Essential Project Management Formulas

A Quick Reference Guide

Cost Performance

$$CPI = \frac{EV}{AC}$$

Schedule Performance

$$SPI = \frac{EV}{PV}$$

Cost Variance

$$CV = EV - AC$$

EV = Earned Value
AC = Actual Cost
PV = Planned Value

Earned Value: The Foundations

Compare planned work, completed work, and actual spending at the same status date.

1 Know the 4 inputs

BAC | Budget at Completion

Total approved budget for the measured scope.

PV | Planned Value

Budgeted value of work scheduled by the status date.

EV | Earned Value

Budgeted value of work actually completed by the status date.

AC | Actual Cost

Cost incurred for the work performed by the status date.

2 The 4 core formulas

Cost Variance

$$CV = EV - AC$$

Positive: under budget
Zero: on budget
Negative: over budget

Schedule Variance

$$SV = EV - PV$$

Positive: ahead of plan
Zero: on plan
Negative: behind plan

Cost Performance Index

$$CPI = \frac{EV}{AC}$$

> 1: cost efficient
= 1: on budget
< 1: cost overrun

Schedule Performance Index

$$SPI = \frac{EV}{PV}$$

> 1: ahead of plan
= 1: on plan
< 1: behind plan

3 Worked example | One status date

Example inputs:

BAC = $100,000

Planned progress = 50% | Actual progress = 40%

AC = $45,000

Assume progress percentages are weighted by budget.

Calculations:

PV = $100,000 × 50% = $50,000
EV = $100,000 × 40% = $40,000
CV = $40,000 − $45,000 = −$5,000
SV = $40,000 − $50,000 = −$10,000
CPI = $40,000 / $45,000 ≈ 0.89
SPI = $40,000 / $50,000 = 0.80

Reading the result:

Costs exceed the budgeted value of completed work by $5,000.
Only 80% of the planned budgeted work has been earned.
Each $1 spent earns about $0.89 of budgeted value.

4 Use the numbers correctly

- ☑ Use one status date, currency, scope, and baseline.
- ☑ EV measures budgeted work value, not revenue.
- ☑ SV is a money value, not days of delay; check the critical path.
- ☑ CPI needs AC > 0; SPI needs PV > 0.

Remember:

EV comes first in all four core formulas.

Measuring Progress Correctly

Turn completed work into budgeted value before judging performance.

1 Budget-weighted progress

For work package i:

$$EV_i = Budget_i \times Verified\ completion_i$$

Use completion as a decimal: 25% = 0.25.

Project EV = sum of all EV_i

$$EV = \sum EV_i$$

BAC = sum of all work-package budgets

$$BAC = \sum Budget_i$$

Earned progress (%)

$$Earned\ progress = \left(\frac{EV}{BAC}\right) \times 100$$

A large work package carries more weight than a small one.

2 Worked example: three work packages

Work	Budget	Complete	Earned value
Design	$20,000	100%	$20,000
Build	$60,000	25%	$15,000
Test	$20,000	0%	$0

Calculations:

BAC = $100,000

EV = $20,000 + $15,000 + $0 = $35,000

Earned progress = $35,000 / $100,000 = 35%

Simple average = (100% + 25% + 0%) / 3 = 41.67%

The simple average overstates progress because budgets differ.

3 Choose a credible earning method

0/100 rule
Earn nothing until the task is finished.

50/50 rule
Earn half at start and half at completion.

Weighted milestones
Earn preassigned budget shares when milestones are achieved.

Physical units
Use accepted units × budgeted unit rate when units are comparable.

Agree the method before reporting. Avoid subjective "nearly finished" estimates.

4 Money spent is not progress

If AC = $42,000:

$$Spent\ share = \frac{AC}{BAC} \times 100 = 42\%$$

$$CPI = \frac{EV}{AC} = \frac{\$35,000}{\$42,000} \approx 0.83$$

42% of the budget has been spent, but only 35% of budgeted work has been earned.

For planned progress, use the approved time-phased baseline; do not assume spending is uniform.

Checks

- [ ] Use accepted completion evidence and one status date.
- [ ] Do not count the same deliverable twice.
- [ ] Update budgets only through approved change control.
- [ ] Remember: weight progress by budget, not by task count.

Forecasting the Final Cost

EAC is the estimate at completion. Select the formula that matches the future.

1 Define the inputs

BAC: approved performance budget.

AC: actual cost incurred to date.

EV: budgeted value of completed work.

$$CPI = \frac{EV}{AC} \quad | \quad SPI = \frac{EV}{PV}$$

ETC: expected cost of the remaining work.

General relationship: $EAC = AC + ETC$

2 Four forecast methods

A. Future work follows original budget rates

$$EAC = AC + (BAC - EV)$$

Use when past cost variance will not recur.

B. Current cost efficiency continues

$$EAC = \frac{BAC}{CPI}$$

Use cumulative CPI for the same baseline and status date.

C. Cost and schedule performance affect remaining cost

$$EAC = AC + \frac{(BAC - EV)}{(CPI \times SPI)}$$

Use only when the combined adjustment is justified.

D. Re-estimate the remaining work

$$EAC = AC + \text{Bottom-up ETC}$$

Use when a detailed new estimate is more credible.

3 One project, four scenarios

Given:

BAC = $100,000	EV = $40,000
AC = $50,000	PV = $50,000
CPI = 0.80	SPI = 0.80

Results:

A: $50,000 + $60,000 = $110,000

B: $100,000 / 0.80 = $125,000

C: $50,000 + $60,000 / 0.64 = $143,750

D: If new ETC = $68,000, EAC = $118,000

These are different assumptions, not four interchangeable answers.

4 Interpret before reporting

- ☑ Record the forecast method and the reason for using it.
- ☑ Keep unrounded CPI and SPI during calculation.
- ☑ Check remaining scope, rates, risks, and supplier commitments.
- ☑ A revised EAC is a forecast; it does not automatically change BAC.
- ☑ Do not average the four estimates without a reason.

Remember: the assumption chooses the formula.

Remaining Cost & Budget Variance

Separate what has already been spent from what is still needed.

1 The two essential equations

Estimate to Complete

$$ETC = EAC - AC$$

Expected additional cost to finish the remaining scope.

