savings, remaining life, utilization, maintenance cost, or failure frequency.

Break-even thinking is powerful because it communicates a decision without requiring stakeholders to agree on one uncertain forecast. Instead of saying, “Replacement is definitely cheaper,” the engineer can say, “Replacement has the lower lifecycle cost if the existing unit would otherwise require more than $18,000 per year in maintenance and downtime, or if its remaining life is less than seven years.”

A switching value turns uncertainty into a decision condition.



Illustrative Pump A and B cumulative undiscounted cash outlays, including overhaul steps and excluding Year-10 residual credits. This graph is not a present-value ranking.

4.6 Payback: Useful but Limited

Simple payback is:

$$\text{Payback period} = \text{Initial premium} \ / \ \text{Annual savings}$$

If a high-efficiency motor costs $30,000 more and saves $10,000 per year, simple payback is three years.

Payback is easy to communicate and useful for screening, but it has important limitations:

- it ignores discounting;
- it ignores benefits after the payback point;
- it does not directly account for different lives;
- it may ignore replacement and residual values;
- it can favor short-lived options with quick early savings; and
- it does not measure total economic value.

A project with a four-year payback and 20 years of savings may be more attractive than a project with a three-year payback and only four years of life. Payback alone cannot show that.

4.7 Equivalent Annual Cost

When alternatives have different lives and provide repeatable service, equivalent annual cost can be useful. It converts present lifecycle cost into an equivalent uniform annual amount over the relevant period.

If P is present lifecycle cost, the equivalent annual cost A over n years at rate i is:

$$A = P\ [i(1+i)\hat{}n \ / \ ((1+i)\hat{}n - 1)]$$

This allows alternatives with different service lives to be compared on an annualized basis, subject to appropriate assumptions about repeatability and replacement.

Equivalent annual cost should not be used mechanically when future replacement technology, capacity, or service requirements are expected to change materially. As with all economic tools, the method must fit the decision.

4.8 Worked Example: Repair or Replace a Process Blower

A process blower is experiencing repeated bearing and seal problems. The owner can perform a major repair or replace the blower with a more efficient unit. Both alternatives can meet current capacity requirements.

Repair existing blower

- Immediate repair: $48,000
- Expected life extension: 5 years
- Annual energy: $54,000
- Annual maintenance: $12,000
- Expected emergency/downtime allowance: $8,000 per year
- Residual value after 5 years: $0

Replace now

- Installed replacement: $145,000
- Expected economic life: 12 years
- Annual energy: $38,000
- Annual maintenance: $5,000
- Expected emergency/downtime allowance: $2,000 per year
- Residual value at Year 12: $18,000

Suppose the owner's service requirement extends 12 years and the real discount rate is 4%. A fair comparison cannot stop at the five-year repair horizon. The repair path must include what happens after Year 5, such as replacement at that point. If the model ignores the later replacement, it gives the repair path seven years of free service.

A simplified 12-year model would include:

- repair at Year 0;
- five years of higher energy, maintenance, and expected failure cost;
- replacement around Year 5;
- operating cost of the replacement from Years 6 through 12; and
- appropriate residual value at Year 12.

The replace-now alternative includes the replacement at Year 0 and lower recurring cost across the full period.

The example also shows why one should not argue, “We already spent $90,000 repairing this blower over the last three years, so we need to get our money out of it.” That prior $90,000 is sunk. It may be evidence of deteriorating reliability, but it does not economically justify another repair.

4.9 Capital Alternatives and Noncost Constraints

Economic preference is one decision input. Capital availability, permitting, outage windows, procurement lead time, workforce capacity, environmental requirements, and technical risk may limit when an alternative can be implemented.

A replacement may have lower lifecycle cost but require a shutdown that is impossible this year. The practical recommendation may be an interim repair followed by scheduled replacement. That does not invalidate the economic analysis; it clarifies the difference between the economically preferred steady-state option and the feasible implementation plan.

Engineers add value when they communicate both.

Module 4 Applied Check

Whenever repair appears dramatically cheaper than replacement, ask whether the model uses the same future service period for both. Whenever replacement appears dramatically better, ask whether the

model gives replacement optimistic reliability, energy, or maintenance assumptions unsupported by evidence.

