QUANTIL

Probabilistic risk and project management

The Risk Profile Probabilistic cost and risk analysis

Cascade Highway Tunnel

Project	Cascade Highway Tunnel
Project number	CHT-2026-001
Client	Ostrevale Regional Transportation Authority
Estimate phase	Detailed engineering (class 2)
Currency	USD
Price date	2026-06-01
Report date	2026-11-07
Prepared by	Generated with the Quantil Quantitative Risk-Cost Integration Model
Document status	Final
Version	1.0
Classification	Public sample

This is a public sample of a Quantil report. The project is fictitious and the figures are illustrative.

Table of contents

1. Executive Summary 4
2. Background and Scope 5
3. Approach in Brief 5
4. Results 6
5. Risk analysis: where the uncertainty sits 8
6. Contingency recommendation 10
7. Scenario comparison 10
8. Assumptions and basis 11
9. Conclusion and recommendation 11
Appendix A. Cost register 13
Appendix B. Risk register 13
Appendix C. Assumptions log 14
Appendix D. Correlation matrix 15
Appendix E. Input quality assessment 16
Appendix F. Scenario comparison 17
Appendix G. Reference projects (benchmarks) 18

About this report

This report translates the uncertainty in your cost estimate into a substantiated, defensible reserve. The analysis was performed with a probabilistic Monte Carlo simulation within the AACE framework. The calculation engine has been independently validated (see the separate validation note). Appendices C through G present the substantiation: assumptions, correlations, input quality, scenarios and benchmarks.

1. Executive Summary

In brief. The base estimate of this project is USD 416.00 million. Based on the probabilistic analysis, we recommend budgeting at the P85 level: USD 515.26 million. This means that the actual cost will, with approximately 85% probability, come in at or below this amount.

The substantiated contingency thereby comes to USD 99.26 million (23.9% of the base estimate). This is not a rule-of-thumb allowance, but an amount derived from the simulation that reflects the real uncertainty and correlation in your project.

USD 416.00 million	USD 476.11 million	USD 515.26 million	USD 99.26 million
Base estimate	P50 (median)	P85 (budget recommendation)	Contingency

Uncertainty range. The analysis places the expected project cost with 80% probability between USD 433.87 million (P10) and USD 524.58 million (P90). That range of approximately USD 90.71 million is the actual uncertainty that must be taken into account in decision-making.

The three biggest drivers of the uncertainty (where management action pays off most) are:

- **Cost item: CIV.300: Bored tunnel, TBM & lining rings**
- **Risk event: Risk R-001: TBM jam / face collapse in the bore**
- **Cost item: TTI.500: Tunnel technical installations (TTI)**

Recommendation
Budget at P85 (USD 515.26 million) and hold the associated management reserve. Focus risk management initially on the three drivers listed above. See chapter 6 for the full contingency recommendation.

2. Background and Scope

This Risk Profile was prepared to quantify the uncertainty around the cost estimate of this project and to translate it into a substantiated reserve. The trigger is the need for a defensible budget that holds up before the board, the auditor or the regulator.

Calculated: 12 cost items with uncertainty ranges, 8 discrete risks and the associated schedule activities, including the correlation between the cost items. Estimate phase: Detailed engineering (class 2). Base date: 2026-06-01.

Out of scope: the substantive correctness of the estimate provided and the assumptions chosen. The reliability of the outcome is only as good as the quality of the input; the data provided were checked for internal consistency and known input errors.

3. Approach in Brief

Instead of calculating with a single estimate figure, the analysis simulates thousands of possible outcomes. Each cost item receives a three-point estimate (minimum, most likely, maximum); the correlation between items is captured in a correlation matrix. On top of that, a overlay of discrete risks (probability x impact) and schedule delay (delay x daily rate).

The thousands of simulated scenarios yield a probability distribution of the total project cost. Its percentiles (P50, P85, P90) form the basis for the budget and reserve recommendation. The method follows the AACE Total Cost Management framework; the calculation engine has been independently validated.

