Contingency Guideline

2nd Edition

"A reference for different practical risk based decision making approaches to managing schedule and cost contingency allowances throughout the project and program investment lifecycle."

Risk Engineering Society (RES)

RISK ENGINEERING SOCIETY

A publication of the Risk Engineering Society (RES) and Engineers Australia

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RISK ENGINEERING SOCIETY

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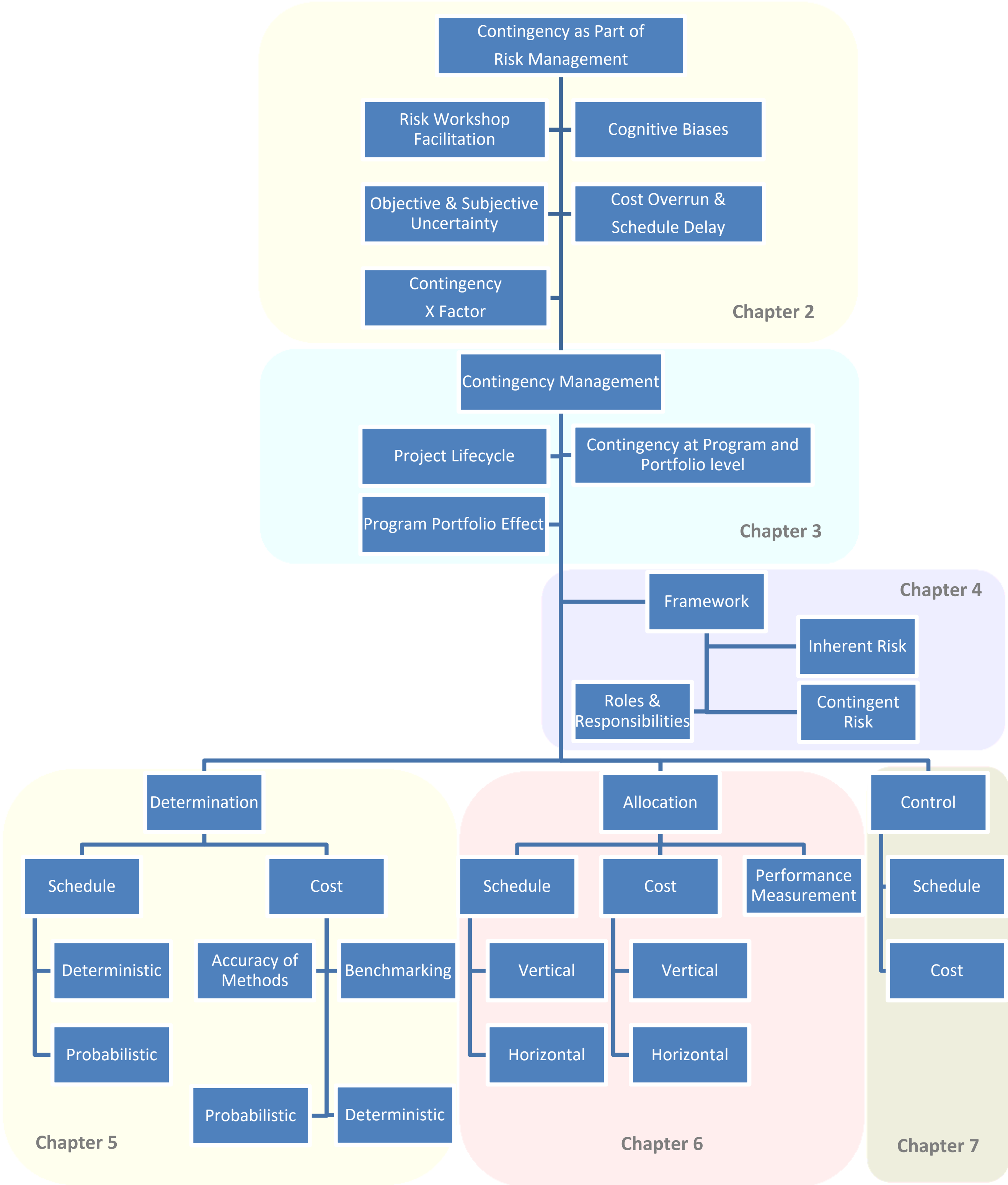
STRUCTURE OF CONTENT



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1. Introduction

1.1 Preamble

The Institution of Engineers Australia, trading as Engineers Australia ("Engineers Australia") <www.engineersaustralia.org.au> is the Australian forum for the advancement of engineering and professional development of its members and the wider engineering society across Australia and globally. Engineers Australia is the largest professional body for engineers in Australia.

Technical Societies of Engineers Australia provide an important and integral link between the profession and specific areas of technical practice. Technical Societies that function as operating units of Engineers Australia are bound by the Royal Charter and By-Laws, regulations and policies of Engineers Australia.

As one of Engineers Australia's Technical Societies, the Risk Engineering Society (RES) <www.engineersaustralia.org.au/risk-engineering-society> contributes to the effective and efficient application of engineering methodologies and approaches at every step of the risk management cycle for strategic, operational, financial or portfolio, program and project management objectives.

Consistent, effective and efficient engineering approaches to uncertainty and risk assessment help businesses to better understand and quantify the range of possible consequences and the organisation's overall risk exposure. This empowers organisations to proactively manage the treatment and response actions for risks and opportunities, while making informed decisions and optimising their investments.

In May 2013, the executive committee of RES identified the need for a new comprehensive guideline on the subject of contingency management – from determination to allocation and then control along the project life cycle. The guideline would address the project management requirements in the delivery of major projects, especially for infrastructure projects and government funded investments.

The 1st Edition of the RES Contingency Guideline was published in May 2016. Considering the dynamic nature of this subject – as well as changing public and private requirements, the maturity of the risk engineering profession and industry necessities – it is the intent of the RES executive committee to periodically review and update this Guideline, to ensure its quality and to keep it up-to-date with new developments in contingency management. Following a comprehensive industry consultation, the 2nd Edition of the RES Contingency Guideline was published in February 2019.

The RES executive committee welcomes any feedback, comments or suggestions for future development of this Guideline from its members, corporate and project risk professionals, cost engineers, cost estimators, project planning and scheduling specialists, contract and commercial managers, and the general public. Please email all communication to res@engineersaustralia.org.au.

1.2 Purpose & Scope

While there are already a large number of publications on the subject of contingency, there were three main reasons for publication of this Guideline:

1. The Guideline is mainly designed to help reach consensus in the methods used for contingency determination across industry and government, by providing comprehensive information on principles and practical methods. It also details when methods are applicable, their reliability, and how they vary at different stages in the project lifecycle

2. Most current recommended practices and guide notes only focus on 'contingency determination', mainly for cost estimation purposes. However, this Guideline also provides practical details about other key aspects of contingency process, e.g. 'allocation', 'control', and 'program contingency', not only for cost estimation but also project planning
3. Application of contingency determination methods can be expensive and time-consuming, so it is important to select the most practical option. This Guideline will help practitioners to discuss and select the optimum method of balancing their requirements and constraints. It highlights that there is no one method to suit all situations, and provides a framework to assist practitioners and organisations in discussing and selecting the best method for their requirements.

The RES Contingency Guideline provides a reference document for different practical approaches and guidance for determining, allocating and managing the most appropriate contingency (time and cost allowances) at different stages of the project and program lifecycle. It excludes escalation and its interaction with other uncertainties.

Please note that the RES Contingency Guideline is a general guide only. It does not set out mandatory or minimum standards or requirements and it does not comprise professional advice. Any person seeking to use or rely on the Guideline should obtain independent professional advice. Where the Guideline refers to the views or opinions of any person or association, those views and opinions are not endorsed by Engineers Australia, unless expressly stated in the Guideline.