4.10 Economic Life, Physical Life, and Technological Life

Physical life is how long an asset can continue to function. Economic life is the period over which keeping the asset is economically preferable to replacement. Technological life reflects how long the asset remains suitable before obsolescence, compatibility, or support limitations create pressure to replace it.

These lives are not always equal. A control system may be physically operable after vendor support ends. A pump may run for decades but become uneconomic because energy and maintenance costs are high. A building system may have remaining physical life but lack capacity for a planned expansion.

Repair-versus-replace analysis should therefore avoid the assumption that “still working” means “economically optimal to keep.” It should also avoid the opposite assumption that older equipment should automatically be replaced. The relevant comparison is future cost and performance.

Challenger-Defender Logic

Engineering-economics texts often describe the existing asset as the defender and a proposed replacement as the challenger. The defender's original purchase price is sunk. Its economic value in the comparison is based on future cost, remaining life, and any current market or salvage value that would be given up by keeping it.

The challenger is evaluated on acquisition cost, future operating and maintenance cost, service life, replacement cycle, and residual value.

This framing helps separate accounting book value from economic decision value. A fully depreciated asset can still be expensive to operate. An asset with a high book value can still be economically rational to replace if future savings are sufficient.

Minimum-Cost Life Concept

For some assets, average annual equivalent cost initially falls as first cost is spread over more years, then rises as maintenance, failure, inefficiency, or obsolescence increase. The economic replacement age can occur near the minimum of that annualized cost curve.

In practice, estimating such a curve requires credible age-related maintenance and failure data. The concept is useful even when exact optimization is not possible: replacement timing should consider how future ownership cost changes with age rather than relying only on a fixed calendar life.

Deferred Replacement Has an Economic Cost

Deferring replacement preserves capital today, but it may increase future operating cost, maintenance, failure exposure, or emergency-replacement risk. A defer option should model those consequences explicitly.

For example, deferring a chiller replacement for three years might avoid a $600,000 capital expenditure today, but incur $55,000 per year of excess energy, $25,000 per year of incremental maintenance, and a potential emergency rental exposure. The economic cost of deferral can be compared with the benefit of postponing the capital spend.

Sometimes deferral is rational because capital is constrained, planned facility changes may alter future requirements, or new technology is expected. The economic model helps quantify the price of waiting.

Repair Bundles and Stepwise Decisions

Real repair decisions are rarely binary. A condition assessment may identify a minimum repair, a comprehensive overhaul, and full replacement. Modeling all three can reveal whether the middle option creates value.

A minimum repair may be appropriate as a short bridge to a planned capital project. A comprehensive overhaul may be economically poor if it costs nearly as much as replacement but does not restore comparable life or efficiency. Replacement may be excessive if the asset's remaining system context will change soon.

The decision framework should allow the implementation strategy to match the planning horizon.

Reliability as a Constraint Versus a Monetized Cost

When failure consequence is severe, reliability may be a constraint rather than a cost category. A hospital emergency-power system, flood-protection gate, fire pump, or critical process trip system may need to meet a minimum reliability standard regardless of calculated expected failure cost.

This distinction is important. Monetizing catastrophic failure can imply that a sufficiently low expected dollar value makes inadequate reliability acceptable. Engineering requirements, regulations, or professional judgment may set a non-economic threshold that all alternatives must satisfy.

After that threshold is met, economic analysis can compare the compliant alternatives.

Applied Mini-Case: Fleet Equipment Replacement

A public works department operates a specialized vacuum truck. The truck is 11 years old. It can be overhauled for $95,000 and is expected to provide four more years of service, with annual maintenance of $32,000. A new truck costs $430,000, is expected to last 10 years, and has annual maintenance of $12,000. The old truck also averages $18,000 more per year in fuel and has caused approximately $20,000 per year in rental and overtime during outages.