How to read a P-value
P85 = USD 515.26 million means: in 85 of 100 simulated scenarios the costs remain at or below this amount. The higher the chosen percentile, the greater the confidence and the higher the required reserve.

4. Results

The table below shows the project cost at the various confidence levels.

Metric	Value
P10 (optimistic)	USD 433.87 million
P25	USD 452.69 million
P50 (median)	USD 476.11 million
P75	USD 501.54 million
P80 (bid level)	USD 507.67 million
P85 (management reserve)	**USD 515.26 million**
P90 (contingency ceiling)	USD 524.58 million
P95 (extreme downside)	USD 539.77 million

In addition: expected value USD 478.16 million, spread (standard deviation) USD 35.09 million, coefficient of variation 7.3%. The distribution is slightly right-skewed (skewness 0.30), which is normal for project costs: overruns happen more often than underruns.

Interpretation: the difference between the base estimate (USD 416.00 million) and the P85 outcome (USD 515.26 million) is the contingency required to reach 85% confidence. The right tail beyond P90 reflects risks with low probability but high impact: monitor, but not necessarily reserve for in full.

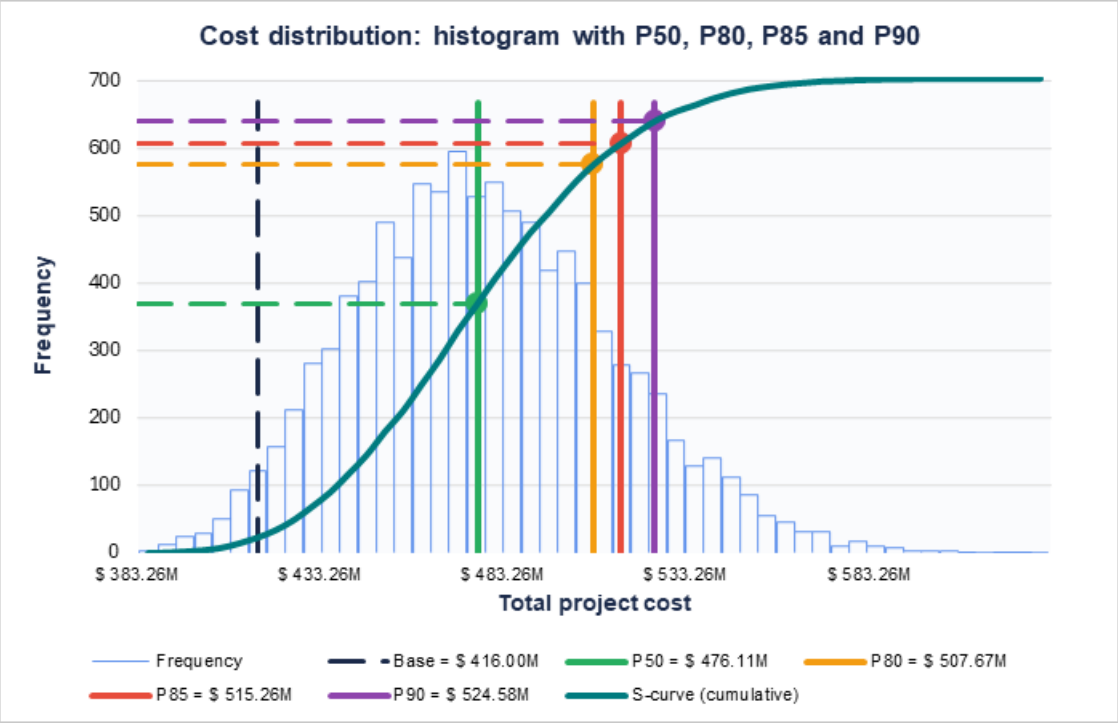


Figure 1. Cost distribution (histogram with P50 / P80 / P85 / P90).