1.3 Applications

While the concepts and definitions being used in this Guideline can be applied across different industries and sectors by both owners and contractors, the language of the Guideline may lean more towards infrastructure projects and government funded investments from project to portfolio.

The Guideline aims to establish the characteristics of good contingency management. It also seeks to stimulate discussion within organisations and in projects so required outcomes of risk and contingency management can be agreed and defined. RES would like to highlight that there are three objectives of a good contingency management approach: to quantify accuracy; to encourage structural thinking; and to support decision making process. Hence, organisations should use risk engineering and contingency determination approaches not only for their explicit results and generated contingency numbers, but also because they force people to share, discuss and validate all key assumptions and outcomes as a team – which is good source of information for decision-makers.

The Guideline is predominantly helpful for project engineers, project managers, risk managers, cost engineers, estimators, project planners and schedulers, contract and commercial managers – in the context of their work on development and delivery of projects and programs. However, it also provides a useful overview for business leaders who need to better understand the subject of contingency and its importance in achieving the objectives of project based organisations, in order to make informed investment decisions which take risks into consideration.

1.4 Definitions

The Guideline acknowledges that there is a broad range of methodologies for defining, assessing and managing contingencies across different industries and organisations. While a 'one size fits all' approach is not appropriate, there are benefits in constructing a common framework with a uniform set of terminologies and approaches, a high degree of transparency, guidance on clear authorisation arrangements, and fit-for-purpose governance. It should be noted that many of the terms and definitions related to the subject of risk management and contingency are industry, contract, organisation and context specific. However, while it is a difficult task to agree on a common language, the terms defined in Appendix A have been used throughout this document. For comparison purposes, multiple definitions of some key terms from different sources have also been included.

1.5 Good Practice Governance

As a part of project cost and duration estimation, it is essential to acknowledge that any contingency determination is an uncertain forecast – an indicative but reasonably realistic and reliable estimation for organisation and/or project purposes which uses the latest available information. However, uncertainty does not justify a lack of discipline or integrity in the process. As a defined process including a set of practices, one must govern and assure the quality of its performance and activities. The following are principles of good practice that should be considered as part of governance:

a) At any time, the Base Estimate and Base Schedule must:
   i) contain all the cost elements and schedule activities including the approved changes
   ii) represent the current assumptions and strategies. Also existing validated trends should be built into the Bases before undertaking any contingency assessment
   iii) have a clear basis of estimate and schedule
   iv) be supported by relevant data, when possible.

b) The process should reflect overarching quality management principles, e.g. documented, transparent, traceable, defendable and timely
c) The process should support effective decision making on investments and as part of change management and project control processes
d) The process should assure all key risks, threats, uncertainties, treatment strategies, risk responses and opportunities be explicitly identified, quantified and assessed
e) Key aspects of an organisation’s culture and project specific strategies, including cognitive and deliberative biases, risk attitude, risk appetite, and risk tolerance, should be also considered
f) Contingency management should address the residual risks (i.e. post treatment risks), the organisation’s desired confidence level, and specific strategic objectives
g) Objectives of contingency management, e.g. investment decision, tender conditions, change management, and delegation of authority, should be evaluated and communicated
h) Should be carried out at every stage of the project lifecycle
i) The method used for both cost and schedule contingency determination should be consistent with the base cost and schedule estimation methods for any given stage of the project
j) Contingency should not be a replacement for appropriate Base Estimate or Schedule development, but should address uncertainty from the quality of planning practices
k) Contingency determination practices should be empirically valid and/or validated as appropriate: either explicitly in the base methods; and/or through validation and benchmarking of the results using a historical knowledge base
l) Practice selection should recognise that different uncertainties and risk types are often best quantified using different methods applied in an integrated way. Cost and schedule risks should be assessed and quantified using integrated methods
m) Where applicable, methods should consider the unique nature of mega-projects and complexity; the overall outcome may be more than the sum of the uncertainties and risks (i.e., non-linear)
n) Methods should recognise that cost and schedule trade-off is part of every decision and management cost versus schedule objectives are a key driver of contingency management
o) When opportunities are identified, they should optimally be capitalised on by referral to a value management process.

2. Contingency as Part of Risk Management

2.1 Structure of Content

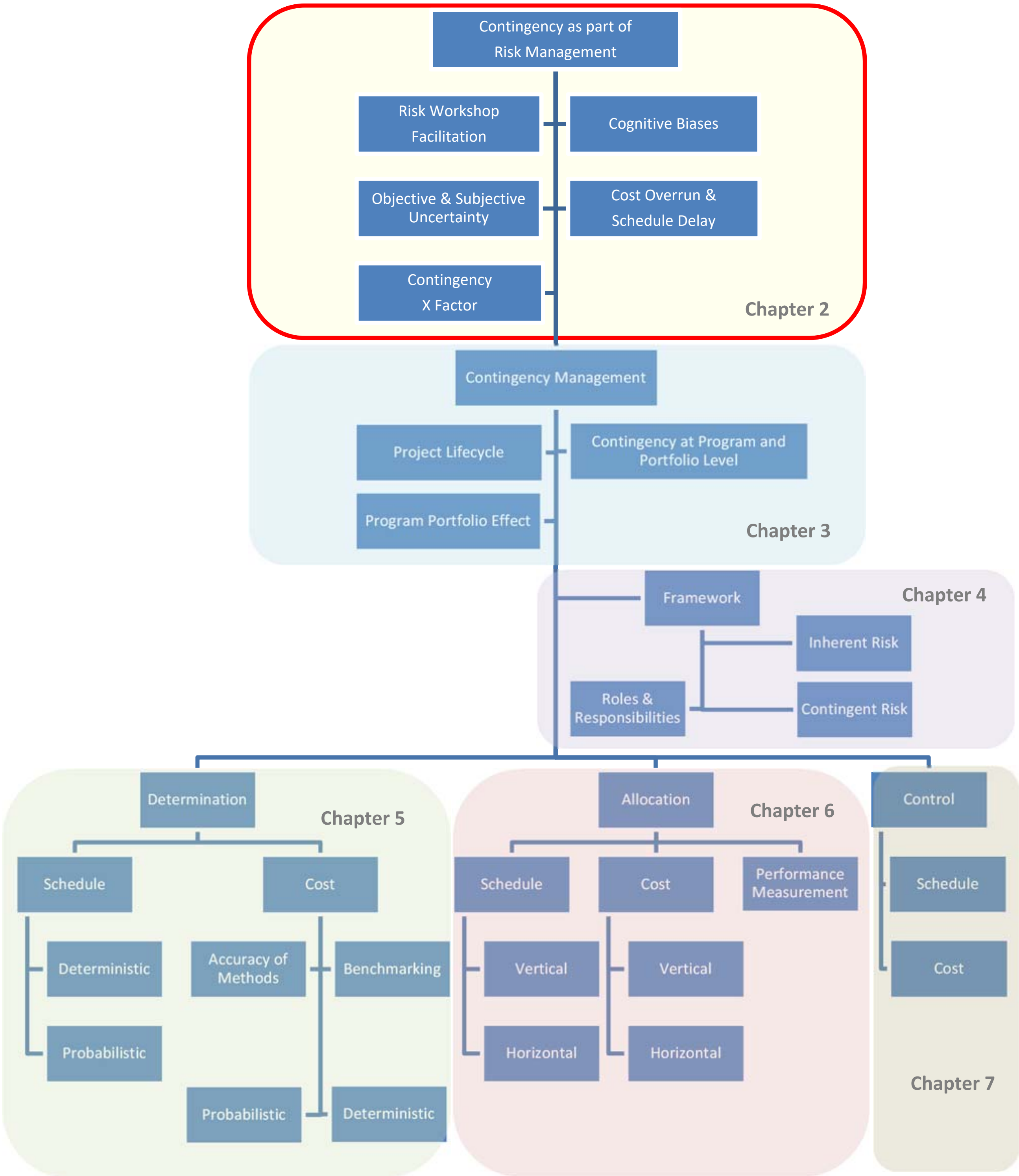


Figure 1: RES Contingency Guideline – Structure of Content

2.2 Risk Management Process

For the purposes of this Guideline, the project risk management process is defined in accordance with ISO 31000:2018 Risk management – Guidelines, as illustrated in Figure 2. A key factor in the success of projects is the integrated application of value and risk management processes – including system engineering – over the full project lifecycle. The focus of system engineering and risk management is to find the solution that represents the best value over the entire project lifecycle, and identify and manage associated risks. This can be contrasted with value management, which has a focus on business requirements.