A superficial comparison says $95,000 is much less than $430,000. A forward-looking economic comparison recognizes that the overhaul path is approximately $58,000 per year more expensive in maintenance, fuel, and outage consequences before discounting, and still requires replacement in four years.

$$\text{Annual difference} = (\$32{,}000 - \$12{,}000) + \$18{,}000 + \$20{,}000 = \$58{,}000$$

The model should compare a common service horizon, perhaps 10 years, including replacement after the repaired truck reaches the end of the four-year extension. It should also test whether the outage allowance is representative and whether the new truck's expected maintenance is supported by fleet data.

The prior purchase price of the old truck is irrelevant. Its current resale value, if any, is relevant because choosing to retain it gives up that value.

Capital Rationing and Portfolio Decisions

Organizations often have more economically positive projects than available capital. A project can be lifecycle-cost effective and still not be funded immediately. Portfolio selection may require benefit-cost ratios, internal rates of return, strategic ranking, risk reduction, or regulatory priority in addition to lifecycle cost.

The engineering analyst should distinguish the project-level conclusion from the portfolio decision. “Alternative B is economically preferred for this project” is different from “this project should be funded before every other capital need.”

Keeping that distinction clear prevents a lifecycle-cost model from being used beyond its intended decision scope.

Sensitivity, Uncertainty & Decision Communication

Economic models are forecasts. Even when the arithmetic is exact, future energy prices, service life, maintenance frequency, utilization, escalation, residual value, and discount rates are uncertain. A professional analysis distinguishes mathematical precision from forecast certainty.

5.1 Identify the Variables That Can Change the Decision

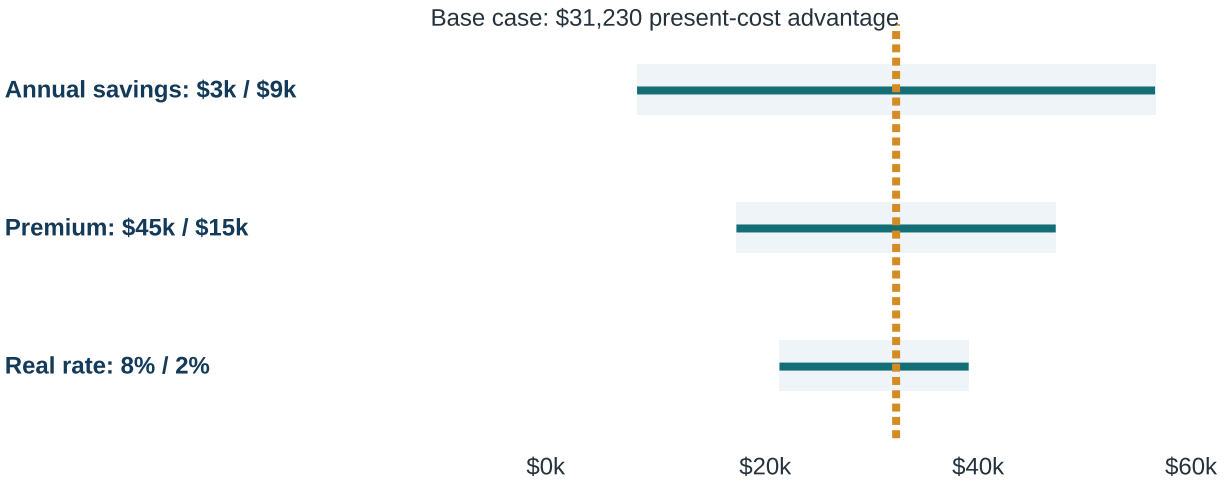
Sensitivity analysis changes one assumption at a time to show how strongly the result responds. It is most useful for material uncertain variables, not every input in the workbook.

Typical sensitivity variables include:

- service life;
- discount rate;
- energy or fuel price;
- annual operating hours;
- maintenance frequency;
- major repair cost;
- replacement timing;
- downtime cost;
- escalation rate; and
- residual value.

The goal is to discover which assumptions deserve the most scrutiny. If lifecycle cost barely changes when residual value varies by 50%, residual value is not a critical decision driver. If a two-year change in service life reverses the recommendation, service life deserves careful engineering support.

Pump B advantage: one assumption changed at a time



Computed one-way sensitivity of the Pump B present-cost advantage. Stated ranges are illustrative; all other Pump A/B inputs remain fixed.

