TRANSPORT AND INFRASTRUCTURE COUNCIL

Australian Transport Assessment and Planning Guidelines

O1 Cost Estimation

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At a glance

- Cost estimation is one of the critical components of transport assessment and planning. It is therefore imperative that these estimates are robust and consistent
- The primary source of guidance on cost estimation in Australia is the Cost Estimation Guidance Notes published by the Australian Government Department of Infrastructure, Regional Development and Cities (2018)
- This document provides a high level overview of key concepts in cost estimation (reflecting the Department's Guidance Notes) as a basic introduction for ATAP Guidelines users
- A project cost estimate comprises three core components:
  - The base estimate: The sum of construction and client costs. First principles estimating is the preferred approach for deriving base estimates
  - The contingency allowance: It can be estimated using either deterministic or probabilistic estimation methods
  - An escalation allowance: This takes into account the changes in costs for the period from the base date of the estimate (the date that the estimate was prepared) to the completion of construction
- Good estimates are accurate, well calibrated, unbiased, provided with supporting documentation and reliable. They should be based on good judgement, good process and good data
- The purpose of an estimate should be clearly stated and reflect the stage of development of the initiative. The required level of accuracy will vary with the stage of project development, with smaller margins of error the more advanced an initiative's development
- In cost–benefit analyses, costs should: reflect opportunity cost (including for land and property); be expressed in real terms; include only cost elements that will be incurred after the decision to proceed with an initiative

1. Introduction

The primary source of guidance on cost estimation in Australia is the Cost Estimation Guidance Notes published by the Australian Government Department of Infrastructure, Regional Development and Cities (2018a).

The ATAP Guidelines do not seek to give detailed guidance on cost estimation. Instead, they adopt and promote use of the Department's guidance.

Use of the Australian Government cost estimation guidelines is required under its Notes on Administration (Department of Infrastructure and Regional Development, 2018b) that govern national funding of land transport projects across Australia. Their use is also required by Infrastructure Australia (IA, 2018). They build on earlier published guidelines (e.g. Department of Infrastructure and Regional Development, 2011).

In the above context, the notes in this document provide a high level overview of key concepts in cost estimation (reflecting the Department's Guidance Notes) as a basic introduction for ATAP Guidelines users.

Context

Cost estimation is one of the critical components of transport assessment and planning. It is therefore imperative that these estimates are robust and consistent.

Cost estimates are required in a range of situations including: policy and strategic planning; rapid and detailed appraisal of initiatives; cost–benefit analysis; funding deliberations; budgeting; and contract negotiation and administration in delivery of initiatives.

The level of precision required to estimate the cost of an initiative will depend on the stage of assessment and planning. Early on, indicative estimates are often sufficient. As one progresses through the assessment and planning processes, the required level of accuracy increases. By the time an initiative is ready to be delivered, highly accurate cost estimates should have been developed, accompanied by sufficient supporting information and detail.

The focus here is on estimation of capital costs of initiatives. Guidance on estimating operating and maintenance costs is provided elsewhere in the Guidelines (see Chapter 5 of Part T2 in relation to cost–benefit analysis; and in relation to individual modes see the Mode-Specific category - for example, chapter 5 in part M1 for public transport).