Variance at Completion

$$VAC = BAC - EAC$$

Positive VAC: forecast under budget.
Zero VAC: forecast on budget.
Negative VAC: forecast over budget.

2 Build an ETC

Current efficiency continues:

$$ETC = \frac{(BAC - EV)}{CPI}$$

Remaining work follows budget rates:

$$ETC = BAC - EV$$

Detailed re-estimate:

$$ETC = \text{sum of remaining cost estimates}$$

Use one selected assumption consistently.
BAC – EV is remaining budgeted work value; it is not automatically the remaining actual cost.

3 Worked example

Given:

BAC = $200,000
EV = $80,000
AC = $100,000
CPI = 0.80

Assume current cost efficiency continues.

Calculations:

EAC = $200,000 / 0.80 = $250,000
ETC = $250,000 – $100,000 = $150,000
VAC = $200,000 – $250,000 = –$50,000

Forecast overrun (%) = (EAC – BAC) / BAC × 100
= $50,000 / $200,000 × 100 = 25%

4 Three amounts that are easy to confuse

Amount	Formula and value
Budget remaining	BAC – AC = $100,000
Budgeted work remaining	BAC – EV = $120,000
Forecast cost remaining	ETC = $150,000

The project needs $50,000 more than the original unspent budget.
ETC is a cost forecast, not a cash-payment schedule.

Checks

- ☑ EAC must reconcile to AC + ETC.
- ☑ VAC compares the forecast with the approved budget.
- ☑ Do not add costs already included in AC to ETC again.
- ☑ Document whether reserves and open commitments are included.
- ☑ Remember: ETC looks forward; AC looks backward.

TCPI: Can the Target Be Met?

Calculate the cost efficiency required for the work that remains.

1 Two targets, two denominators

To finish within the approved budget:

$$TCPI_{BAC} = \frac{BAC - EV}{BAC - AC}$$

To finish within a selected revised estimate:

$$TCPI_{EAC} = \frac{BAC - EV}{EAC - AC}$$

Numerator: budgeted value of unfinished work.
Denominator: funds available for that work.

BAC: budget at completion
EAC: estimate at completion

EV: earned value
AC: actual cost

2 Worked example

BAC = $100,000 | EV = $40,000 | AC = $50,000

$$\text{Current CPI} = \frac{EV}{AC} = 0.80$$

Budgeted work remaining = $100,000 − $40,000 = $60,000

Target A: finish at BAC

Funds remaining = $100,000 − $50,000
= $50,000

$$TCPI_{BAC} = \frac{\$60,000}{\$50,000} = 1.20$$

Each future $1 must earn $1.20 of budgeted work.

Target B: finish at EAC = $125,000

Funds remaining = $125,000 − $50,000
= $75,000

$$TCPI_{EAC} = \frac{\$60,000}{\$75,000} = 0.80$$

Current cost efficiency would support this revised estimate.

3 Read TCPI alongside CPI

CPI describes efficiency achieved so far.
TCPI describes efficiency required from now on.

- TCPI > 1: future work must cost less than its budgeted value.
- TCPI = 1: future work must meet its budgeted rates.
- TCPI < 1: the target allows some future cost inefficiency.

A TCPI well above current CPI needs a credible recovery plan.

4 Apply the result

- ☑ Validate remaining scope, resource rates, risks, and commitments.
- ☑ Test whether proposed changes can produce the required efficiency.
- ☑ Reforecast if the target is no longer credible.
- ☑ Changing EAC alone does not approve a new budget.
- ☑ If remaining funds are zero or negative while work remains, the ratio is not a usable recovery target.

Remember:
TCPI is a requirement, not a promise.

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Building a Project Budget

Convert quantities, rates, and defined reserves into a traceable estimate.

1 Core estimating equations

Parametric cost

$$\text{Cost} = \text{Quantity} \times \text{Unit rate}$$

Labor cost

$$\text{Cost} = \text{Work hours} \times \text{Loaded hourly rate}$$

Bottom-up estimate

$$\text{Total estimate} = \sum \text{work-package estimates}$$

Notes

Loaded rates may include benefits and agreed overhead.
Check what each rate already includes before adding costs.

2 Worked estimate

Labor:	480 hours × $50/hour = $24,000
Materials:	300 units × $40/unit = $12,000
Supplier package:	$8,000
Direct costs	= $24,000 + $12,000 + $8,000 = $44,000
Project indirect costs	= $6,000
Base estimate	= $44,000 + $6,000 = **$50,000**

3 From estimate to authorized budget

Illustrative identified-risk contingency = $5,000

Cost baseline = Base estimate + Contingency
= $50,000 + $5,000 = **$55,000**

Illustrative management reserve = $3,000

Total project budget = Cost baseline + Management reserve
= $55,000 + $3,000 = **$58,000**

For this example, BAC = $55,000.
Management reserve is outside the performance baseline.
These reserve amounts are example inputs, not recommended percentages.

4 Sensitivity to a rate change

If the labor rate rises from $50 to $55/hour:
Cost increase = 480 × ($55 − $50) = $2,400
Revised base estimate = $50,000 + $2,400 = $52,400
Reassess reserves separately; do not assume they stay sufficient.
Revised estimates enter the baseline only after approval.

Checks

- ☑ Use consistent currencies, units, price dates, and tax treatment.
- ☑ Avoid duplicating overhead in both loaded rates and indirect costs.
- ☑ Include exclusions, assumptions, and estimate uncertainty.
- ☑ Keep quantity changes separate from rate changes.
- ☑ Time-phase the approved baseline to establish planned value.

Remember:
A good estimate can be traced back to its inputs.

Three-Point & PERT Estimates

Express uncertainty with optimistic, most likely, and pessimistic estimates.

1 Define the inputs

O = Optimistic estimate
M = Most likely estimate
P = Pessimistic estimate

- Use the same units and scope; require $O \le M \le P$.
- Ask estimators which conditions produce each value.

2 The key equations

Triangular mean

$$\frac{O + M + P}{3}$$

Classic PERT mean

$$\frac{O + 4M + P}{6}$$

Classic PERT standard deviation

$$\sigma \approx \frac{P - O}{6}$$

Variance

σ^2

- PERT weights the most likely estimate four times.
- The standard-deviation rule is an approximation.