5.2 One-Way Sensitivity and Switching Values

A one-way sensitivity test changes one variable while holding others constant. It can be presented as a table, chart, or switching value.

Suppose Alternative B has a $45,000 lifecycle-cost advantage in the base case because it saves energy. If the energy-price assumption falls, the advantage narrows. The engineer can solve for the

energy price at which the alternatives have equal lifecycle cost. That switching price may be more informative than simply presenting a base-case savings estimate.

Switching values answer questions such as:

- How short would service life have to be before the premium option no longer pays?
- How high would maintenance cost have to become before replacement is preferred?
- What annual utilization is required to justify the efficiency upgrade?
- At what discount rate do the alternatives become approximately equal?

These statements communicate robustness directly.

5.3 Scenario Analysis

Sensitivity analysis changes one variable at a time. Scenario analysis changes several related assumptions together to represent coherent futures.

A downside scenario might combine shorter service life, higher maintenance, lower residual value, and slower utilization growth. An upside scenario might combine longer life, lower maintenance, and higher utilization. The base scenario represents the most supportable expected assumptions.

Scenarios are particularly useful when variables are related. For example, harsh operating conditions may simultaneously reduce component life, increase maintenance, and increase downtime. Changing only one of those variables can understate the effect of the operating environment.

DOWNSIDE	BASE	UPSIDE
Lower life / higher recurring cost / weaker residual value	Evidence-based central assumptions	Longer life / lower recurring cost / stronger residual value
Test a coherent unfavorable future	Document why this combination is credible	Test a coherent favorable future

5.4 Uncertainty Is Not an Excuse to Avoid Analysis

Engineers sometimes respond to uncertainty by saying that future costs cannot be known, so lifecycle analysis is unreliable. That conclusion is too strong. Uncertainty is a reason to show ranges and decision conditions, not a reason to default automatically to first cost.

A transparent model can distinguish:

- known values, such as a current bid price;
- engineering estimates, such as expected service life;
- policy inputs, such as an owner-specified discount rate;
- market assumptions, such as energy escalation; and
- uncertain event costs, such as major failure or downtime.

The model can then focus review effort on the uncertain inputs with the greatest decision impact.

5.5 Avoid False Precision

If service life is uncertain between 12 and 18 years, reporting lifecycle-cost difference to the nearest dollar suggests a level of certainty the inputs do not support. Use appropriate significant figures and present ranges or sensitivities where material.

Likewise, do not hide uncertainty by averaging everything into one number. A base-case lifecycle cost is useful, but it should be accompanied by enough context to show whether the preferred alternative is robust.

False precision can also arise from overly detailed escalation models. If a 20-year forecast uses a different inflation rate for 15 categories but the data supporting those rates are weak, the model may

look sophisticated while becoming less defensible. Model detail should follow decision importance and data quality.

5.6 Communicating the Recommendation

A defensible economic recommendation should allow a decision-maker to understand the chain from assumptions to conclusion. At minimum, communicate:

1. the decision and alternatives;
2. technical equivalence or important performance differences;
3. perspective and study period;
4. major cost categories included and excluded;
5. discount-rate and dollar-basis assumptions;
6. base-case result;
7. material sensitivity or scenario findings;
8. non-economic constraints or risks; and
9. the recommended alternative and conditions that could change it.

DECISION RECORD	WHAT TO SHOW
Assumptions	Rates, lives, quantities, prices and timing
Boundary	Perspective, period, inclusions and exclusions
Method / results	Cash-flow model, present cost and difference
Sensitivity	Variables that change ranking and switching conditions
Recommendation	Preferred feasible alternative, limits and triggers

Avoid presenting a spreadsheet total as if it were self-explanatory. Decision-makers need the economic logic and the engineering context.

5.7 Capstone Scenario: Selecting a Pumping-System Upgrade

A utility must upgrade a pumping station. Two technically acceptable alternatives are under consideration.