2. Brief overview of cost estimation

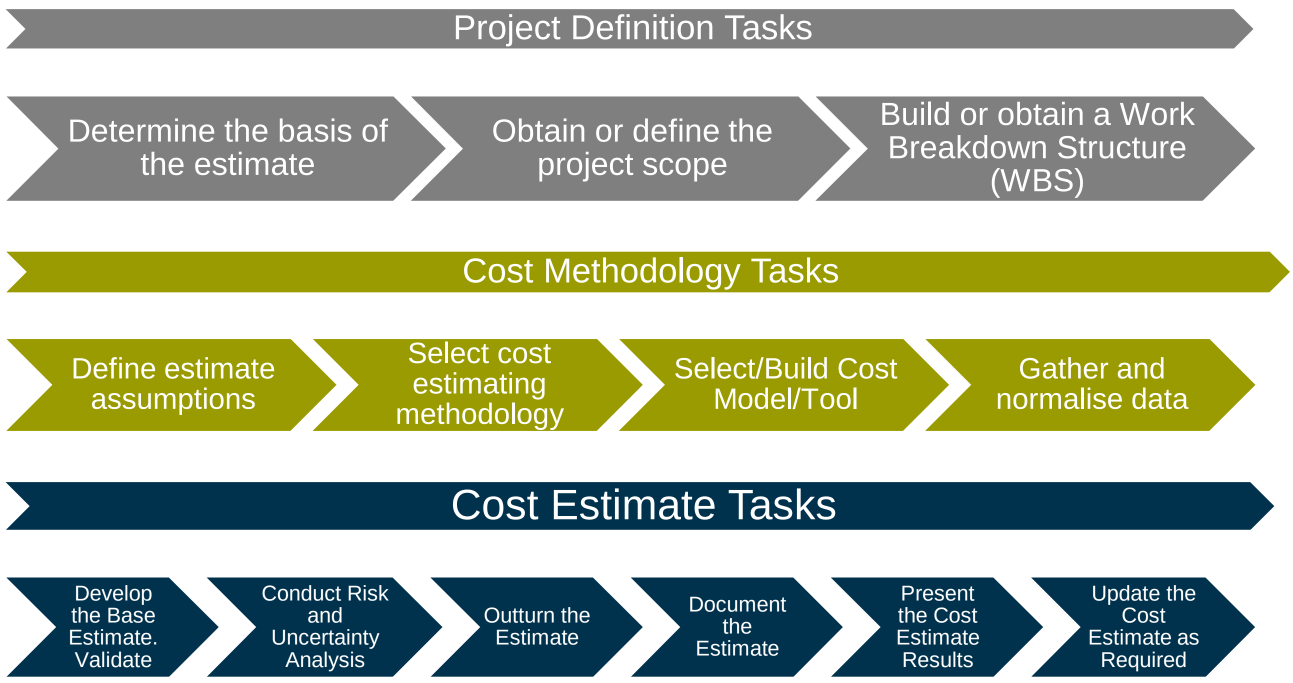
Capital cost estimates are central to establishing the basis for key decisions about initiatives, for establishing the metrics against which the success of initiatives will be measured and for communicating the status of an initiative at any given point in time (US Department of Transport, 2007). Best practice in cost estimation throughout each phase of an initiative will lead to efficient use of scarce public resources and help mitigate the risk of cost overruns. It also provides increased certainty for public sector organisations, governments, and the public to whom government agencies are accountable.[1]

Best practice should consist of an overall cost estimating process:

- Of established, repeatable methods of assessing project risks and determining input quantities
- That result in high-quality cost estimates that are comprehensive and as accurate as possible, and can be easily and clearly traced, replicated and updated.

The cost estimating process is shown schematically in Figure 1 below. Note that for convenience the process is described as a series of successive steps. In practice, it is often an iterative, non-linear process.

Figure 1 The cost estimation process



Source: Adapted from United States Government Accountability Office (2009) and NASA (2015)

[1] Risk mitigation factors used in developing the cost estimate should be replicated and effectively reflected in the actual contracts signed by contractors. Risk mitigation factors should not be left as a residual risk which has not been either transferred to the contractor or specifically accounted for with a migration plan put in place as part of the project brief.

2.1 Components of an estimate

A project cost estimate itself comprises three core components:

- The Base Estimate
- A Contingency Allowance, and
- An Escalation Allowance.

2.1.1 The Base Estimate

The Base Estimate is the *sum* of the Construction Costs and Client's Costs.

Construction costs are the costs required to plan and complete the tasks or activities associated with the construction elements of an initiative. They include: direct and indirect costs, for example, preliminaries and supervision, earthworks, pavements and drainage.

Client costs are the costs incurred by the proponent (for example a public sector agency) to develop and deliver an initiative: project management, design and investigation, client specified insurances, fees, levies, land and property acquisition.