3 Worked activity example

O = 4 days
M = 7 days
P = 16 days

Triangular mean = $(4 + 7 + 16) / 3 = 9$ days
PERT mean = $(4 + 4 \times 7 + 16) / 6 = 8$ days
$\sigma \approx (16 - 4) / 6 = 2$ days
Variance $\approx 2^2 = 4$ days^2

- The expected duration is not a guaranteed finish date.
- Different distribution assumptions produce different means.

4 Combine an independent sequence

Task A: mean 8 days, standard deviation 2 days.
Task B: mean 10 days, standard deviation 3 days.

Sequence mean = $8 + 10 = 18$ days
Sequence variance = $2^2 + 3^2 = 13$ days^2
Sequence standard deviation = $\sqrt{13} \approx 3.61$ days

- Add variances, not standard deviations.
- This calculation assumes independent activity durations.

Checks

- ☑ Use calendar days or working days consistently.
- ☑ Do not infer a confidence level from the mean alone.
- ☑ Correlated tasks need covariance or simulation.
- ☑ Competing paths and merge points can increase schedule risk.
- ☑ A fixed-path PERT calculation is not a full project simulation.
- ☑ Remember: estimation describes uncertainty; it does not remove it.

Critical Path Calculations

Find the earliest project finish using activity durations and dependencies.

1 Set the counting convention

Use elapsed working time starting at day 0.

This example uses finish-to-start links with zero lag.

ES = Early Start
EF = Early Finish
LS = Late Start
LF = Late Finish
D = Activity duration

2 Forward and backward passes

Forward pass:

ES = Maximum predecessor EF

$$EF = ES + D$$

Start activities have ES = 0.

Backward pass:

LF = Minimum successor LS

$$LS = LF - D$$

Set terminal LF to the earliest project finish for this example.
At a merge, all required predecessors must be complete.

3 Worked network in a table

Dependencies: A starts first; B and C follow A; D follows both B and C.

Activity	Duration	Predecessor	ES	EF	LS	LF
A	3	None	0	3	0	3
B	4	A	3	7	3	7
C	2	A	3	5	5	7
D	3	B, C	7	10	7	10

For D: ES = max(7, 5) = 7 Project duration = 10 working days.

4 Identify the controlling path

Path A–B–D = 3 + 4 + 3 = 10 days
Path A–C–D = 3 + 2 + 3 = 8 days

Critical path: A–B–D

Total Float = LS − ES = LF − EF

A = 0 | B = 0 | C = 2 | D = 0 days

C can slip by 2 days without moving the project finish in this model.

Checks

- ☑ Do not mix day-0 arithmetic with inclusive day-1 counting.
- ☑ Use consistent working calendars.
- ☑ Resource limits, lags, and imposed dates can change the result.
- ☑ More than one critical path can exist.

Remember: the longest dependency path controls the earliest finish.

Float, Lags & Dependencies

Understand which delays affect the next activity and which affect the project.

1 Two types of float

Total Float (TF)

$$TF = LS - ES = LF - EF$$

Delay available before the required project finish is affected.

Free Float (FF)

$$FF = \text{Minimum successor } ES - EF$$

Delay available before any immediate successor's early start moves.
This FF formula assumes finish-to-start links with zero lag.

ES/EF: early start/finish | LS/LF: late start/finish

2 Worked float example

Given:

Activity X: ES = 4, EF = 9, LS = 7, LF = 12.
Its earliest successor starts at day 11.

Calculations:

$TF = 7 - 4 = 12 - 9 = 3$ days

$FF = 11 - 9 = 2$ days

Interpretation:

- A 2-day slip uses free float without moving the successor.
- A 3-day slip can move the successor by 1 day, but stays within total float.
- Float is shared along connected paths; do not add it as independent spare time.

3 Four dependency relationships

A is the predecessor; B is the successor.
S = start | F = finish | L = lag

Finish-to-start (FS)	Start-to-start (SS)	Finish-to-finish (FF)	Start-to-finish (SF)
$S_B \geq F_A + L$	$S_B \geq S_A + L$	$F_B \geq F_A + L$	$F_B \geq S_A + L$

Use consistent calendars and time units.

4 Lag and lead examples

FS with +2-day lag:

If A finishes on day 6, B starts no earlier than day 8.

FS with −1-day lag:

If A finishes on day 6, B may start on day 5.
A negative lag is a lead and allows overlap.
Check that overlap is technically feasible and does not hide risk.

Checks

- ☑ Zero float identifies critical work in a simple unconstrained CPM model.
- ☑ Imposed deadlines can create negative float.
- ☑ Float is schedule flexibility; a buffer is deliberately reserved time.
- ☑ Recalculate after logic, calendar, or duration changes.
- ☑ Remember: total float protects the finish; free float protects successors.

Schedule Crashing: Time vs Cost

Shorten the controlling schedule path at an understood incremental cost.

1 Calculate the crash slope

Cost slope

$$\text{Cost slope} = \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal duration} - \text{Crash duration}}$$

Units: money per unit of time saved.

Assume a linear cost-duration tradeoff within the stated limits.

Notes

Crashing adds resources or cost; fast-tracking overlaps work and can increase rework risk.

2 Compare two eligible activities

Activity A

Normal: 8 days at $4,000
Crash: 5 days at $7,000
Maximum reduction = 3 days

Slope = ($7,000 − $4,000) / (8 − 5)
= $1,000 per day

Activity B

Normal: 6 days at $3,000
Crash: 4 day at $4,200
Maximum reduction = 2 days

Slope = ($4,200 − $3,000) / (6 − 4)
= $600 per day

3 Worked 3-day reduction

Assume A and B are on the same sole critical path.
No other path becomes critical during this reduction.
Crash B by 2 days: 2 × $600 = $1,200
Crash A by 1 day: 1 × $1,000 = $1,000
Additional direct cost = $2,200
If time-related overhead falls by $900 per project day:
Overhead saving = 3 × $900 = $2,700
Net cost change = $2,200 − $2,700 = −$500
Under these assumptions, the project finishes 3 days earlier and total cost falls by $500.