ISO 31000:2018 states that "the purpose of risk management is the creation and protection of value. It improves performance, encourages innovation and supports the achievement of objectives". To achieve this goal, risk and contingency management should take the expertise and opinions of stakeholders into account, and follow an ordered, iterative process. Historical data should be combined with high quality information, and practitioners should conduct additional investigations where needed.

Following appropriate and fit for purpose risk assessment, the risk treatment process should begin. This process includes specifying which risk treatment options are appropriate for various conditions (noting they may not be mutually exclusive). This ensures that stakeholders understand the process, and allows practitioners to monitor progress against the treatment plan.

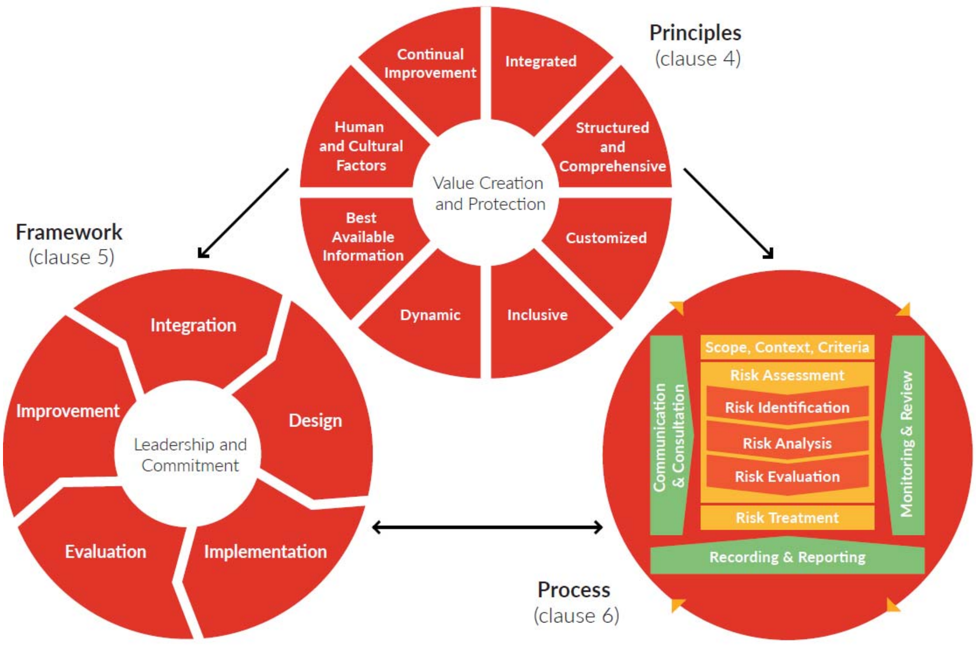


Figure 2: ISO 31000:2018 Risk management – Guidelines (principles, framework and process)

One or more risk treatment options may be selected. Some treatments (as specified by ISO 31000:2018) are listed below:

a) avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk
b) taking or increasing the risk in order to pursue an opportunity
c) removing the risk source
d) changing the likelihood
e) changing the consequences
f) sharing the risk (e.g. through contracts, buying insurance)
g) retaining the risk by informed decision

When further risk treatment is not feasible or justifiable, but the residual risk is still not acceptable (e.g. above the organisation's risk appetite but within its tolerance and capacity) allocating an allowance is an additional treatment option to manage the potential negative impact of the risk if it occurs. As part of the risk treatment plan, the project team should determine the cost and time impacts of significant risks and allocate this allowance within the cost and schedule plans to cover the potential cost and/or time impacts of uncertainties and/or identified risks.

This allowance is known as contingency which addresses potential variations from the Base Estimate (which may add cost and/or time) and opportunities (which may reduce cost and/or time). Contingency management is a key element within the organisation's risk and change management processes. It is essential to ensure that risks are identified, treated and effectively responded to, if they occur.

2.3 Objective and Subjective Uncertainties

For the purpose of this Guideline, uncertainty is defined in accordance with the US Government's *Joint Cost Schedule Risk and Uncertainty Handbook* as a potential variation in any phase or activity of the cost estimating or scheduling process, and any other project process and its performance. Possible causes can include knowledge deficiencies, or random inconsistencies in cost estimation or scheduling processes. In order to understand how this has affected cost and schedule estimates, the practitioner needs to holistically determine and model the associated uncertainty. Uncertainty can be classified as 'objective uncertainty' or 'subjective uncertainty'.

2.3.1 Objective Uncertainty

When practitioners use a replicable and proven process to derive their cost and schedule parameters, the associated uncertainty can be called 'objective'. One example of such a process is statistical analysis of appropriate and high quality historical data.

If empirically-based applicable statistical data was used as a basis of cost and time estimates, the practitioner should have access to the required information to incorporate the uncertainty in the cost and schedule risk model (e.g. the definitions of best case and worst-case boundaries nature of the probability distribution). In this situation, the bounds of the specific confidence interval to be used should be furnished by the statistical calculations (note: 'level' is not 'bounds'). However, one must ensure that the statistical data does not reflect the impact of critical risk events, escalation, currency, or other non-contingency risks in past projects – only nominal variation in performance.

For instance, relevant rainfall data at a station close to a future project should be used for forecasting general site conditions as well as possible rain events during project delivery – making sure to isolate rain events that one might consider a major event. The appropriate probability distribution can also be assessed before its application to forecasting. In the context of contingency assessment, this begins with the collection and normalisation of relevant historical data. The normalisation would include correcting for the impact of critical risk events, escalation and currency risks.

This Guideline highlights two objective methods (as detailed in the *US Joint Agency Cost Schedule Risk and Uncertainty Handbook*) for estimating uncertainty:

- Developing parametric equations through regression analysis
- Fitting distributions to normalised historical data or estimates

2.3.2 Subjective Uncertainty

When cost and schedule estimates are largely based on the opinions of Subject Matter Experts (SMEs) in place of empirical statistical analysis, the associated uncertainties may be called 'subjective'. This means that it cannot be modelled objectively, because there is not sufficient supporting data or information. While subjective uncertainty is not highly regarded in terms of its precision or reliability, it can feature significantly in contingency estimation, as information deficiencies, schedule and resource constraints can adversely affect thoroughness.

Therefore, risk practitioners are often required to defer to the expertise of project engineers, managers, estimators, schedulers and other internal and external stakeholders – which is known as 'elicitation'. Elicitation can be difficult, and is affected by a number of biases. One such bias is an overly optimistic view of project outcomes. Optimism is a form of cognitive bias, which refers to a distortion in how individuals analyse information in response to strategic misrepresentation, organisational culture, or group and personal psychology. See Section 2.6.3, 2.6.4 and 2.6.5 for further details.

RES Recommendation: whenever possible, uncertainties should be based on empirical data rather than expert opinion, and fitted data should be used to choose distributions in preference to subjective selection.