For initiatives where the scope is sufficiently defined, and in particular for high value initiatives, the Base Estimate is typically estimated using a methodology known as *First Principles Estimating:*

- *First principles estimating* involves the calculation of project-specific costs based on a detailed study of the resources required (plant, labour, material and subcontractors) to accomplish each activity of work contained within the project's work breakdown structure (WBS). Productivity assumptions are applied to all labour and plant costs with adjustments made to account for unique or unusual site characteristics.

First principles estimation method is preferred to other base estimate approaches, including:

- *Unit rate estimating* which calculates the quantity of each item of the initiative by multiplying the quantity of work by historical unit rates obtained from previous initiatives. While a relatively quick method of estimating, unlike a first principles estimate, it lacks precision. Since each initiative has unique constraints and requirements, such an approach contains inherent inaccuracies because factors and allowances developed for a previous initiative (that might not be applicable to the initiative being estimated) will be applied within the unit rate; and
- *Global estimating* which is a method of estimating involving the use of 'all in' or 'global' composite rates such as road cost per kilometre. While less satisfactory for more developed initiatives, this method may be appropriate at the very early stage of an initiative when the scope is not sufficiently defined to enable a first principles estimate to be developed.

2.1.2 Contingency allowance

Cost estimation is not a precise science – it involves risks and uncertainties. A Contingency Allowance estimates the component of a project's cost that accounts for, or reflects, risk and uncertainties associated with a project.

Methods for establishing contingency for cost estimates are generally divided into two groups[2]:

- Deterministic methods, and the
- Probabilistic method.

The former treat all of the input parameters as constants. In contrast, the latter treats all input parameters as variables that change according to an assigned probability distribution.

The probabilistic method is the ideal approach, and its use is recommended wherever possible, as the associated process provides the opportunity to discuss and document the risk with relevant stakeholders and agree the appropriate quantum and probability for each risk item.

However, it is recognised that the effort required to conduct a probabilistic assessment is greater than for a deterministic assessment, and may not be justified for certain initiatives (e.g. for small scale initiatives, and in the early stages of planning and assessment). As a result, deterministic estimation plays an ongoing role in cost estimation.

Both the probabilistic and deterministic approaches require input from experienced practitioners.

Deterministic methods

A number of deterministic methods are available.

Rigorous deterministic methods (from least to most sophisticated) are:

- Reference class forecast method
- Factor based method, and
- Range based method.

Each method has a role to play during the various phases of an initiative (see Figure 1 of Department of Infrastructure, Regional Development and Cities (2018a) Guidance Note 3B for details).

Simpler deterministic methods consist of:

- The Simple Method (application of a flat rate percentage to the Base Estimate), and
- The Item Based Approach.

See Department of Infrastructure, Regional Development and Cities (2018a) Guidance Note 3B for further discussion on deterministic contingency estimation. Use of a rigorous deterministic method is preferred. Note that the Department of Infrastructure, Regional Development and Cities recommends <u>against</u> use of the Simple Method or Item Based Approach

Deterministic project costing may be appropriate for smaller projects and rapid CBAs, where the greater effort required to undertake a probabilistic assessment may not be warranted. However, to be useful, the technique requires access to reliable benchmark data, particularly at the whole of project level, in order to estimate the contingency allowance (BITRE 2014).

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[2] While modern mathematical methods such as Fuzzy Techniques and Artificial Neural Networks (ANN) are classed as a separate contingency calculation methods, they are rarely, if ever, used on land transport infrastructure projects.

Probabilistic methods

Probabilistic or risk-based cost estimation methods are a form of quantitative risk analysis which generally use Monte Carlo simulation to estimate the anticipated most likely cost of an initiative as well as contingency at various confidence levels. Monte Carlo simulation generates a sample of all possible project outcomes and the likelihood of occurrence of each. Consequently, the results of a Monte Carlo simulation include the confidence levels that can be assigned to all the generated outcome values of the total cost of the initiative.

See Department of Infrastructure, Regional Development and Cities (2018a) Guidance Note 3A for further discussion.