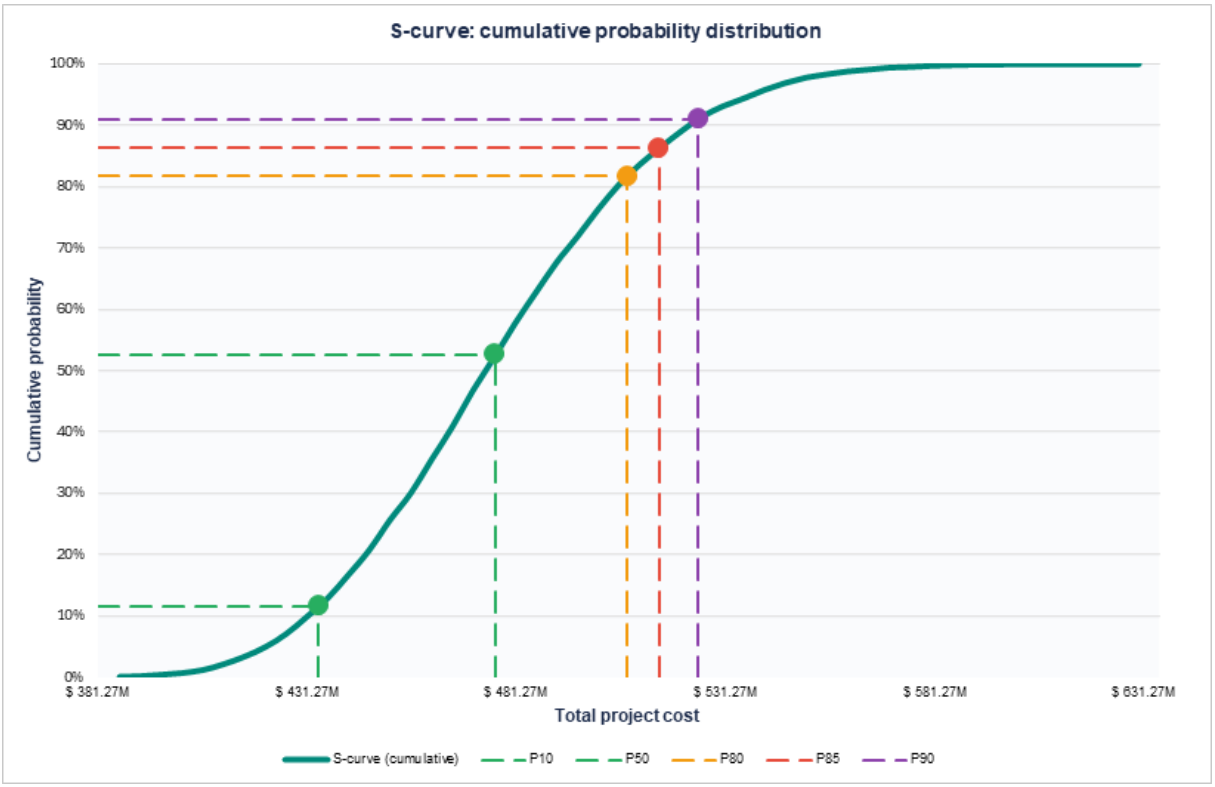


Figure 2. S-curve: which budget gives which confidence.

Reading the S-curve. For each budget amount, the S-curve shows the probability that the actual project cost comes in at or below it. You read it as follows: on the vertical axis, choose the confidence level that fits your risk appetite, follow the line to the right, and read the corresponding budget on the horizontal axis. The steeper the curve, the more concentrated the possible outcomes; the flatter and longer the right tail, the greater the chance of a large outlier.

For this project: at P50 (USD 476.11 million) the probability of overrun is still 50%: too tight as a control budget. At P85 (USD 515.26 million) a 15% probability of overrun remains, a common and defensible level for the budget request. The difference between the two is the amount you hold as a reserve. Above P90 the curve flattens: extra budget buys less and less additional confidence there, which indicates that fully covering the extreme tail is generally not cost-effective.