Alternative A - Conventional configuration

- Installed cost: $1.20 million
- Expected service life: 20 years
- Annual energy and routine maintenance: $185,000
- Major renewal: $220,000 in Year 10
- Residual value at Year 20: $80,000

Alternative B - Premium high-efficiency configuration

- Installed cost: $1.48 million
- Expected service life: 20 years
- Annual energy and routine maintenance: $150,000
- Major renewal: $180,000 in Year 12
- Residual value at Year 20: $100,000

The premium is $280,000. Annual recurring savings are $35,000. A simple first-cost comparison favors A. A simple payback calculation suggests eight years for the $280,000 premium based only on annual recurring savings, before considering renewal and residual differences.

A lifecycle present-value model may show B as economically preferred, depending on the discount rate and operating assumptions. But the engineer should then ask what can change the result.

Sensitivity 1 - Utilization: If expected pumping hours are 25% lower, energy savings may decline enough to reduce B's advantage.

Sensitivity 2 - Service life: If the premium equipment is expected to be replaced early because of obsolescence, its residual and long-term savings may be lower.

Sensitivity 3 - Energy price: Higher future real energy prices favor B; lower prices reduce its advantage.

Sensitivity 4 - Renewal timing: If A's major renewal can be deferred several years based on condition, its present lifecycle cost improves.

Sensitivity 5 - Discount rate: A higher discount rate places less weight on distant savings and tends to favor the lower-first-cost alternative.

The final recommendation might state that Alternative B has the lower lifecycle present cost in the base case and remains preferred across expected energy-price and renewal-cost ranges, but becomes approximately equal to A if annual operating hours fall below a defined threshold. That statement is more useful than reporting a single lifecycle-cost difference without context.

5.8 Professional Documentation Practices

Keep the economic model and technical basis connected. Useful records can include:

- source quotations and cost estimates;
- operating-hour assumptions;
- energy model outputs;
- maintenance records;
- condition assessments;
- service-life rationale;
- discount-rate policy or reference;
- escalation source;
- model version and reviewer;
- sensitivity ranges; and
- decision memorandum or recommendation.

If the analysis is revised, preserve the assumptions that changed. Economic models often evolve during design and procurement; traceability prevents later confusion about why the preferred alternative changed.

5.9 Final Decision Checklist

Before issuing an engineering-economic recommendation, confirm:

- The alternatives provide the required function or performance differences are explicitly recognized.
- The cost perspective and study period are defined.
- Future costs that differ materially among alternatives have been considered.
- Sunk costs have not been used to justify future spending.
- Cash flows are placed on a consistent time basis.
- Real/nominal assumptions are internally consistent.
- Service lives and replacement cycles are compared fairly.
- Residual value treatment is documented.
- The major uncertain assumptions have been stress-tested.
- The recommendation states non-economic constraints and limitations.
- A reviewer can reconstruct the result from the documented assumptions and model.

Engineering economics is not about finding the cheapest option. It is about making the economic consequences of engineering choices visible enough to support responsible judgment.

5.10 Data Quality, Model Governance, and Independent Review

Economic models can become decision-critical engineering work products. Their quality depends on both formulas and governance. A model should have clear ownership, version control, protected formulas where appropriate, documented assumptions, and independent review proportionate to the decision.

A useful review asks three different questions:

1. Formula review: Are calculations mathematically correct?
2. Assumption review: Are service lives, costs, rates, and timing supportable?
3. Decision review: Does the model compare the right alternatives and include the consequences that matter?

Three Review Failures to Avoid

- Correct formulas, wrong assumptions: mathematically accurate output built on unsupported service life, utilization, or cost.
- Correct assumptions, wrong boundary: good data applied to a study period or perspective that does not match the decision.
- Correct model, weak communication: a sound analysis that hides the switching condition, uncertainty, or non-economic constraint decision-makers need to see.

Formula review alone is insufficient. A perfectly calculated model using an unrealistic 30-year equipment life can still produce a poor recommendation.

Source Hierarchy for Assumptions

Not all inputs have equal support. A practical hierarchy may be:

- contractual or owner-prescribed values;
- current firm quotations or bids;
- measured operating data;
- documented maintenance history;
- validated engineering calculations;
- published agency or industry data;
- manufacturer information;
- analogous-project experience; and
- professional judgment where stronger evidence is unavailable.

The model should identify which high-impact assumptions rely primarily on judgment. Those are natural candidates for sensitivity testing and expert review.