2.1.3 P-values, P50 and P90

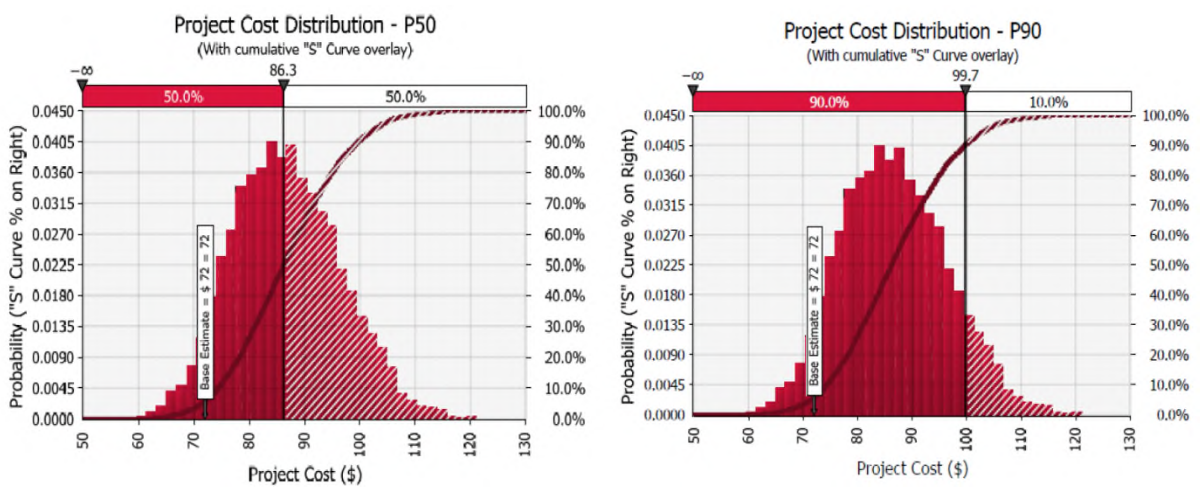
With probabilistic estimation, each generated estimate of total project cost from a simulation can be given a P value that indicates the likelihood that the total project cost will be less than or equal to that amount. For instance:

- A P50 cost estimate is the project cost with sufficient contingency to provide 50 per cent likelihood that this cost would not be exceeded
- A P90 cost estimate is the project cost with sufficient contingency to provide 90 per cent likelihood that this cost would not be exceeded.

Combining all generated estimates produces a project cost probability distribution. Figure 2 below shows a probability distribution generated from a Monte Carlo simulation:

- The chart on the left depicts the P50 value
- The chart to the right depicts the P90 value.

Figure 2 Monte Carlo simulation outputs

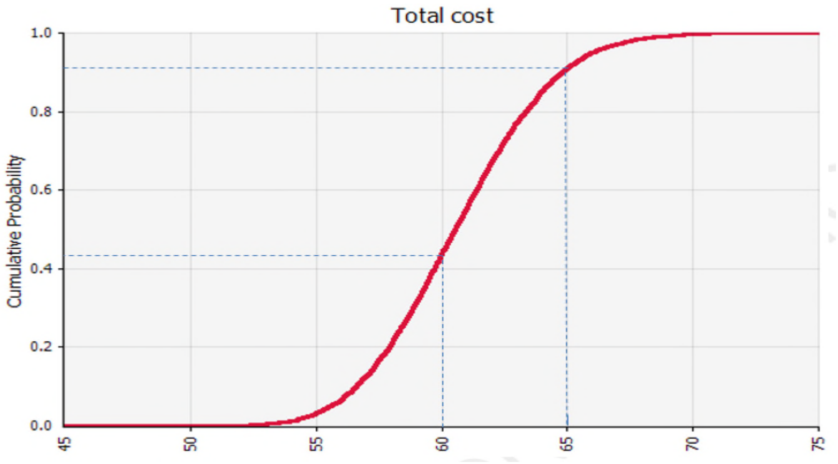


The overlay S shaped curve on each chart in Figure 2 is a cumulative representation of the cost probability distribution (i.e. a cumulative probability distribution). It:

- Permits any P value, including the P50 and P90 costs, to be directly read off the chart

- Allows the user to determine the probability of a final cost falling between two values. For example, Figure 3 below shows that the probability of the cost of the initiative being between $60 and $65 is 47% (91% – 44%). Alternatively, it shows that we are 95% confident that the cost will be between $55 and $67. Reporting cost ranges in this way is useful as P50 and P90 values are often misunderstood.