2.4 Risk Workshop Facilitation

Despite the wide range of risk assessment software available, the process of conducting a successful risk workshop to identify risks and capture different views and experiences – and the risk model development process which follows – can be challenging experiences for project teams and organisations. The primary focus of the workshop facilitator is to keep the process and group moving effectively in identifying and discussing risks, exploring treatments, planning risk responses and cost/schedule trade-offs, and generally capturing ideas and knowledge. Depending on the objectives, each risk workshop usually has three phases:

a) Before the risk workshop – the key challenge for the facilitator is to lead participants in the required preparation actions. The information gathered during this phase should be provided to all participants before the workshop, and is generally included in the final report. The amount of information provided at this phase depends on the risk assessment objectives, participants' risk management maturity, timeframe and available resources, as well as the projects complexity and scope
b) During the risk workshop – to achieve consistent risk management outcomes as well as high quality risk data for further risk assessment, the facilitator needs to explain which factors can be defined as risks, and which are excluded. Risks can be identified in a number of ways, including: checklists; brainstorming sessions; historical data; decomposition techniques; process maps; Fault Tree Analysis; Hazard and Operability Study (HAZOP); Safety in Design; and Failure Mode, Effects and Criticality Analysis (FMECA). The workshop may also include risk quantification at decision gates or quarterly assurance reviews
c) After the workshop – the facilitator creates a draft assessment report which includes relevant data gathered in the workshops. The facilitator gives all workshop attendees the opportunity to comment and further analyse the draft, then delivers the report to the person managing risk assessment for the project or organisation for approval. The report is then made available to decision-makers and other relevant stakeholders.

For optimum results, quantitative risk workshops should assess both cost and schedule in an integrated way. One principle is to consider cost-schedule trade-off – which cannot be done effectively with separate cost and schedule risk workshops. Further details and recommendations for facilitating successful risk workshops, and characteristics of good risk workshop facilitators are summarised in Appendix B.

2.5 Contingency X Factor

Contingency is determined to support investment and control decisions. For contractors, there is also pricing risk, while owners are more focused on maximum investment returns. Making an informed decision on required optimum contingency for both project owners and contractors is fundamental. The challenge of determining the optimum contingency is called the Contingency X Factor.

2.5.1 Project Development Phase

During project development phase or tendering, it is essential that adequate contingency allowance be determined, while considering the desired confidence level. Too much contingency may understate investment return or decrease the chance of winning the project; too little could allow uncompetitive investments to be approved, or compromise program delivery. This challenge highlights the importance of risk quantification and contingency determination and pricing for both contractors and owners at project development phase.

Figure 3 below simply illustrates the Contingency X Factor for contractor tender pricing during bid determination (i.e. tendering). It should be noted that the relationship between contingency and confidence levels may not be linear.

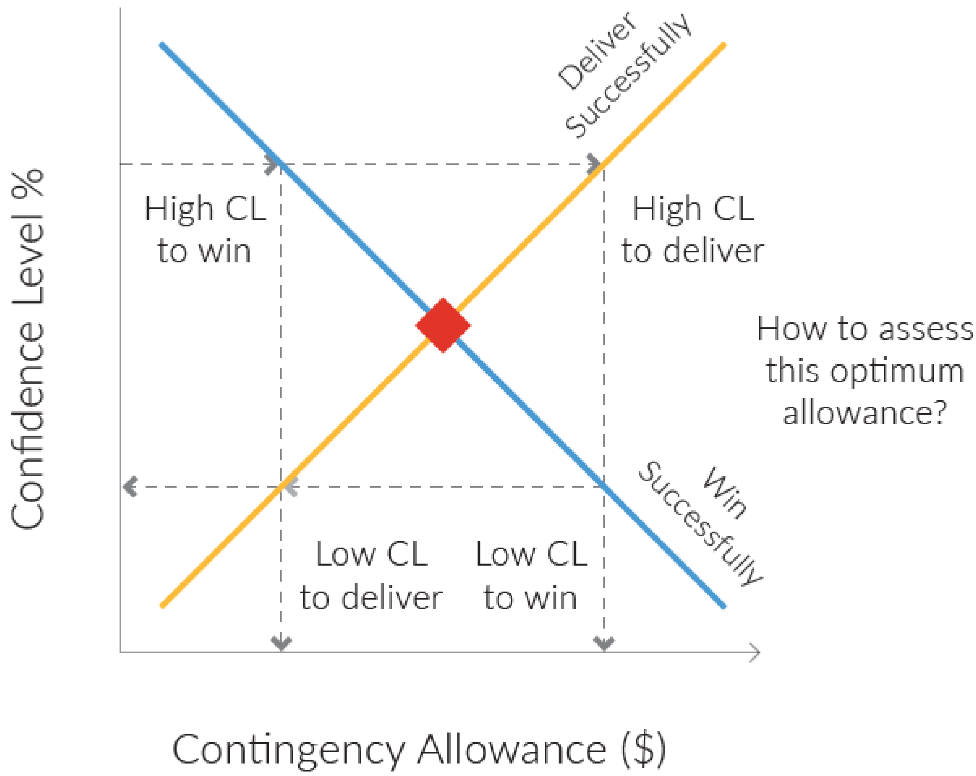
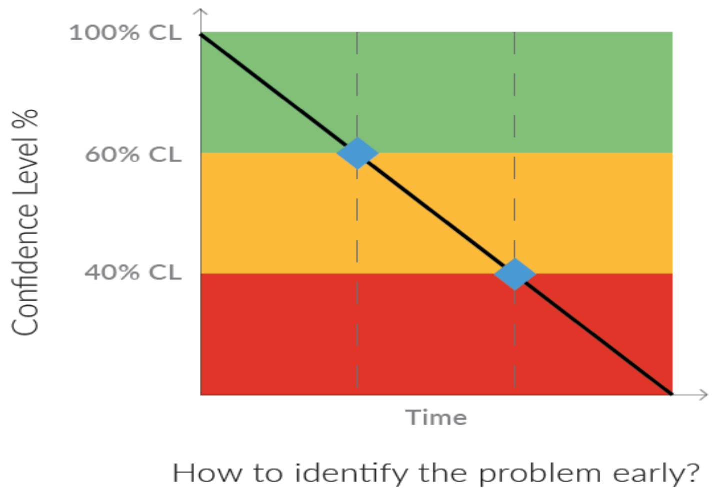


Figure 3: Contingency X Factor during development/planning phase

2.5.2 *Project Delivery Phase*

During the project delivery phase, it is important to quantitatively monitor and measure the project risk exposure on a regular basis to ensure adequate and reasonable contingency is available for the desired confidence level. For projects with many unexpected events or variations, it is quite common to see a continuous decrease in the project confidence level as the project progresses. At very low confidence levels (less than 30-40%), the problem will become obvious, resulting in variations or Extensions of Time (EOTs). However, it is important to identify this problem as early as possible to maximise the opportunities to undertake corrective actions. The recommended approach to determine the Contingency X factor during delivery and execution phase is presented in Figure 4 below.



RES Recommendation: to set up more effective early warning indicators, use a regular (no longer than quarterly) quantitative risk-based confidence level assessment during the delivery phase, with three zones of: GREEN (e.g. from 90% to 60%); AMBER (e.g. from 60% to 40%); and RED (e.g. below 40%) in addition to traditional project progress measurement and performance reporting.

Figure 4: Contingency X Factor during Delivery/Execution Phase

2.6 *Cost Overruns and Schedule Delays (Slip)*

This Guideline defines cost overrun as the amount by which a project exceeds its initial cost estimate – adjusted for escalation and major business scope change – at its final decision making milestone, e.g. Final Business Case. When capital is limited, over-budget projects have the potential to cause other projects to run over time, or be cancelled altogether. This could adversely affect multiple project budgets, and make it more difficult to obtain funding for future ventures. However, being under budget (e.g. due to too much contingency) will lock up capital and may result in under-investment.