Range Estimates and Triangular Thinking

When an input is uncertain, a low/base/high range can be more informative than a single point estimate. For example, service life might reasonably be 12, 15, or 18 years. Maintenance could be $18,000, $25,000, or $35,000 per year. These ranges can be combined into scenarios or used individually in sensitivity analysis.

The range should represent plausible uncertainty, not an arbitrary +/-10%. The analyst should be able to explain why the bounds were selected.

Probabilistic Analysis: When It Helps

For high-value decisions with many uncertain variables, probabilistic methods such as Monte Carlo simulation can estimate a distribution of lifecycle outcomes rather than one total. This course does not require probabilistic modeling, but engineers should understand its role.

A probabilistic model assigns distributions to uncertain inputs and repeatedly samples them. The result might show, for example, that Alternative B has lower lifecycle cost in 78% of simulated cases. That information can be valuable when the alternatives are close and uncertainties are material.

However, simulation does not cure weak assumptions. A sophisticated probability distribution built on unsupported data can create false confidence. Deterministic sensitivity and scenario analysis are often sufficient for routine engineering decisions.

Correlated Variables

Some assumptions move together. Higher utilization can increase energy consumption, maintenance, and wear. Harsh environmental exposure can shorten service life and increase repair frequency. Fuel price and inflation may not be independent.

One-way sensitivity analysis intentionally isolates variables, but scenario analysis should consider realistic relationships. When probabilistic methods are used, correlation may need explicit treatment.

Communicating Robustness

Decision-makers often want a clear recommendation, not a lecture on uncertainty. The engineer can communicate robustness concisely:

- “Alternative B is lower cost in the base case by approximately $180,000 present value.”
- “B remains preferred if annual operating hours stay above 3,200 hours.”
- “The result is most sensitive to service life and energy price.”
- “If service life falls below 11 years, the alternatives become approximately equal.”
- “The conclusion is not materially affected by residual value.”

This format is more useful than listing ten sensitivity tables without interpretation.

When Economic and Technical Preferences Conflict

An economic model may prefer an alternative with higher technical risk, lower resilience, or more demanding maintenance. The recommendation should not hide that conflict.

A strong decision memo can state that Alternative A has the lowest lifecycle cost, while Alternative B offers higher reliability or lower implementation risk at an economic premium. Management can then decide whether the premium is justified by non-economic objectives.

Engineering economics supports transparent tradeoffs. It should not be used to force every engineering value into dollars.

Applied Mini-Case: Building Heating-System Selection

An owner is comparing a conventional boiler replacement with a higher-cost heat-pump-based system. The heat-pump alternative has lower expected energy use but requires electrical infrastructure upgrades and has greater uncertainty in cold-weather performance and future electricity rates.

The economic model includes:

- installed equipment and electrical upgrade;
- annual energy consumption from an engineering model;
- gas and electricity price assumptions;
- scheduled maintenance;
- equipment replacement cycles;
- expected service life; and
- residual value at the study-period end.

The base case favors the heat-pump option by $90,000 present value over 20 years. Sensitivity shows the result is highly dependent on annual operating efficiency and relative electricity/gas price. Under a low-efficiency/high-electricity scenario, the conventional boiler is lower cost by $60,000.

A poor recommendation would simply say, “Heat pump saves $90,000.” A stronger recommendation states the base-case advantage, identifies the two dominant assumptions, shows the switching conditions, and discusses whether the owner's decarbonization or resilience objectives affect the final choice.

Economic Review Questions for Decision Meetings

When presenting a lifecycle analysis, be prepared to answer:

- Why were these alternatives selected?
- Are they technically equivalent?
- What perspective is used?
- Why was this study period selected?
- Which costs dominate the result?
- Which costs were intentionally excluded?
- Where did the discount rate come from?
- Are dollars real or nominal?
- What service lives were assumed and why?
- How are replacements and residual values treated?
- Which assumption can most easily reverse the decision?
- What evidence supports the preferred alternative?

If those questions can be answered clearly, the economic model is likely serving its purpose.