5. Risk analysis: where the uncertainty sits

The tornado analysis ranks the cost items by their contribution to the total uncertainty. The top items account for most of the spread; that is where risk management pays off the most.

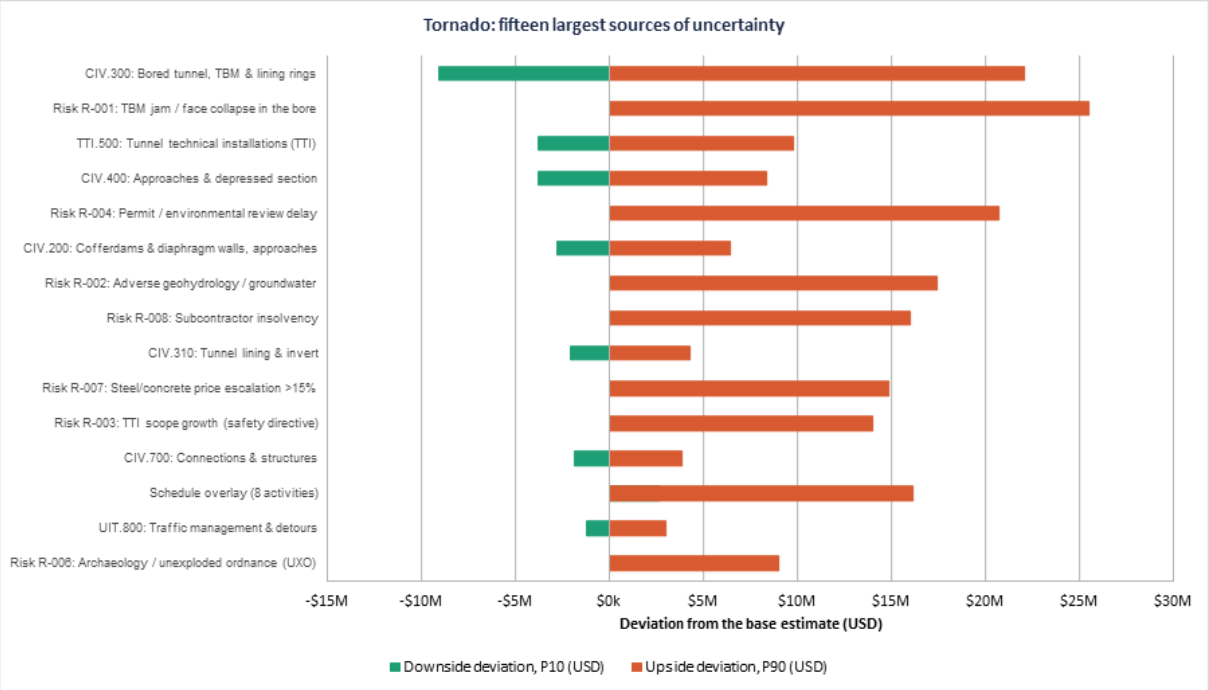


Figure 3. Tornado: largest drivers of the uncertainty.

Recommended attention, in order of importance:

- **Cost item: CIV.300: Bored tunnel, TBM & lining rings:** secure the estimate and mitigation measures for this item; it is a major driver of your reserve.
- **Risk event: Risk R-001: TBM jam / face collapse in the bore:** secure the estimate and mitigation measures for this item; it is a major driver of your reserve.
- **Cost item: TTI.500: Tunnel technical installations (TTI):** secure the estimate and mitigation measures for this item; it is a major driver of your reserve.
- **Cost item: CIV.400: Approaches & depressed section:** secure the estimate and mitigation measures for this item; it is a major driver of your reserve.
- **Risk event: Risk R-004: Permit / environmental review delay:** secure the estimate and mitigation measures for this item; it is a major driver of your reserve.

Risk matrix: spread of the risks

In addition to the cost drivers, the individual risk events have been placed in a five-by-five matrix based on probability and impact. The overview below shows how many risks fall in each tolerance band.