4 Choose the next step carefully

- ☑ Recalculate the critical path after each reduction.
- ☑ Crashing noncritical work may not shorten the project.
- ☑ With multiple critical paths, shorten all controlling paths or a shared critical activity.
- ☑ Check practical resource limits and minimum durations.

Checks

- ☑ Count only overhead that actually disappears when time is saved.
- ☑ Include quality, coordination, and overtime effects.
- ☑ Use incremental costs rather than total activity costs.
- ☑ Remember: buy project time, not just activity time.

Expected Monetary Value

Compare uncertain financial outcomes using their probabilities.

1 Core equations

Single risk EMV

$$EMV = P \times X$$

Probability x Monetary impact.

Decision EMV

$$EMV = \sum (P \times Outcome)$$

Sum of (Probability x Outcome).

Key points

- Use probabilities as decimals: 30% = 0.30.
- For exhaustive, mutually exclusive outcomes, probabilities sum to 1.
- Here, gains are positive and losses are negative.
- EMV is a weighted average, not a guaranteed outcome.

2 Worked decision comparison

Option A has two possible net outcomes:

Success: 60% chance of +$80,000
Failure: 40% chance of −$20,000

$$EMV_A = 0.60 \times \$80{,}000 + 0.40 \times (-\$20{,}000)$$
$$= \$48{,}000 - \$8{,}000 = \$40{,}000$$

Option B delivers a certain net gain of $30,000.

$$EMV_B = 1.00 \times \$30{,}000 = \$30{,}000$$

A risk-neutral comparison favors A by $10,000.
A still carries a 40% probability of losing $20,000.

3 Evaluate a risk response

Without response:

30% chance of a $50,000 loss.

Expected loss = 0.30 x $50,000 = $15,000

With response:

Pay $4,000 now; loss probability falls to 10%.

Expected total cost = $4,000 + 0.10 x $50,000
= $9,000

Expected saving = $15,000 − $9,000 = $6,000

The response is favorable on expected cost under these assumptions.

4 Use decision logic correctly

- ☑ Work from final outcomes back toward the initial decision.
- ☑ At a chance node, probability-weight the outcomes.
- ☑ At a decision node, compare the feasible alternatives.
- ☑ Subtract a certain decision cost once, not once per risk by mistake.
- ☑ Keep outcomes on a common monetary and timing basis.

Checks

- Validate probability and impact estimates.
- Include residual risks and response costs.
- Consider downside tolerance, obligations, and nonfinancial objectives.
- Remember: the highest EMV may not match the decision maker's risk tolerance.

Risk Exposure & Contingency

Estimate average exposure, then choose reserves for the required confidence.

1 Expected loss exposure

Expected loss per risk

$$\text{Expected loss}_i = \text{Probability}_i \times \text{Loss}_i$$

Use positive loss amounts in this page's cost convention.

Total expected loss

$$\text{Total expected loss} = \sum (\text{individual expected losses})$$

Expected values add even when risks are correlated. Correlation still affects the spread and extreme outcomes.

2 Worked risk register

Risk	Probability	Loss if it occurs	Expected loss
Rework	20%	$20,000	$4,000
Supplier delay	10%	$30,000	$3,000
Equipment issue	25%	$12,000	$3,000

Total expected loss = $4,000 + $3,000 + $3,000 = $10,000

The project may lose less or more than $10,000.
This mean exposure is not automatically an adequate contingency.

3 Mean versus confidence-based reserve

Mean-based example

Illustrative base cost = $100,000

Expected loss allowance = $10,000

Mean-based total = $110,000

Confidence-based example (P80)

Suppose a separate simulation gives a P80 total of $118,000.

P80 contingency = $118,000 − $100,000 = $18,000

P80 means 80% of modeled outcomes are at or below that amount.

It is conditional on the model and its assumptions, not a guarantee.

The P80 figure cannot be calculated from the mean alone.

4 Build the reserve sensibly

- ☑ Use residual exposure after planned responses.
- ☑ Include uncertainty in quantities, prices, and productivity.
- ☑ Model shared causes and correlated risks where material.
- ☑ Keep management reserve separate from contingency in the cost baseline.
- ☑ Do not double-count risks already included in estimate ranges.
- ☑ Do not cancel severe threats with uncertain opportunities without analysis.

Checks

- ☑ Specify the confidence target and review date.
- ☑ Update probabilities and impacts as evidence changes.
- ☑ Track reserve use against the risks it covers.
- ☑ Assign owners and response triggers to major risks.

Remember: A reserve is a deliberate risk decision, not a universal percentage.

ROI, Benefit-Cost & Payback

Use complementary measures to evaluate a project's financial case.

1 Simple return on investment

Formula:

$$\text{ROI (\%)} = \frac{\text{Total benefits} - \text{Total costs}}{\text{Total costs}} \times 100$$

State the evaluation horizon and what counts as a benefit or cost.

Example:

Benefits = $150,000; costs = $100,000.
Net benefit = $50,000
ROI = $50,000 / $100,000 × 100 = 50%

This simple ROI is not an annualized return and ignores timing.

2 Benefit-cost ratio

Formula:

$$\text{BCR} = \frac{\text{Present value of benefits}}{\text{Present value of costs}}$$

Use the same discount rate, horizon, and valuation basis.

Example:

Discounted benefits = $120,000.
Discounted costs = $100,000.
BCR = $120,000 / $100,000 = 1.20

BCR > 1: quantified benefits exceed costs.
BCR = 1: quantified benefits equal costs.
BCR < 1: quantified benefits are below costs.

A larger ratio does not necessarily mean more total value.

3 Simple payback with equal cash flows

Formula:

$$\text{Payback} = \frac{\text{Initial investment}}{\text{Annual net cash inflow}}$$

Use net cash inflow, not sales revenue.

Example:

Investment = $60,000; annual net inflow = $20,000.

Payback = $60,000 / $20,000 = 3 years

4 Payback with unequal cash flows

Inputs:

Investment = $60,000.
Year 1 net inflow = $20,000.
Year 2 net inflow = $25,000.
Year 3 net inflow = $30,000.

Calculation:

Unrecovered after year 2 = $60,000 − $45,000 = $15,000

Interpolated payback = 2 + $15,000 / $30,000 = 2.5 years

This assumes year-3 cash arrives evenly. If it arrives only at year-end, recovery occurs at year 3.