Figure 3 Using the S-curve to determine the probability that a cost will fall between two values



2.1.4 Real cash flow

Once the P50 and/or P90 value (for the *combination* of the Base Estimate and the Contingency Allowance) have been determined, it is then spread over the years of the construction period to reflect expected delivery activity.[3] This generates the initiative's Real Cash Flow (before escalation during the construction period).

2.1.5 Escalation allowance, outturn (nominal) cash flow and cost

An Escalation Allowance is then applied to the Real Cash Flow (including Contingency Allowance) in the financial years in which the expenditure will occur. This takes into account the changes in costs for the period from the base date of the estimate (the date that the estimate was prepared) to the completion of construction. Drivers of escalation include changes in market conditions, technology, regulation, general industry or regional-wide productivity and other economic factors that generally affect an economic sector or segment (AACE International, 2011). Escalation rates may vary between different economic sectors or segments, different geographical regions and so on.

Application of the escalation allowance results in two outputs:

- The Outturn (nominal) cash flow
- The total outturn (nominal) cost – the sum of the outturn cash flow.

[3] In the project delivery stage, the spread should match that in the project delivery Gantt chart.

2.2 Purpose and scope of an estimate

A cost estimate is rarely a single number, but rather a compilation of many lower-level cost element estimates. Credible cost estimates are produced by giving due consideration to the steps outlined at Figure 1 and should be accompanied by detailed supporting documentation.

The purpose of a cost estimate is determined by its intended use, and its intended use determines its scope and detail. Purposes of an estimate could include:

- Screening and economic viability of initiatives
- Selection of alternatives or preferred options
- To support the financing or budget approvals process of initiatives
- Tender and bid check estimates
- Cost to completion forecasts at any given time once an initiative is already under way.

The scope of the estimate is not to be confused with the scope of the initiative. The scope of the estimate refers to the level of detail and inclusions within the estimate itself, which is driven by its intended purpose and by the needs of the customer. The scope of the estimate will be determined by such issues as:

- The time involved/available
- What elements of the work need to be estimated
- The level of estimate detail to be included
- The phase of development that the initiative is in.

2.3 Attributes of a good estimate

By their very nature, estimates are uncertain projections of future events and circumstances. If something is only partially understood, any estimate about it will be uncertain. Generally, the accuracy of the estimates at a given point in an initiative's development will reflect what is known about the initiative at that stage.

Once the key parameters intended to feed into a cost-benefit analysis have been identified, be they cost elements, benefit parameters, or unknown risk events, their values must be assessed. It is rare to have representative historical information that can be used without any human intervention; estimating the value of a parameter almost invariably involves some level of subjective judgement. If to be used in a risk analysis model parameters are usually assessed in terms of three point estimates of low, most likely and high possible outcomes for the value concerned. These are not engineering measurements or data derived from scientific observations. They are an informed opinion.

Subjective assessments will always be at risk of bias. While there is no option but to use subjective assessments, it is prudent to take steps to limit or avoid bias. Techniques to overcome potential bias are described in detail throughout Guidance Note 3A (Department of Infrastructure, Regional Development and Cities 2018a).

Estimates of parameters can be wrong in many ways. While there is perhaps no definitive answer to the question "what is a good estimate?", achieving one requires good judgement by experts, good process and good data.

Expert judgement

Burgman (2015) suggests the quality of an expert's judgment can be characterised in four ways:

- *Accuracy* measures how close an expert's quantitative estimate is to the truth. Accuracy can be measured by the difference between an expert's estimate and the correct answer. Over several estimates, it may be the average difference.
- *Bias* measures the tendency of an expert to deviate consistently from the truth in a single direction, either too high or too low. Bias can only be measured over the answers to several questions.
- *Calibration* is the frequency with which uncertainty intervals enclose the truth, compared to the frequency with which the expert expects them to. Calibration can be measured by counting, over several questions, the frequency with which the expert's intervals enclose the truth.
- *Reliability* is a property of an expert. It is the degree to which an expert's estimates are repeatable and stable.