Risk level	Count
Critical (score 20-25)	2
High (score 10-16)	6
Medium (score 5-9)	0
Low (score 1-4)	0
Total active risks	**8**

Which risks require attention first

The risks below fall in the critical or high band. These are the risks on which the steering committee first assigns a mitigation measure with an owner and a deadline.

Risk	Category	Probability	Impact		Level
R-002: Adverse geohydrology / groundwater	Technical	40.0%	USD 12.00 million		**Critical**
R-007: Steel/concrete price escalation >15%	Market	40.0%	USD 10.00 million		**Critical**
R-003: TTI scope growth (safety directive)	Technical	45.0%	USD 9.00 million		**High**
R-005: Unforeseen utilities (locate records)	Technical	50.0%	USD 5.00 million		**High**
R-001: TBM jam / face collapse in the bore	Technical	30.0%	USD 18.00 million		**High**
R-004: Permit / environmental review delay	External	35.0%	USD 14.00 million		**High**
R-006: Archaeology / unexploded ordnance (UXO)	External	25.0%	USD 7.00 million		**High**
R-008: Subcontractor insolvency	Commercial	15.0%	USD 16.00 million		**High**

Reading. The matrix focuses attention: 2 risks fall in the critical band and 6 in the high band. Together they account for most of the exposure. The full placement of each risk and the average risk score are on the RISK_MATRIX tab.

6. Contingency recommendation

The core of this report: how much should you reserve, and how does that compare to a traditional allowance?

Metric	Value
A. Base estimate (deterministic)	USD 416.00 million
B. Deterministic contingency (rule of thumb)	USD 51.26 million
C. Deterministic budget (A+B)	USD 467.26 million
D. Probabilistic contingency (P85 - A)	**USD 99.26 million**
E. Management reserve (P85 - C)	**USD 48.00 million**
F. Risk overlay (EMV of discrete risks)	USD 29.80 million
G. Total exposure at P85 (A+D)	**USD 515.26 million**

What this means. A traditional rule-of-thumb allowance would amount to USD 51.26 million (12.3%). The probabilistic analysis shows that a substantiated reserve USD 99.26 million (23.9%) is required: a difference of USD 48.00 million. That difference is precisely the value of this analysis: it prevents both a buffer that is too low (with overrun risk) and a buffer that is too high (with capital tied up unnecessarily).

Budget recommendation

Request a budget at P85: USD 515.26 million. Hold the management reserve (USD 48.00 million) at executive level, to be released only on demonstrated need. Within the organization, use the deterministic budget as the working budget and escalate for access to the reserve.

7. Scenario comparison

In addition to the base run, the analysis shows how the budget moves under an optimistic and a pessimistic scenario. This shows you not only the expected picture, but also the range within which your budget may land if conditions turn out favorable or adverse.

Cost metric	Optimistic	Base	Pessimistic
Base estimate (adjusted)	USD 403.52 million	USD 416.00 million	USD 436.80 million
P50 total cost	USD 447.24 million	USD 476.11 million	USD 517.06 million
P85 total cost	**USD 483.44 million**	**USD 515.26 million**	**USD 561.09 million**
P90 total cost	USD 492.06 million	USD 524.58 million	USD 571.58 million
Probabilistic reserve	USD 79.92 million	USD 99.26 million	USD 124.29 million
Risk events (EMV, included in the P85)	USD 20.86 million	USD 29.80 million	USD 38.74 million

How to read this. The base scenario is your reference. The optimistic scenario assumes more favorable conditions (less spread, lower risk probabilities, moderate escalation); the pessimistic scenario assumes the opposite. At P85 the required budget moves between USD 483.44 million (optimistic) and USD 561.09 million (pessimistic), with USD 515.26 million as the base. That range makes visible how sensitive your budget is to conditions, and helps you decide which confidence level is appropriate.

Why this matters

The scenario comparison shows that budget certainty is not a given but depends on assumptions that you can name and manage. By knowing the difference between optimistic and pessimistic, you can target the factors that move your budget the most, instead of defending a single number as if it were fixed.