5 Checks

- ☑ Simple payback ignores cash flows after recovery and the time value of money.
- ☑ Compare alternatives on a consistent scope and horizon.
- ☑ Use NPV when cash-flow timing materially affects the decision.
- ☑ Remember: recovery speed and value creation answer different questions.

Present Value & NPV

Compare future cash flows on a common value date.

1 Discount one cash flow

$$PV_t = \frac{CF_t}{(1+r)^t}$$

CF_t = net cash flow at the end of period t.
r = discount rate per period, written as a decimal.
t = number of periods from today.

Here PV means present value, not EVM planned value.

Future value: $FV_t = PV \times (1+r)^t$

2 Calculate net present value

$$NPV = CF_0 + \sum_{t=1}^{N} \frac{CF_t}{(1+r)^t}$$

CF_0 is today's net cash flow; an investment is negative.
N is the number of periods in the evaluation horizon.

- $NPV > 0$: value exceeds the required return under the assumptions.
- $NPV = 0$: the required return is just met.
- $NPV < 0$: value falls short of the required return.

3 Worked example at 10% per year

Initial investment at time 0 = −$50,000.
All later cash flows occur at year-end.

Year	Net cash flow	Divisor $(1+r)^t$	Present value
1	$22,000	1.10	$20,000
2	$24,200	1.21	$20,000
3	$26,620	1.331	$20,000

PV of future inflows = $60,000

NPV = −$50,000 + $60,000 = +$10,000

The result adds $10,000 of value at the chosen required return.

4 Connect NPV and IRR

- IRR is a discount rate that makes NPV equal zero.
- Do not add or average project IRRs.
- Cash flows with multiple sign changes can have multiple IRRs or no useful IRR.
- Use NPV and business constraints to compare feasible alternatives.

Checks

- ☑ Match monthly rates with months and annual rates with years.
- ☑ Use cash flows consistently; do not substitute accounting profit.
- ☑ Include relevant tax, working capital, and residual value assumptions.
- ☑ Keep nominal cash flows with nominal rates, and real cash flows with real rates.
- ☑ Remember: discount every future amount to the same date.

Effort, Duration & Capacity

Convert a work estimate into a realistic resource plan.

1 Keep the units separate

Effort: total person-hours needed to complete the work.

Duration: working time from start to finish.

Capacity: person-hours available per working day.

Daily capacity = People × Hours per day × Availability

$$\text{Duration} = \frac{\text{Effort}}{\text{Daily capacity}}$$

Availability is a fraction, such as 75% = 0.75.

2 Worked duration example

Example inputs:

Estimated effort = 240 person-hours.
Team = 4 people.
Working day = 8 hours.
Availability for this work = 75%.

Calculations:

Daily capacity = 4 × 8 × 0.75 = 24 person-hours/day

$$\text{Duration} = \frac{240}{24} = 10 \text{ working days}$$

These are working days, not automatically 10 calendar days.
Assume the work is divisible and people have suitable skills.

3 Calculate required staffing

Formula:

$$\text{People} = \frac{\text{Effort}}{\text{Duration} \times \text{Hours per day} \times \text{Availability}}$$

Example calculation:

To complete the same 240 hours in 5 working days:

$$\text{People} = \frac{240}{5 \times 8 \times 0.75} = 8$$

Round staffing needs up when partial people cannot be assigned.
Then check dependencies, onboarding, and coordination constraints.
Doubling headcount does not guarantee halving duration.

4 Estimate labor cost

Formula:

Labor cost = Paid hours × Loaded hourly rate

Examples:

If all 240 work hours are charged at $50/hour:
Labor cost = 240 × $50 = $12,000

If the project pays for the entire team allocation:
Paid hours = 4 × 8 × 10 = 320 hours
Allocation cost = 320 × $50 = $16,000
Choose the charging rule that matches the agreement.

✓ Checks

- ☑ Subtract leave and other commitments before promising capacity.
- ☑ Do not subtract the same availability loss twice.
- ☑ Fixed waiting time does not shrink when labor is added.
- ☑ Model specialist bottlenecks separately.
- ☑ Remember: effort is work; duration is elapsed working time.

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Productivity & Unit Cost

Connect accepted output, labor effort, and the cost of completing work.

1 The key equations

Labor productivity

$$\text{Labor productivity} = \frac{\text{Accepted units}}{\text{Labor hours}}$$

Labor hours per unit

$$\text{Labor hours per unit} = \frac{\text{Labor hours}}{\text{Accepted units}}$$

Labor cost per unit

$$\text{Labor cost per unit} = \frac{\text{Hourly labor rate}}{\text{Productivity}}$$

Total unit cost

$$\text{Total unit cost} = \text{Labor} + \text{Materials} + \text{Other cost per unit}$$

- Use comparable units and the same measurement period.
- Count person-hours, not just the crew's elapsed hours.

2 Worked production example

Given:

Accepted output = 120 units.
Labor input = 80 person-hours.
Loaded labor rate = $30 per person-hour.

Materials = $12 per unit | Other costs = $3 per unit.

Calculations:

Productivity = 120 / 80 = 1.5 units/person-hour
Hours per unit = 80 / 120 ≈ 0.667
Labor unit cost = $30 / 1.5 = $20
Total unit cost = $20 + $12 + $3 = $35
Cost for 120 units = 120 × $35 = $4,200

3 Compare with the plan

Productivity comparison:

Planned productivity = 2 units/person-hour.
Actual productivity = 1.5 units/person-hour.

$$\text{Relative productivity} = \frac{\text{Actual}}{\text{Planned}} \times 100 = \frac{1.5}{2} \times 100 = 75\%$$

Labor unit cost comparison:

Actual labor unit cost = $20.
Planned labor unit cost = $30 / 2 = $15.

Labor unit cost is $5 higher, an increase of 33.33%.

4 Forecast remaining labor

Given:

Remaining quantity = 300 comparable units.

Assume the observed productivity and hourly rate continue.