Similarly, schedule delay – or slip – is a measure of the time by which a project exceeds the initially forecast completion date, at its final decision making milestone, e.g. Final Business Case. Schedule delays usually cause cost increases – either through penalty clauses, time and effort, escalation, or a combination of these factors. Extra resource costs may also be incurred when making up for lost time. In worst case scenarios, schedule recovery efforts can fail to improve performance and the added resources compound cost overruns. This is a risk of trading cost for schedule that practitioners must consider in integrated analysis.

Despite decades of international studies and efforts to predict and/or reduce project cost overruns or schedule delays, major projects around the world continue to be significantly affected. Table 1 presents some studies which assess the cost performance of various projects across Australia and globally.

#	**Study**	**Year**	**Sector**	**Number of projects**	**Mean – cost overrun**	**Standard Deviation (SD) – cost overrun**	**Note**
1	Grattan Institute	2016	Transport	836	26%		11% of cost overruns directly attributable to scope changes. 89% attributable to other causes.
2	Bertisen & Davis	2008	Mining	63	25%	30%	
3	Odeck	2004	Roads	610	7.88%	29.2%	
4	Flyvbjerg, Holm, & Buhl	2004	Rail	58	44.7%	38.4%	Key findings: 20-40% average cost overrun; 86% of projects studied exceeded cost estimates; large infrastructure cost estimates "highly and systematically misleading".
5	Flyvbjerg, Holm, & Buhl	2004	Bridges & tunnels	33	33.8%	62.4%	
6	Flyvbjerg, Holm, & Buhl	2004	Roads	167	20.4%	29.9%	
7	Pohl & Mihaljek	2002	World Bank Projects	1015	22%		
8	Gypton	2002	Mining	60	22%		
9	Thomas	2001	Mining	21	17%		
10	Bennett	1997	Mining	16	27%		
11	Odeck & Skjeseth	1995	Toll Roads	12	5%		
12	AGS	1994	Roads	8	86%		
13	AGS	1994	Rail	7	17%		
	Pickrell	1990	Rail	8	60%		
14	Fouracre, Allport, & Thomson	1990	Metro	21	45%		
15	Merrow	1988	various	47	88%		
16	Department of Industry, Technology & Research (VIC)	1980s	various in Australia and UK	21			Cost overruns of over 20% in 50% of government projects studied.
17	Castle	1985	Mining	17	35%		
Average					**34.2%**	**37.8%**	

Table 1: A number of studies on cost overrun projects

RES also acknowledges many other industry researchers, including: John Hackney (1965 and 1991), Rand Corp, Independent Project Analysis (IPA), Construction Industry Institute (CII) and others. A number of research has highlighted that cost overruns and slips are largely caused by measurable practices and inherent project system and scope attributes – and can be quantified using empirical data. Hackney, Rand, CII and IPA have developed different parametric models to rate risks and quantify them reasonably.

Based on research including that listed above, this Guideline groups the key factors contributing to cost overruns and/or schedule delays into two groups: hard and soft factors. Hard factors can include issues such as scope variations and technical problems, while soft factors include cognitive biases, strategic misrepresentation and organisational culture. These risks are caused by inherent (including systemic) and contingent risks, which are described further in Section 4.3.

2.6.1 Scope Variations

This Guideline defines scope variation as changes to the plan set down for a project during initial development – noting that design evolution may not be a scope change to the business. Appropriate contingencies, combined with a robust design that meets stakeholders' requirements, can help to reduce this issue. Estimates of the effect of scope changes on cost overruns vary. In 2016, the Grattan Institute found that scope changes only account for about 11% of cost overruns in transport projects in Australia.

However, where scope variation really comes into play is during the estimating process, where the level of scope definition is the major source of uncertainty. This concept is the basis of project stage-gate systems which are now ubiquitous. As a good practice, this Guideline recommends that project risk quantification should address the level of scope definition directly using empirically known relationships. Unfortunately, many practitioners rely purely on subjectivity – which is preventing industry from improving its cost growth performance.

2.6.2 Technical Factors

Technical factors may lead to cost overrun or schedule delay. They include system quality issues such as: inefficient, inconsistent and deficient planning and forecasting techniques; inadequate validated relevant data; and mistakes. Other examples are the inherent risks (see Section 4.3) and uncertainties associated with most major projects, such as: complex internal and external interfaces; lack of relevant experience; and technology. Resulting errors may be reduced or eliminated with better forecasting models, empirically-based data, and more experienced teams.

RES Example: examples of technical risk factors for a design and construct (D&C) project are:

a) the eventuation or emergence of additional contingent risks as well as those identified
b) all identified risks eventuated, and extra cost changes occurred
c) the worst-case consequences occurred for most of the identified risks
d) uncontrolled change or uncontrolled scope change
e) design development changes including design mistakes
f) inappropriate procurement (contracting or expediting), or inefficient contract management
g) project complexity, including: technical, project size, interfaces, political, cultural, etc.
h) standards and policy changes
i) third party influences, e.g. design costs associated with diversions or utilities adjustments
j) unmeasured items
k) property acquisition requirements, including:
   - permanent project areas (e.g. sub-surface easements)
   - temporary or permanent habitat requirements
   - facilities provided by principal or client for contractor (e.g. traffic diversions, site offices)
   - separate site offices and facilities for principal
   - land requirements for client works within the project
   - land owner compensation
   - residual land value of sites cleared during project demolitions
   - alterations to property access

2.6.3 Cognitive Biases

A cognitive bias generally refers to a deviation from rational judgment, leading to illogical inferences about other people and situations. These psychological factors can affect people's ability to make rational decisions based on available empirical evidence and the likelihood of outcomes. In some cases, biases may lead to faster decisions when timeliness is more valuable than accuracy.

Hidden biases often color or distort the perception of risk and its consequences. For example, research indicates that people are generally overconfident in their ability to solve complex issues, despite evidence to the contrary. All project participants are susceptible to different types of biases. Some factors which may increase the likelihood of cognitive biases during risk workshops and contingency process include:

- optimistic single value estimates and timelines
- pressure to meet predetermined targets, due to technical, political, social, and other objectives
- exclusion of some contingent risks from time and cost estimations.
- schedule restraints due to the Merge Bias Effect (MBE), for example:
    - project schedules have an additional level of complexity over cost estimates – schedule logic. In complex projects, parallel strands of logic converge at milestones or activities. The probability of achieving those milestones on time is calculated by multiplying the probability of each of the logic strands being completed according to schedule.

The MBE (mentioned above) is one of the main reasons why it is so challenging to accelerate projects or make up for lost time. It is also a reason why projects, particularly complex projects, tend to be unrealistically optimistic when using deterministic scheduling techniques. Simplifying schedules or focusing only on the critical path removes the constraint of the MBE.

To increase the quality of risk management and the accuracy of contingency determination, it is critical to be aware, plan for, and mitigate the possible impacts of cognitive biases within the organisation and project team. Table 2 represents some common biases that may affect contingency determination.

Cognitive bias	Description
Anchoring bias	In a risk workshop, people may base their judgment on the first estimate of the likelihood of risk occurrence and potential consequences.
Availability heuristic	People may weight available information too highly. For example, a project manager may assert that high rainfall will not affect schedule as it has never delayed any of her previous projects.
Group thinking	People are likely to agree with views if they are expressed by others.
Blind-spot bias	Workshop participants may be less likely to see their own cognitive biases than other than those of their fellow participants.
Confirmation bias	People are predisposed to selectively absorb facts that validate their existing opinions.
Overconfidence	Overconfident workshop participants may believe that they are able to overcome higher risks.
Optimism bias	People may lean towards unrealistically optimistic estimates of cost and schedule.
Recency bias	Workshop participants may judge the importance of data based on how recently it was obtained.