This list is certainly not complete but it's a useful starting point. If an expert is routinely close to the truth but provides very wide margins of confidence (i.e. estimates are poorly calibrated), the judgements are accurate but uninformative. If an expert confidently provides narrow bounds but is routinely far from the truth, the judgements are precise but inaccurate. In neither case will the estimate be useful for a decision-maker who is trying to choose between alternative solutions or trying to set the budget for the initiative.

Process

Good process involves risk workshops and scenario analyses involving multiple experts from different disciplines (geotechnical, project management, industrial relations, construction engineering, tunnelling if applicable, bridges if applicable, procurement, environmental etc), particularly to ensure the probability distributions for specific costs take account of what can go wrong.

Independent expert reviews are also important to provide confidence of the quality and outcomes of an estimate.

Data

Relevant data required for a good estimate is wide-ranging in nature, and includes data on weather, historical, geological, etc. The more information that goes into an estimate the better, subject of course to the cost of obtaining data, so a balance has to be sought.

3. Specific Issues

3.1 Representation of costs in cost–benefit analysis (CBA)

A CBA requires use of the best estimates of both benefits and costs. That is, the *expected value* or *mean* value. See ATAP Part T2 for further discussion (chapters 3 and 11).

Note the relationship between the best estimate (mean / expected value) and P50. P50 is the *median* value. P50 will equal the mean / expected value only if the probability distribution is symmetrical. If the distribution is reasonably symmetrical, the P50 value can be used as an approximation of the best estimate. However, it is always preferable to use the mean / expected value whenever it is available. Cost estimation software (Monte Carlo) produces an estimate of the expected value.

The P90 investment cost estimate might be used for a sensitivity test.

In all cases, the cost estimate used in the CBA must:

- Reflect opportunity / resource costs (see ATAP Part T2 Section 2.1 for a discussion – including removing taxes and including subsidies (see ATAP Part T2 Box 3)
- Be in real costs . That is, it must exclude the escalation allowance (see section 2.1.5 above) and the cash flow must be in real terms (section 2.1.4 above).
- Land and property costs should be included at their opportunity cost value. In some cases, land acquisition for an initiative will be excess to final requirements. The land cost reflected in the CBA should reflect only the net cost after resale of expected surplus land
- Only include cost elements that will be incurred after the decision to proceed with an initiative. Any costs incurred prior to that are ‘sunk costs’ and should be excluded from the CBA.

3.2 Relationship to optimism bias

Optimism bias and its relationship to cost estimation is discussed in ATAP Part O2.

3.3 Level of accuracy expected during development stage of the initiative

As mentioned in the introduction, the level of accuracy required in cost estimates will depend on the stage of assessment and planning. In the ATAP Framework these stages are:

- Policy choices and system planning
- Rapid appraisal
- Detailed appraisal
- Funding procurement and delivery.

Early on, indicative estimates are often sufficient. As one progresses through assessment and planning processes, the required level of accuracy increases. By the time an initiative is ready to be delivered, highly accurate cost estimates should have been developed, accompanied by sufficient supporting information and detail.

3.3.1 Deterministic versus probabilistic estimation

Section 2.1.2 noted that while the use of probabilistic cost estimation is ideal wherever possible, the associated effort (and therefore cost) is greater than for a deterministic assessment. Accordingly, it may not be justified for certain initiatives (e.g. for small scale initiatives, and in the early stages of planning and assessment).

Policies on when to use deterministic versus probabilistic estimation methods will vary between jurisdictions. Generally, the need for probabilistic methods increasing the greater the scale and complexity of specific initiatives, the greater the likely costs, and the later one is in the project development process.

For example, the Australian Government (Department of Infrastructure, Regional Development and Cities 2018b) specify the cost estimation method to be used (for initiatives it funds) based on expected outturn cost:

- For initiatives under $25 million: A rigorous deterministic method is appropriate
- For initiatives exceeding $25 million: Use of probabilistic cost estimation is required.

On the other hand, in Victoria for example, road projects under $500,000 can use a deterministic estimating technique, and probabilistic estimation for initiatives exceeding this amount.