Calculations:

At actual productivity:
Hours needed = 300 / 1.5 = 200 hours
At planned productivity:
Hours needed = 300 / 2 = 150 hours
Extra hours = 50
Extra labor cost = 50 × $30 = $1,500

5 Checks

- ☑ Include rejected output and rework consistently in the definition.
- ☑ Separate learning effects, weather, and work complexity.
- ☑ A production rate measures output; it does not prove quality or business value.
- ☑ Remember: verify the unit before comparing the rate.

Team Capacity & Coordination

Check the workload and the communication structure before adding more work.

1 Measure resource loading

Resource loading formula

$$\text{Loading (\%)} = \frac{\text{Assigned work hours}}{\text{Available hours}} \times 100$$

Spare capacity formula

$$\text{Spare capacity} = \text{Available hours} - \text{Assigned work hours}$$

Key points:

- Loading above 100% indicates an over-allocation in the chosen period.
- Define whether available hours exclude leave, meetings, and other duties.

2 Worked weekly plan

Example calculation:

Three people × 40 hours = 120 gross hours.
Leave = 16 hours | Other committed duties = 8 hours.
Available project capacity = 120 − 16 − 8 = 96 hours.
Assigned project work = 108 hours.

$$\text{Loading} = \frac{108}{96} \times 100 = 112.5\%$$

Capacity shortfall = 108 − 96 = 12 hours

Take action:

- Reassign, defer, or reduce at least 12 hours of work.
- Check each person and skill; an acceptable team total can hide a specialist overload.

3 Full-time equivalents

FTE formula

$$\text{FTE} = \frac{\text{Hours in the period}}{\text{Standard full-time hours in that period}}$$

Example at a 40-hour weekly standard:

$$\text{108 hours of work} = \frac{108}{40} = 2.7 \text{ FTE}$$

$$\text{96 available hours} = \frac{96}{40} = 2.4 \text{ FTE}$$

Key points:

- FTE measures equivalent capacity, not the number of individuals.
- State the standard hours and reporting period.

4 Potential communication channels

Formula

$$\text{Channels} = \frac{n(n-1)}{2}$$

n = distinct participants who could communicate pairwise.

Examples and key points:

- For 6 people: 6 × 5 / 2 = 15 channels.
- For 8 people: 8 × 7 / 2 = 28 channels.
- Adding 2 people creates 13 additional potential pairs.
- Adding one person to an n-person group adds n potential channels.
- This counts possible undirected pairs, not meetings or actual message traffic.

Checks

- ☑ Use the same time period in every ratio.
- ☑ Do not mistake high utilization for high business value.
- ☑ Make ownership and escalation paths clear.
- ☑ Allow capacity for uncertainty rather than promising every available hour.
- ☑ Remember: staffing changes both capacity and coordination needs.

Agile Velocity & Forecasts

Use a team's own delivery history to make a conditional planning estimate.

1 Define the measure

Sprint velocity
Sum of points on items meeting the Definition of Done.

Average velocity

$$= \frac{\text{Total completed points}}{\text{Number of observed sprints}}$$

Count completed items once; do not credit unfinished work as Done.

Story points are relative estimates, not hours or universal productivity units.

Velocity is an optional planning practice, not a Scrum requirement.

2 Worked forecast

Completed points in five equal-length sprints:

18, 22, 20, 24, 16

$$\text{Average velocity} = \frac{(18 + 22 + 20 + 24 + 16)}{5}$$

$$= \frac{100}{5} = 20 \text{ points per sprint}$$

Remaining scope = 95 points.

$$\text{Estimated sprints} = \frac{\text{Remaining points}}{\text{Average velocity}}$$

$$= \frac{95}{20} = 4.75$$

Round up to 5 whole sprints for this planning estimate.
At 2 weeks per sprint: $5 \times 2 = 10$ weeks.

3 Show scenarios, not false certainty

At 16 points/sprint: $\frac{95}{16} = 5.94 \rightarrow 6$ sprints.

At 20 points/sprint: $\frac{95}{20} = 4.75 \rightarrow 5$ sprints.

At 24 points/sprint: $\frac{95}{24} = 3.96 \rightarrow 4$ sprints.

Illustrative range: 8–12 weeks at 2 weeks per sprint.

This range is not a statistical confidence interval.
The average alone does not specify an on-time probability.

4 Account for scope growth

If the backlog gains 4 comparable points each sprint:

$$\text{Net burn} = \text{Completed points} - \text{Added points}$$

$$= 20 - 4 = 16 \text{ points per sprint}$$

$$\text{Planning estimate} = \frac{95}{16} = 5.94 \rightarrow 6 \text{ sprints}$$

If additions equal or exceed delivery, the backlog will not shrink under that model.

✓ Checks

- ☑ Use comparable sprints, estimation conventions, and team conditions.
- ☑ Reforecast when scope, capacity, or the Definition of Done changes.
- ☑ Do not compare different teams by their point totals.
- ☑ Use throughput and probabilistic methods when more suitable.
- ☑ Remember: a forecast informs a conversation; it is not a guarantee.

Flow Metrics & Little's Law

Measure how work moves from a defined start point to a defined finish point.

1 Four flow measures

Work in Progress (WIP)
items started but not finished.

Throughput
items finished per unit of time.

Cycle time
elapsed time from start to finish.

Work item age
elapsed time since an unfinished item started.

- Define the workflow boundaries before collecting data.
- Do not mix request-to-delivery lead time with a narrower cycle time.

2 The average relationship

Average WIP = Average throughput × Average cycle time

$$\text{Average cycle time} = \frac{\text{Average WIP}}{\text{Average throughput}}$$

$$\text{Average throughput} = \frac{\text{Average WIP}}{\text{Average cycle time}}$$

- Use consistent units and the same workflow boundaries.
- For this practical application, use a stable system over a representative period.
- These are system averages, not a promise for an individual item.

3 Worked flow example

A stable workflow finishes 80 comparable items over 20 working days.

$$\text{Throughput} = \frac{80}{20} = 4 \text{ items/day}$$

Measured time-average WIP = 16 items.

$$\text{Average cycle time} = \frac{16}{4} = 4 \text{ working days}$$

If average WIP becomes 12 while throughput remains 4:

$$\text{Average cycle time} = \frac{12}{4} = 3 \text{ working days}$$

- This is conditional on unchanged throughput and comparable work.
- One WIP snapshot is not a time-average WIP measurement.