Table 2: A number of different types of cognitive biases

To reduce the effect of cognitive biases, it is critical to identify and assess the key potential causes of delay and/or cost overrun by using methods that explicitly anticipate these biases and address them objectively, and also consistently facilitating a number of review meetings, conversations, meetings, and workshops.

2.6.4 Strategic Misrepresentation

Strategic misrepresentation is intentionally altering project plans (e.g. schedule, cost and risks) for political, regulatory, economic, reputational, competitive, personal or other benefits. One example is project or program owners deliberately understating the probability of a project failing, while amplifying the likelihood of success. However, it should be also noted that deception and corruption are topics beyond the scope of the risks and uncertainties measured by risk practitioners.

Since 1989, a number of studies have highlighted the negative impact of strategic misrepresentation on cost overruns. For example, a Grattan Institute study of 836 Australian transport projects highlighted that cost overruns are 23% higher on average for projects announced close to an election than for similar projects announced at other times.

The list below provides a few examples of strategic misrepresentation in decision making:

- premature announcement of projects driven by political agenda, e.g. for electoral gain
- underestimation of internal and external interfaces and their potential negative impacts
- organisational pressure to secure more projects, e.g. market share or competition
- personal objectives to secure more projects, e.g. bonuses or promotion.

2.6.5 Organisational Culture

Political, economic and psychological factors – usually caused by individuals – have been assessed by a number of recent studies. However, further investigation is needed into whether organisational culture can lead to poor project planning and forecasting and consequent cost overruns and/or schedule delays. One example of organisational culture factors is found in consultancy firms – where there is a false expectation that to have a successful business, consultants need to adjust results to serve the client's objectives and expectations.

2.7 Further Reading

- AACEi, PGD 01 – *Guide to Cost Estimate Classification Systems*, Rev. August 2018, <library.aacei.org/pgd01/pgd01.shtml>
- AACEi, PGD 02 – *Guide to Quantitative Risk (under development in Feb 2019) Analysis* <web.aacei.org/resources/publications/professional-guidance-documents>
- AACEi, PGD 03 – *Guide to Cost Estimating (under development in Feb 2019)*
- AACEi, CE-48: *Understanding Estimate Accuracy (DRAFT in Feb 2019)*
- Association for Project Management, *Project Risk Analysis and Management Guide*, APM Publishing, 2nd Edition, 2004
- Flyvbjerg, B., *The Oxford Handbook of Megaproject Management*, Oxford Handbooks , 2017
- Grattan Institute, *Cost Overruns in Transport Infrastructure*, 2016
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3. Key Concepts of Contingency Management

3.1 Structure of Content

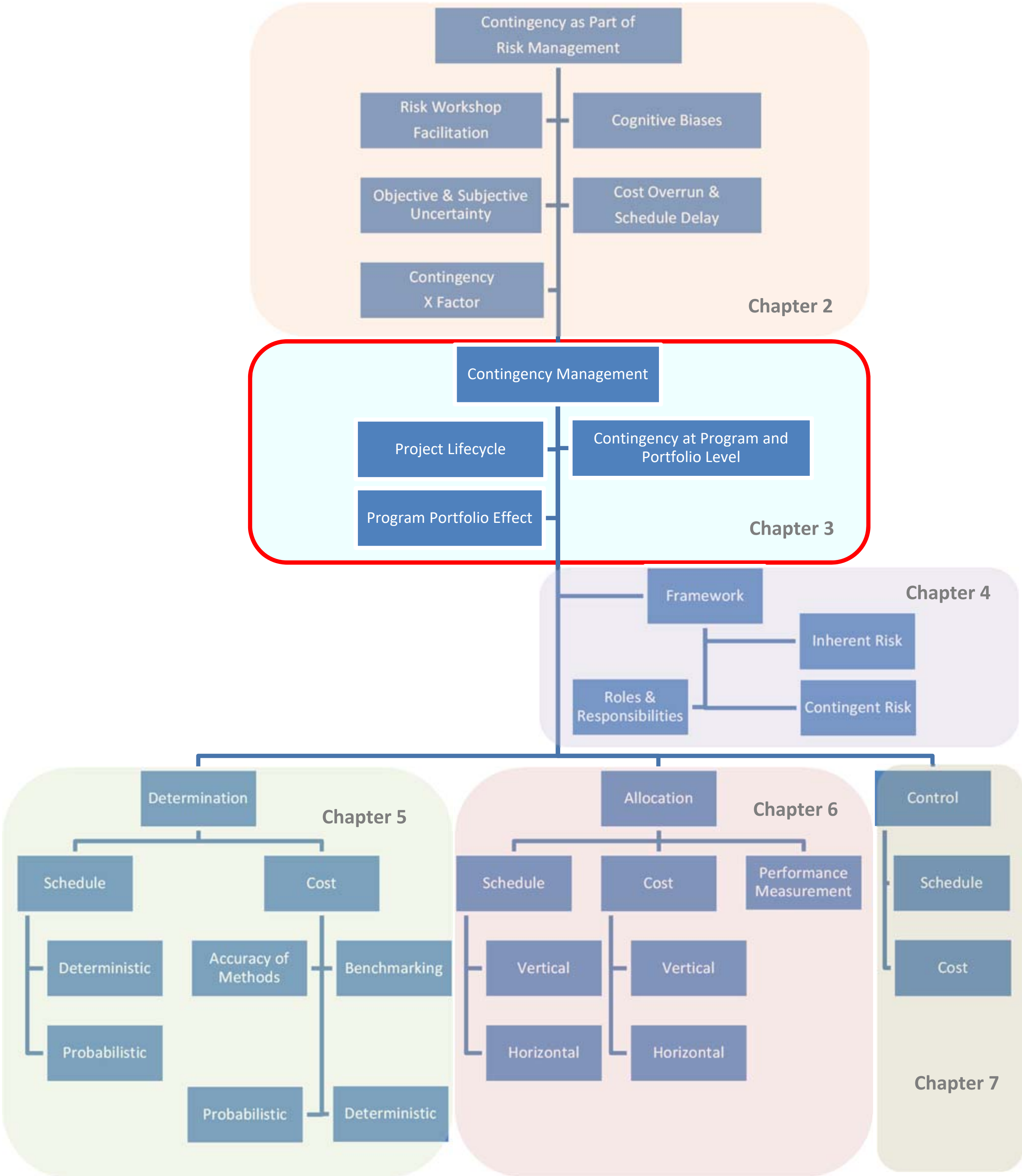

Figure 5: RES Contingency Guideline – Structure of Content

3.2 Contingency & Project Lifecycle

Almost all enterprises, public or private, have a level of stage-gate project scope definition processes in place. These gate reviews are part of an effective risk management process, based on research showing that staged funding avoids wasting money on the wrong projects, while increasing chances of success for those that are approved.

A good practice project lifecycle is divided into phases with decision gates supported by approved procedures and processes. Contingency management should be a dynamic process throughout the project lifecycle.