8. Assumptions and basis

- Cost uncertainty is modeled with Beta-PERT distributions (shape factor lambda = 4) on the three-point estimates provided.
- Correlation between cost items is incorporated through a correlation matrix and Cholesky-correlated sampling.
- Discrete risks are included as an overlay (probability x impact range), separated from the cost uncertainty to avoid double counting.
- Schedule delay is translated into cost as delay times daily rate, at activity level.
- The simulation was run with a large number of iterations; the reported percentiles are statistically stable.

Transparency. The full calculation is open in the workbook and traceable. The calculation engine has been independently validated; the validation note is supplied with the tool.

Verification of the calculation engine

The calculation engine is tested with a built-in verification suite that checks the mathematical correctness of the simulation. The results below come directly from the tool.

Test	What it tests	Tolerance	Result
Mean of the Beta-PERT	Draw 100,000 values from Beta-PERT(10, 20, 50, lambda 4). The measured mean should equal the analytical mean of 23.33.	±0.09	PASS
Variance of the Beta-PERT	The measured variance should equal the analytical variance of the same Beta-PERT.	±2%	PASS
Reproduction of the correlation via Cholesky	Draw 10,000 correlated values from a known 3x3 matrix. The measured correlation should equal the input correlation.	±0.04	PASS
Hit rate of a risk event	A risk with a probability of 30% should occur in about 30% of the 10,000 iterations.	±1.8%	PASS
Reproducibility and known-answer of the generator	Two series with the same seed should be identical, and the generator should give the published value 0.127011122046577 from L'Ecuyer's default state (known-answer).	Exact	PASS
Validity of the correlation matrix	The correlation matrix entered on the CORRELATION sheet is tested for validity. If the combination is impossible, this check fails and the engine warns before the run.	Boolean	PASS
Increasing P-values	The percentiles from the latest run should be ascending: P10 < P25 < P50 < P75 < P80 < P85 < P90 < P95. A distribution function cannot decrease. If the simulation has not been run yet, this check is skipped and does not count.	Boolean	PASS

What this means. All seven engine tests passed. The tests check the mathematical correctness of the calculation engine: the distributions, the correlation, the reproducibility and the ordering of the percentiles. Last run: 2026-08-29 12:27:18. Engine: modMonteCarlo_v3 v3.1 | MRG32k3a (L'Ecuyer 1999), Quantil modQuantilRandom v1.0.

9. Conclusion and recommendation

We recommend budgeting this project at the P85 level of USD 515.26 million, with a substantiated contingency of USD 99.26 million (23.9%). Subject to the assumptions in chapter 8, this gives a defensible, numerically substantiated budget on which governance decisions can rely.

Specific recommendations:

1. Set the project budget at P85 (USD 515.26 million) and formally record the contingency of USD 99.26 million in the business case.
2. Focus risk management in the first quarter on the three largest drivers: CIV.300: Bored tunnel, TBM & lining rings, Risk R-001: TBM jam / face collapse in the bore and TTI.500: Tunnel technical installations (TTI). Secure the estimate and the mitigation measures here, because these items account for most of the uncertainty.
3. Manage the management reserve (USD 48.00 million) at executive level, separate from the working budget, and release it only on demonstrated need.
4. Repeat the probabilistic analysis at the next estimate milestone or as soon as a top risk materializes, so that the budget tracks the current uncertainty.

Key message for the steering committee

A traditional allowance does not cover the uncertainty of this project; the figures call for a reserve of 23.9%. With a budget at P85 (USD 515.26 million) and targeted control of the three largest drivers, the project can be delivered within budget with 85% confidence.