4 Flow efficiency and inventory

$$\text{Flow efficiency (\%)} = \frac{\text{Active work time}}{\text{Total elapsed time}} \times 100$$

Example: 6 active hours within 30 elapsed hours.

$$\text{Flow efficiency} = \frac{6}{30} \times 100 = 20\%$$

- Use the same time basis for both values.

Inventory check:

Ending WIP = Starting WIP + Started items − Finished items

- Adjust separately for cancellations and boundary changes.

Checks

- ☑ Watch blocked items and aging work, not only finished items.
- ☑ Control WIP without starving the workflow.
- ☑ Do not assume reducing WIP always leaves throughput unchanged.
- ☑ Use observed distributions or simulation for delivery confidence.
- ☑ Remember: finishing work reduces WIP; starting more work does not.

Quality: Defects, Yield & DPMO

Define what you count before comparing quality measures.

1 Defects and defective units

- A defect is one nonconformity.
- A defective unit has one or more defects.
- One unit can contain several defects.

Defective rate (%)

$$= \frac{\text{Defective units}}{\text{Inspected units}} \times 100$$

Defects per unit (DPU)

$$= \frac{\text{Total defects}}{\text{Inspected units}}$$

2 Worked inspection example

Example data:

Units inspected = 500.
Defective units = 25.
Total defects found = 40.
Defect-free units = 500 − 25 = 475.

Calculations:

Defective rate = 25 / 500 × 100 = 5%
DPU = 40 / 500 = 0.08 defects per unit

Important:

Do not report 40 defects as 40 defective units.

3 Defects per million opportunities

Formulas:

$$DPO = \frac{\text{Defects}}{\text{Units} \times \text{Opportunities per unit}}$$

$$DPMO = DPO \times 1{,}000{,}000$$

Notes:

- Use meaningful, consistent opportunity definitions.
- DPMO is not the percentage of defective units.

Example (using the same data):

Assume 5 clearly defined opportunities per unit.

Total opportunities = 500 × 5 = 2,500

DPO = 40 / 2,500 = 0.016

DPMO = 0.016 × 1,000,000 = 16,000

4 First-pass and rolled yield

First-Pass Yield (FPY)

$$= \frac{\text{Units passing without rework}}{\text{Units entering}}$$

If 475 of 500 units pass the first attempt:

$$FPY = \frac{475}{500} \times 100 = 95\%$$

Rolled Throughput Yield

Separate three-stage process:
Conditional first-pass yields = 95%, 90%, and 98%.

Rolled Throughput Yield = 0.95 × 0.90 × 0.98
= 0.8379 = 83.79%

Note: Multiply aligned stage yields as decimals, not as whole percentages.

5 Checks

- ☑ Count rework consistently; final acceptance can hide first-pass failures.
- ☑ Keep product mix, inspection coverage, and definitions comparable.
- ☑ Report severity as well as counts.
- ☑ Do not convert DPMO into a sigma level without stating the model.
- ☑ Remember: fewer defects and fewer defective units are related but different measures.

The Cost of Quality

Measure the cost of achieving quality and the cost of failing to achieve it.

1 Four cost categories

Prevention
Avoiding defects through planning, training, and process design.

Appraisal
Checking conformity through inspection, testing, and audits.

Internal failure
Defects found before delivery, such as scrap and rework.

External failure
Defects found after delivery, such as returns and warranty work.

2 Core equations

Cost of Conformance
= Prevention + Appraisal

Cost of Poor Quality
= Internal failure + External failure

Total Cost of Quality
= Cost of Conformance + Cost of Poor Quality

Use COQ for total cost of quality and COPQ for failure costs.

Do not treat the two terms as interchangeable.

3 Worked quality-cost example

Category	Cost
Prevention	$3,000
Appraisal	$2,000
Internal failure	$7,000
External failure	$8,000

Conformance cost = $3,000 + $2,000 = $5,000

COPQ = $7,000 + $8,000 = $15,000

COQ = $5,000 + $15,000 = $20,000

If total project cost for the same period is $200,000:
COQ share = $20,000 / $200,000 × 100 = 10%

4 Evaluate a prevention investment

Suppose extra prevention costs $3,000 and avoids $8,000 in failure costs over the same horizon.

Expected net saving = $8,000 − $3,000 = $5,000

Expected new COQ = $20,000 + $3,000 − $8,000 = $15,000

Simple incremental ROI = $5,000 / $3,000 × 100 ≈ 166.67%

This is a forecast; verify actual savings after implementation. Prevention spending can rise while total quality cost falls.

Checks

- ☑ Assign each cost once to a consistent category.
- ☑ Include internal labor used for rework and problem handling.
- ☑ Keep observed costs separate from estimated lost sales or goodwill.
- ☑ Compare equal periods and similar output volumes.
- ☑ Remember: inspect to detect; prevent to reduce recurrence.

Break-Even & Sensitivity

Test the sales volume needed to cover a project's commercial cost structure.

1 Define the variables

P = selling price per unit
V = variable cost per unit
F = fixed costs for the chosen period
Q = units sold during that period

Contribution per unit = $P - V$

Operating profit = $Q(P - V) - F$

Assume one product, constant unit rates, and a relevant operating range.

2 Worked break-even example

Given:

$P = \$80$ | $V = \$50$ | $F = \$24{,}000$

Contribution per unit:

$\$80 - \$50 = \$30$

Break-even units:

$$\frac{F}{(P - V)} = \frac{\$24{,}000}{\$30} = 800 \text{ units}$$

Break-even revenue:

$800 \times \$80 = \$64{,}000$

Contribution ratio:

$$\frac{P - V}{P} = \frac{\$30}{\$80} = 37.5\%$$

Alternative check:

Break-even revenue = F / Contribution ratio

$$= \frac{\$24{,}000}{0.375} = \$64{,}000$$

3 Add a target profit

$$\text{Required units} = \frac{F + \text{Target profit}}{P - V}$$

For a target operating profit of $12,000:

$$\text{Required units} = \frac{\$24{,}000 + \$12{,}000}{\$30} = 1{,}200$$

Check: $1{,}200 \times \$30 - \$24{,}000 = \$12{,}000$

Round up if the calculation gives a fractional saleable unit.