As shown in Figure 6, six phases will be used in this Guideline, namely: Initiation; Strategic Assessment (i.e. Preliminary Business Case); Concept (i.e. Final Business Case); Delivery Readiness; Delivery; and Finalisation. The Guideline also defines six decision gates:

- Gate 0: Project Justification
- Gate 1: Strategic Assessment (i.e. Preliminary Business Case)
- Gate 2: Business Case (i.e. Final Business Case)
- Gate 3: Pre-Tender
- Gate 4: Tender Evaluation
- Gate 5: Pre-Commissioning
- Gate 6: Post-Implementation

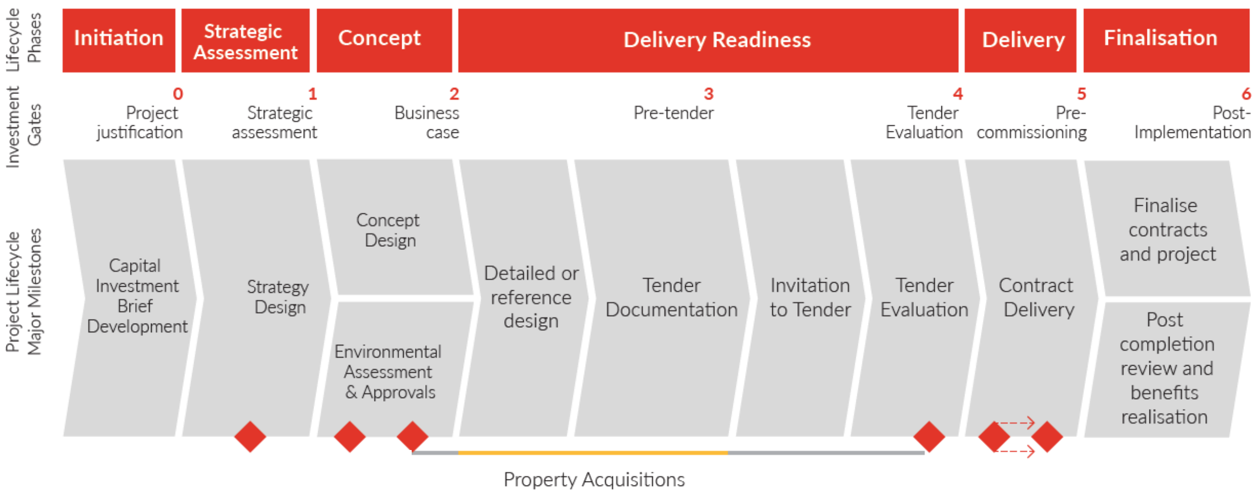

Figure 6: A typical project lifecycle and its key phases and milestones

The required contingency for a desired confidence level changes throughout the project lifecycle depending on a variety of factors. Some examples are: actual progress of activities against the project plan, scope variations, unforeseen events, public opinion, technology and complexity, political changes, and impacts of internal and external stakeholders.

It should be noted that the level of scope definition and associated estimate and schedule classifications should also be measured as a basis for objective contingency determination.

RES Recommendation: as a minimum, risk and contingency workshops should be planned at the key points below (with reference to Figure 6):

- at the end of the Initiation Phase
- during the Strategic Assessment Phase:
  - to support assessing the required contingency within the Preliminary Business Case
  - to support Optioneering and Value Engineering for the selection of the preferred option.
- during the Concept Phase: to support the assessment of contingency in the Final Business Case
- during the Delivery Readiness Phase:
  - to support tender documentation, i.e. contingency allocation to different packages
  - to support tender evaluation, i.e. comparing tender responses against risk assumptions
  - to support setting project Performance Measurement Baseline for progress reporting.
- during the Delivery Phase:
  - to support contingency control as well as the change control process
  - to assess the project confidence level against the desired confidence level.

Another approach – recommended by AACEi – is to classify cost and schedule estimates according to the level of the project (e.g. Class 1, 2, 3, 4, and 5). However, it should be noted that accuracy and class are not interrelated. Accuracy can only be determined through Quantitative Risk Analysis (QRA), and each scope and estimate will have its own unique range driven by its unique uncertainties and risk profile. Figure 7 below illustrates the concept of improving accuracy with increased scope definition (as a percentage of the full definition).

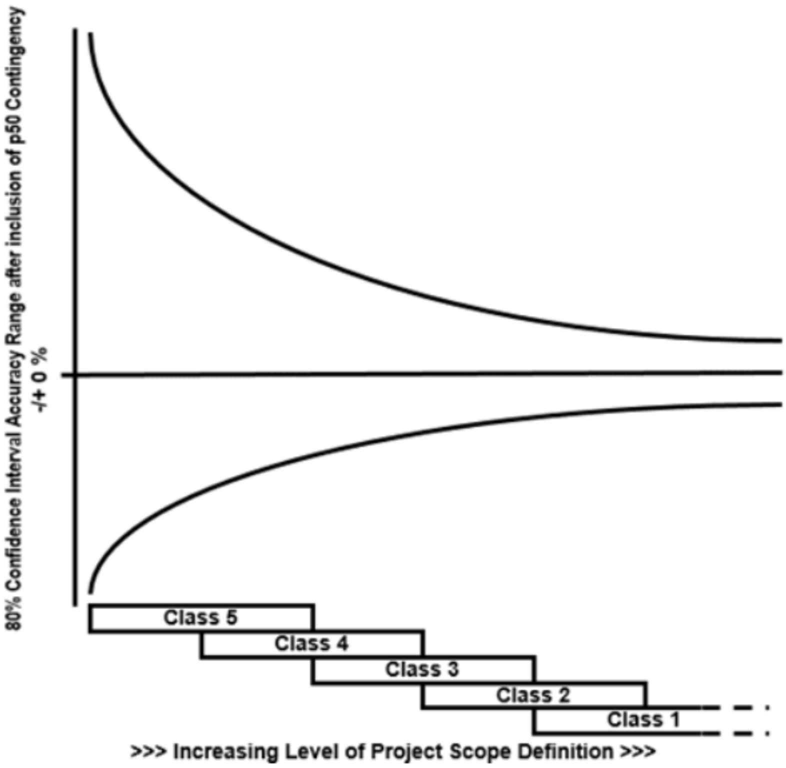

Figure 7: Estimate accuracy improves as the level of project definition improves (RP CE-48, AACEi)

Research shows that the level of scope definition, i.e. inherent risks (Section 4.3), is the dominant uncertainty in early phases, driving the need for significant contingency. The level of technology and complexity are also major risk drivers that can be identified early, prior to each decision gate.

For most projects, the Base Estimate and Base Schedule change as the project progresses through various phases of its lifecycle and additional planning, engineering and design information become available. Each possible outcome value of the total project cost can have a P value, or confidence level, which indicates the probability of underrunning that cost. For example, a P50 cost incorporates enough contingency for a 50% probability that the project will not overrun this cost.

As the Base Estimate changes, the estimated contingency requirements for different confidence levels also change. Ideally, the P50 or mean value of the cost distribution will stay constant from phase to phase. In practice, the P90 contingency generally decreases and the P50 contingency increases as the Base Estimate increases and further scope and uncertainties are defined and quantified. This is presented in Figure 8. Definitions of terms used above (including P values, Base Estimate and Base Schedule) are at Appendix A.