Appendix A. Cost register

Code	Description	Minimum	Most likely	Maximum
CIV.100	Preparation & engineering (FEED/final design)	USD 16.56 million	USD 18.00 million	USD 21.96 million
CIV.200	Cofferdams & diaphragm walls, approaches	USD 36.96 million	USD 42.00 million	USD 56.28 million
CIV.300	Bored tunnel: TBM & lining rings	USD 101.48 million	USD 118.00 million	USD 167.56 million
CIV.310	Tunnel lining & invert	USD 30.26 million	USD 34.00 million	USD 43.52 million
CIV.400	Approaches & depressed section	USD 51.04 million	USD 58.00 million	USD 76.56 million
TTI.500	Tunnel technical installations (TTI)	USD 39.10 million	USD 46.00 million	USD 68.08 million
CIV.600	Pavement, markings & finishing	USD 20.24 million	USD 22.00 million	USD 25.96 million
CIV.700	Connections & structures	USD 24.64 million	USD 28.00 million	USD 36.40 million
UIT.800	Traffic management & detours	USD 13.76 million	USD 16.00 million	USD 22.72 million
UIT.810	Site setup, utility locates & conditioning	USD 10.56 million	USD 12.00 million	USD 16.56 million
IND.900	Project management & supervision	USD 12.88 million	USD 14.00 million	USD 17.36 million
IND.910	Permits, damage compensation	USD 6.64 million	USD 8.00 million	USD 12.40 million

Appendix B. Risk register

ID	Risk	Probability	Impact (ML)
R-001	TBM jam / face collapse in the bore	30.0%	USD 18.00 million
R-002	Adverse geohydrology / groundwater	40.0%	USD 12.00 million
R-003	TTI scope growth (safety directive)	45.0%	USD 9.00 million
R-004	Permit / environmental review delay	35.0%	USD 14.00 million
R-005	Unforeseen utilities (locate records)	50.0%	USD 5.00 million
R-006	Archaeology / unexploded ordnance (UXO)	25.0%	USD 7.00 million
R-007	Steel/concrete price escalation >15%	40.0%	USD 10.00 million
R-008	Subcontractor insolvency	15.0%	USD 16.00 million

Appendix C. Assumptions log

For each assumption, the basis on which it rests is recorded. This makes the origin of the entered figures traceable and verifiable.

ID	CBS	Assumption	Category	Source / basis	Validated
A-001	CIV.100	Engineering scope per the FEED/final design package, with 15% allowance for design growth in the tunnel detailing	Scope	Deliverable from the engineering partner, rev. 3.2, February 2026	2026-02-15
A-002	CIV.300	Price of steel and concrete for the tunnel segments based on the Q1 2026 spot price plus an 8% procurement premium	Market	Supplier quotation for segment steel, valid until 2026-06-30	2026-03-10
A-003	CIV.300	Tunnel length and number of rings per the approved alignment, version 2.1	Scope	Approved route decision, alignment v2.1	2026-01-20
A-004	CIV.310	Single-pass tunnel lining; quantities for the secondary lining per the geotechnical baseline report	Technical	Client technical requirements, rev. 4	2026-02-28
A-005	CIV.400	Length and depth of the approaches per the geohydrological investigation of Q3 2025	Technical	Geohydrological investigation report, 2025	2025-11-15
A-006	CIV.200	Unit rates for diaphragm walls and excavation based on the US civil contractor market 2026	Market	Market consultation with diaphragm wall contractors, December 2025	2025-12-20
A-007	CIV.300	TBM advance rate and ground workability assumed at 65% of theoretical capacity	Schedule	Geotechnical investigation report with borehole logs along the alignment	2026-01-10
A-008	TTI.500	Scope of the tunnel technical installations per the current safety directive, without extra redundancy	Technical	National tunnel safety standard, 2024 edition	2025-09-30
A-009	IND.900	Project management and supervision at 3.4% of direct costs, based on in-house metrics	Commercial	In-house project database, comparable Class 2 infrastructure projects	2026-03-01
A-010	General	Base currency US dollar; no currency risk assumed on the domestic civil scope	Market	Forward exchange rate as of 2026-03-15; hedging strategy still to be determined	2026-03-15
A-011	General	No scope changes after award; change orders are priced separately	Commercial	Project charter v1.0, article 4.2	2026-01-15
A-012	General	Inflation of 2.5% per year applied to the 2027-2028 expenditure profile	Market	CBO medium-term projection, March 2026	2026-03-20

Appendix D. Correlation matrix

The correlation matrix records which cost items move together. Correlation is the largest lever on the tail of the distribution and therefore on the reserve; this matrix shows which correlation has been incorporated in the analysis.