3.3.2 Estimate classes

The Department of Infrastructure, Regional Development and Cities (2018a) Guidance Note 3A provides the matrix shown in Table 1 below from AACE International 2018. It demonstrates the use of estimate classes showing expected accuracy ranges that reflect the evolving level of maturity of the cost estimate during a project life cycle. Note that expected accuracy range must not be used to determine a contingency allowance. The +/- value represents typical percentage variation of actual costs from the cost estimate *after* application of appropriate contingency for given scope. It does not preclude a specific actual project result from falling inside or outside of the indicated range of ranges identified in the table.

Table 1: Cost estimate classes

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES Expressed as % of complete definition	END USAGE Typical purpose of estimate	METHODOLOGY Typical estimating method	EXPECTED ACCURACY RANGE Typical variation in low and high ranges at an 80% confidence interval
Class 5	0% to 2%	Concept screening	Cost/length factors, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Cost/length, factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Source: Department of Infrastructure, Regional Development and Cities (2018a) Guidance Note 3A

It should be noted that the greater the level of accuracy required for a project, the higher the expenses required to estimate accurately.

3.3.3 In appraisals

For the appraisals of initiatives (from Part T2 of the Guidelines):

- The majority of initiatives submitted for rapid appraisal are likely to be at an early stage of development, with limited planning and limited available data. However, an estimate of investment costs is still essential
- Based on the experience of Australian jurisdictions, the following expected margin for error / level of accuracy in cost estimates are a guide for use in appraisal:
  - Rapid CBAs:
    - Smaller projects (say under $25 million)[4]: -20 per cent to +40 per cent []
    - Larger projects (say greater than $25 million): -10 per cent to +15 per cent
  - Detailed CBAs: ±10 per cent

[4] The setting of a threshold between small and large project will vary between jurisdictions and settings. It is somewhat subjective but may be a practical tool. The $25 million threshold used here matches the Australian Government threshold referred to in section 3.3.1. Other jurisdictions may choose a different threshold.

3.4 Funding considerations

ATAP does not make any specific recommendations about how cost estimates should be used in funding considerations. Such considerations involve negotiations between infrastructure agencies, funding agencies (Treasury departments, Australian Government) and advisory agencies (e.g. Infrastructure Australia). Those negotiations typically revolve around using the mean, P50 and P90 cost estimates.

In funding submissions to the Australian Government, cost estimates are given specific names as one progresses through the project development process: strategic estimate; concept estimate; preliminary estimate; detailed pre-tender estimate.

3.5 Probabilistic estimation software

Several software packages are commercially available. Some of the more common packages include:

- @Risk (Palisade Corporation)
- Crystal Ball (Oracle)
- ModelRisk (Vose Software)
- Polaris (Booz Allen)

ATAP does not endorse any particular product and notes that the majority of packages have similar functionality.

3.6 Other related parts of ATAP

Part T2 provides further detail on costs in cost–benefit analysis.

Where relevant, some Parts of ATAP Mode-Specific Guidance also provide complementary discussion on costs.

Appendix A Glossary of key terms

Base Estimate: The sum of the Construction Costs and Client's Costs at the applicable base date. It represents the best prediction of the quantities and current rates which are likely to be associated with the delivery of a given scope of work. It should not include any allowance for risk (contingency) or escalation.

Contingency: An amount added to a base estimate to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs. These can include, but are not limited to, planning and estimating errors and omissions, price variation as at the date of estimate (other than general escalation), design developments and changes within the scope, and variations in market and environmental conditions.

Outturn cost: The sum of the price-escalated costs for each year of an initiative's duration. Outturn Cost calculation requires the non-escalated cost of an initiative to be presented as a cash flow and the application of an escalation factor for each project year to derive the price escalated cost for each year. In economic terms, non escalated costs are referred to as Real costs while Outturn Costs are referred to as Nominal costs.

Work breakdown structure: A hierarchical decomposition of the work to be executed to accomplish the objectives of the initiative and create the required deliverables. The work breakdown structure organises and defines the total scope of the initiative.

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