4 Sensitivity to a price reduction

A 10% price reduction changes P from $80 to $72.
Assume V stays $50 and F stays $24,000.
New contribution = $72 − $50 = $22 per unit
New break-even volume = $24,000 / $22 ≈ 1,090.91
At least 1,091 whole units are needed to avoid a loss.
At 1,200 units, profit becomes 1,200 × $22 − $24,000 = $2,400.

5 Checks

- ☑ A positive contribution margin is required for this break-even model.
- ☑ Keep fixed costs and volumes in the same period.
- ☑ Model sales mix separately for multiple products.
- ☑ Operating break-even is not the same as cash payback.
- ☑ Remember: small price changes can create large volume requirements.

Putting the Formulas Together

Use one consistent project snapshot to calculate status, forecast, and recovery needs.

1 The project snapshot

BAC = $150,000 | PV = $60,000
EV = $45,000 | AC = $50,000

All values use the same approved scope, baseline, currency, and status date.

BAC: total performance budget.
PV: scheduled budgeted work.
EV: completed budgeted work.
AC: incurred cost.

2 Diagnose current performance

$$CV = EV - AC = \$45{,}000 - \$50{,}000 = -\$5{,}000$$

$$SV = EV - PV = \$45{,}000 - \$60{,}000 = -\$15{,}000$$

$$CPI = \frac{EV}{AC} = \frac{\$45{,}000}{\$50{,}000} = 0.90$$

$$SPI = \frac{EV}{PV} = \frac{\$45{,}000}{\$60{,}000} = 0.75$$

$$\text{Earned progress} = \frac{EV}{BAC} \times 100 = 30\%$$

$$\text{Budget spent} = \frac{AC}{BAC} \times 100 \approx 33.33\%$$

- Cost exceeds the budgeted value of completed work.
- Only 75% of the scheduled budgeted work has been earned.
- The schedule variance is in money, not days.

3 Forecast assuming CPI continues

$$EAC = \frac{BAC}{CPI} = \frac{\$150{,}000}{0.90} \approx \$166{,}666.67$$

$$ETC = EAC - AC \approx \$116{,}666.67$$

$$VAC = BAC - EAC \approx -\$16{,}666.67$$

Forecast overrun ≈ 11.11% of BAC

Budgeted work remaining:
BAC − EV = $105,000

Carry full precision through calculations; round reported money at the end.

4 Test a recovery target

To finish at BAC:

$$TCPI_{BAC} = (\$150{,}000 - \$45{,}000) / (\$150{,}000 - \$50{,}000)$$
$$= \$105{,}000 / \$100{,}000 = 1.05$$

To finish at the selected EAC:

$$TCPI_{EAC} = \$105{,}000 / \$116{,}666.67 \approx 0.90$$

The original budget needs future efficiency of 1.05, compared with 0.90 achieved so far.

Action notes

- ☑ Investigate cost drivers and critical-path delays.
- ☑ Validate the remaining estimate and proposed recovery actions.
- ☑ Report assumptions alongside the forecast.

Remember: calculate, interpret, then decide.

Your Formula Quick-Reference

Use this index after checking the assumptions on each referenced page.

1 Progress & cost control — pages 01–06

$$\text{Earned progress (\%)} = \frac{EV}{BAC} \times 100$$

$$CV = EV - AC \quad | \quad SV = EV - PV$$

$$CPI = \frac{EV}{AC} \quad | \quad SPI = \frac{EV}{PV}$$

$$EAC = \frac{BAC}{CPI}$$ when current cost efficiency continues

$$ETC = EAC - AC \quad | \quad VAC = BAC - EAC$$

$$TCPI_{BAC} = \frac{BAC - EV}{BAC - AC}$$

BAC: budget | EV: earned value | AC: actual cost
PV: planned value | EAC: total cost forecast
See page 03 for alternative EAC assumptions.

2 Time & uncertainty — pages 07–12

$$\text{PERT mean} = \frac{O + 4M + P}{6}$$

$$\text{PERT standard deviation} \approx \frac{P - O}{6}$$

O: optimistic | M: most likely | P: pessimistic

$$\text{Total float} = LS - ES = LF - EF$$

LS/ES: late/early start | LF/EF: late/early finish

$$\text{Crash slope} = \frac{\text{Extra cost}}{\text{Time saved}}$$

$$EMV = \text{Sum of (Probability} \times \text{Monetary outcome)}$$

3 Value, people & flow — pages 13–19

$$\text{Simple ROI (\%)} = \frac{\text{Benefits} - \text{Costs}}{\text{Costs}} \times 100$$

$$\text{Present value} = \frac{\text{Future cash flow}}{(1 + r)^t}$$

r: discount rate per period | t: number of periods

$$\text{Duration} = \frac{\text{Effort}}{\text{Daily resource capacity}}$$

$$\text{Productivity} = \frac{\text{Accepted units}}{\text{Labor hours}}$$

$$\text{Potential communication channels} = \frac{n(n-1)}{2}$$

n: number of distinct participants

$$\text{Estimated sprints} = \frac{\text{Remaining points}}{\text{Average velocity}}$$

$$\text{Average cycle time} = \frac{\text{Average WIP}}{\text{Average throughput}}$$

4 Quality & commercial results — pages 20–23

$$DPMO = \frac{\text{Defects}}{\text{Total opportunities}} \times 1{,}000{,}000$$

Total opportunities = Units × Opportunities per unit

$$COQ = \text{Prevention} + \text{Appraisal} + \text{Internal failure} + \text{External failure}$$

$$\text{Break-even units} = \frac{\text{Fixed costs}}{\text{Contribution per unit}}$$

Contribution per unit = Selling price − Variable unit cost

Page 23: integrated performance and forecast example.

5 Before using any result

- ☑ Confirm units, scope, dates, denominator, and assumptions.
- ☑ Keep full precision; round only the reported answer.
- ☑ A forecast is conditional, not guaranteed.

Reference foundations

PMI: earned value, scheduling, risk, and communication.
OpenStax: financial appraisal and break-even.
ASQ: quality measures and quality costs.
Scrum.org and ProKanban: team planning and flow.