	CIV.100	CIV.200	CIV.300	CIV.310	CIV.400	TTI.500	CIV.600	CIV.700	UIT.800	UIT.810	IND.900	IND.910
CIV.100	1.00	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
CIV.200	0.35	1.00	0.65	0.65	0.65	0.65	0.35	0.35	0.35	0.35	0.35	0.35
CIV.300	0.35	0.65	1.00	0.65	0.65	0.65	0.35	0.35	0.35	0.35	0.35	0.35
CIV.310	0.35	0.65	0.65	1.00	0.65	0.65	0.35	0.35	0.35	0.35	0.35	0.35
CIV.400	0.35	0.65	0.65	0.65	1.00	0.65	0.35	0.35	0.35	0.35	0.35	0.35
TTI.500	0.35	0.65	0.65	0.65	0.65	1.00	0.35	0.35	0.35	0.35	0.35	0.35
CIV.600	0.35	0.35	0.35	0.35	0.35	0.35	1.00	0.65	0.65	0.65	0.35	0.35
CIV.700	0.35	0.35	0.35	0.35	0.35	0.35	0.65	1.00	0.65	0.65	0.35	0.35
UIT.800	0.35	0.35	0.35	0.35	0.35	0.35	0.65	0.65	1.00	0.65	0.35	0.35
UIT.810	0.35	0.35	0.35	0.35	0.35	0.35	0.65	0.65	0.65	1.00	0.35	0.35
IND.900	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	1.00	0.65
IND.910	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.65	1.00

Values between 0 (independent) and 1 (fully correlated). The diagonal is 1 by definition.

Appendix E. Input quality assessment

A probabilistic result is only as reliable as its input. The assessment below gives an objective indication of the quality of the data provided.

Dimension	Score	Threshold	Status	Weight
Anchoring effect in the ranges	100	>= 70	PASS	20
Completeness of the correlations	100	>= 50	PASS	15
Coverage of the risk register	50	>= 60	REVIEW	15
Depth of the schedule integration	100	>= 60	PASS	15
Recording of the assumptions	100	>= 80	PASS	15
Fit with the estimate class	60	>= 70	REVIEW	20
Sum of the weighting factors (the composite score is at top left)				100

Appendix F. Scenario comparison

In addition to the probabilistic analysis, three scenarios (optimistic, base, pessimistic) placed side by side, so that the sensitivity to the assumptions is visible.

Parameter	Optimistic	Base	Pessimistic
Scenario name	Smooth execution	Reference	Adverse conditions
Factor on uncertainty (min)	0.95	1	1.1
Factor on uncertainty (max)	0.9	1	1.15
Factor on risk probabilities	0.7	1	1.3
Factor on schedule delay	0.6	1	1.5
Market escalation (%)	-0.03	0	0.05

Appendix G. Reference projects (benchmarks)

The rows below are the illustrative example data supplied with the workbook. They are not validated reference projects and must not be read as a benchmark of this project. Replace them on the BENCHMARKS sheet with your own comparable projects, with source and year.

Source	Year	Region	Type	CAPEX (USD)	Civil %
Illustrative reference A (example data)	2024	NW Europe	Bored highway tunnel	420,000,000	70%
Illustrative reference B (example data)	2024	Europe	Urban tunnel with approaches	480,000,000	68%
Illustrative reference C (example data)	2023	Global	Highway tunnel	360,000,000	72%
Illustrative reference D (example data)	2024	Netherlands	Immersed or bored tunnel	450,000,000	69%

This report was generated with the Quantil report generator based on the simulated QRCIM workbook. No rights can be derived from this report; see the disclaimer.