Final Applied Exercise: Build the Recommendation, Not Just the Spreadsheet

Assume two technically acceptable equipment alternatives differ as follows:

- Alternative A costs $250,000 installed and $55,000 per year to operate and maintain.
- Alternative B costs $330,000 installed and $42,000 per year to operate and maintain.
- Both are expected to serve 12 years.
- B has a $25,000 residual value; A has $10,000.
- The owner uses a 4% real discount rate.

The initial premium for B is $80,000. Its annual recurring savings are $13,000. The 12-year present-value factor at 4% is approximately 9.385. The PV of recurring savings is about $122,000. The residual-value advantage also favors B after discounting. The base case therefore supports B economically.

Now test uncertainty. If annual savings are only $7,000, the PV of recurring savings falls to roughly $65,700 and may no longer recover the first-cost premium after considering residual value. The economic decision is therefore sensitive to the recurring-cost estimate.

The professional recommendation should identify the required annual savings for B to break even. That switching value tells the owner what operating-cost evidence deserves verification before committing capital.

Completed switching-value calculation

$$\mathrm{P/A} = [1 - (1.04)^{-12}] \,/\, 0.04 = 9.385074$$

$$\text{PV of residual advantage} = (\$25{,}000 - \$10{,}000) \,/\, (1.04)^{12} = \$9{,}368.96$$

$$\text{Required annual savings} = (\$80{,}000 - \$9{,}368.96) \,/\, 9.385074 = \$7{,}525.89/\text{year}$$

Under the stated illustrative assumptions, B breaks even at about $7,526 in annual recurring savings. At $13,000/year, B has a present-cost advantage of about $51,375; at $7,000/year, it is about $4,936 more expensive. Verify recurring-cost evidence near the switching value before committing capital.

This final exercise summarizes the course: establish equivalent alternatives, compare future differences on a common basis, identify what drives the result, test uncertainty, and communicate the condition under which the recommendation changes.

Course Summary

The most important principles of this course are straightforward:

1. Define the required function and feasible alternatives before comparing cost.

2. Compare future consequences that differ because of the decision; do not let sunk costs drive the choice.
3. Use a consistent study period, perspective, dollar basis, and discount-rate basis.
4. Convert cash flows occurring at different times to a common basis before comparing alternatives.
5. Look beyond first cost to operations, maintenance, repair, replacement, downtime, end-of-life cost, and residual value when those categories are material.
6. Compare repair and replacement over equivalent future service requirements.
7. Treat payback as a screening measure, not a complete lifecycle criterion.
8. Use sensitivity, scenarios, and switching values to show how uncertainty affects the decision.
9. Document assumptions, sources, boundaries, limitations, and tradeoffs.
10. Use economic analysis to support - not replace - technical, safety, reliability, compliance, and professional judgment.

Principal references and source links

- NIST Handbook 135e2025, Life Cycle Costing Manual for the Federal Energy Management Program, August 2025; supersedes the 2022 edition/update. Example 5.1 and printed pp. 71–72 support the reproduced HVAC cash-flow data. Open source
- NIST life-cycle-cost programs and FEMP annual-supplement resources. Use the applicable analysis year, method and factors rather than copying an instructional percentage. Open source
- ASTM E917-17(2023), Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems. Scope reference; applicable project requirements govern. Open source
- ISO 15686-5:2017, Buildings and constructed assets — Service life planning — Part 5: Life-cycle costing. Scope reference for building and constructed-asset analysis. Open source
- FHWA Life-Cycle Cost Analysis resources. Differential costs of transportation investment and preservation alternatives; use the owner's adopted method. Open source

The course uses established engineering-economics concepts also covered in the NCEES FE Reference Handbook. For federal programs, verify whether FEMP rules, OMB Circular A-94 or other agency-specific guidance controls the analysis. No single instructional discount rate is prescribed here for all projects.

Sources checked November 15, 2026. Numerical examples are simplified teaching inputs, not actual prices or project recommendations. Technical requirements, owner policies and the applicable analysis method govern.

Instructor

Matthew Ward, MBA, CIA — BuilderCE instructor for this engineering-economics course.

> **Study guide complete.** Return to the BuilderCE lesson page and select Continue to begin the final examination. A score of at least 70% is required to pass. Retakes are permitted.