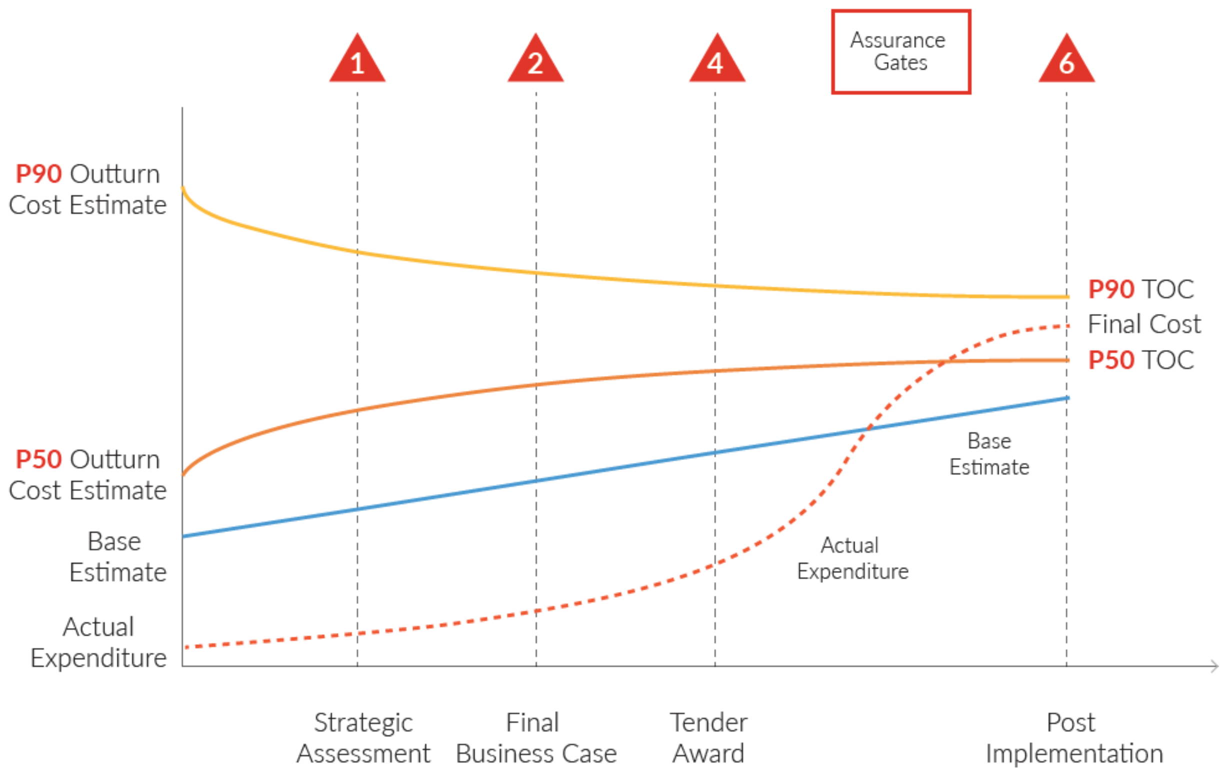

Figure 8: Cash flow and P(X) contingency movement in a typical successful project

It is common for owners to compare the project's Final Actual Cost against the project Total Outturn Cost (TOC) estimate (e.g. TOC P50 and TOC P90) in the Final Business Case (FBC). Three possible scenarios are presented in Figure 9. It should be noted that funding a project at P90 level is not common in the private sector, as it may lock up capital for other deserving projects.

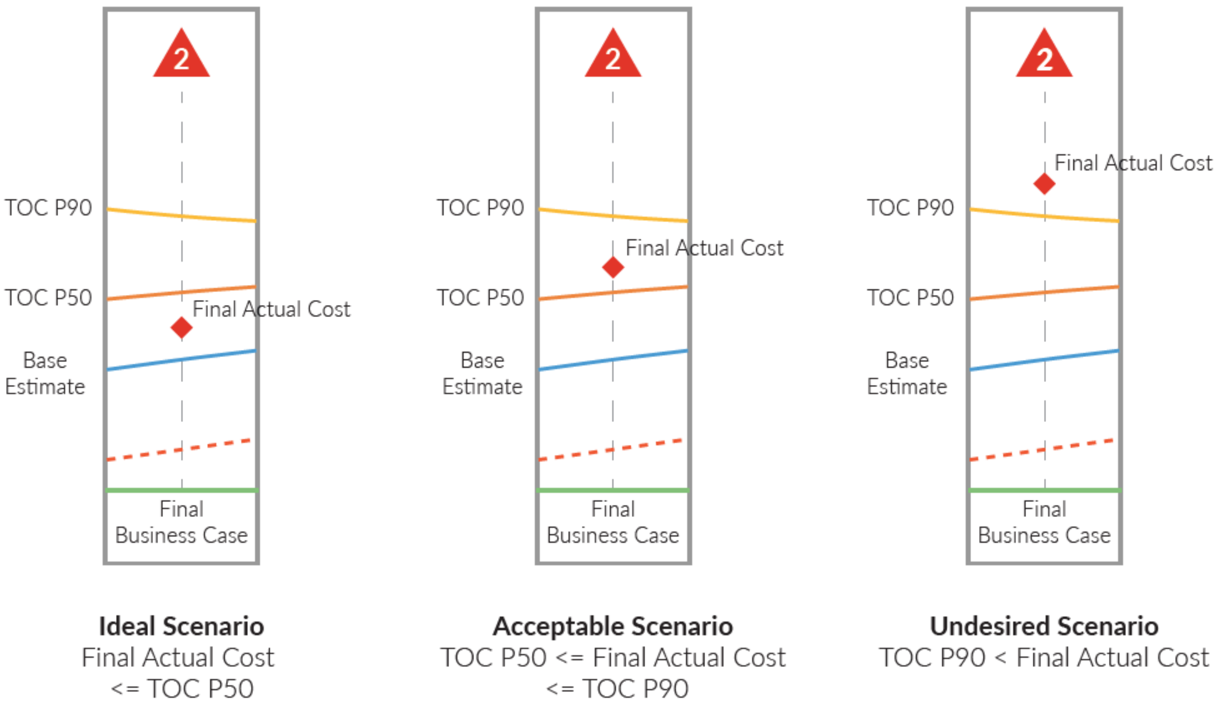

Figure 9: Three possible scenarios of Final Actual Cost against Base Estimate, TOC P50 and TOC P90

Further explanation of the scenarios in Figure 9 is below:

- In the ideal scenario, the project's actual cost is less than or equal to the TOC P50 estimate at Final Business Case (FBC)
- In the acceptable scenario, the final actual cost does not exceed the initial Base Estimate plus the budgeted (or allocated) contingency, e.g. TOC P90. In this scenario, the net changes caused by occurred risks and/or inherent risks were fully absorbed by the contingency reserve
- In the undesired scenario, the final actual cost is well above the initial Base Estimate and budgeted (or allocated) contingency reserve, e.g. TOC P90. However, the RES Contingency Guideline acknowledges that while these projects might not be desirable from a project cost and/or schedule objective, they might be achieving other key objectives – for example stakeholder and community asset outcomes and benefits.

In addition, an assessment of project schedule – from phase to phase – is also needed. The schedule estimate uncertainty tends to be less than that of the cost estimate. This is partly due to cost and schedule trading, i.e. the completion date is often made involute by the business – therefore costs increase as the project seeks to achieve an increasingly difficult goal as scope information increases.

3.3 Contingency at Program & Portfolio Level

Proactive project risk and contingency management aim to increase the probability of achieving cost and schedule objectives. This includes managing risks so as to address program and portfolio (i.e., overall capital budget) objectives which may differ in some respects from the individual projects. One strategy is to carry out risk and contingency management at the project level, followed by assessment of additional or secondary risks (e.g. compounding) at a higher program and portfolio level – combined with integration of risk and contingency information. Research suggests that this approach is positively associated with program and overall project portfolio success, and provides an effective platform to assess the organisation's risk exposure.

Risk and contingency management should be carried out simultaneously for projects and their parent programs. Periodic risk and contingency management at the portfolio level, tied to overall capital management, will provide added benefits. Movement and reallocation of contingencies between projects within a portfolio may not be permitted – especially within the public sector. However, having a method of contingency assessment at all levels of projects, programs and portfolio is very valuable, and necessary for a program where projects with a common objective report through a program director.

Overall contingency management is concerned with assessing and utilising funds set aside to cover costs that exceed the Base Estimate at different organisational levels.

This has been illustrated in Figure 10.

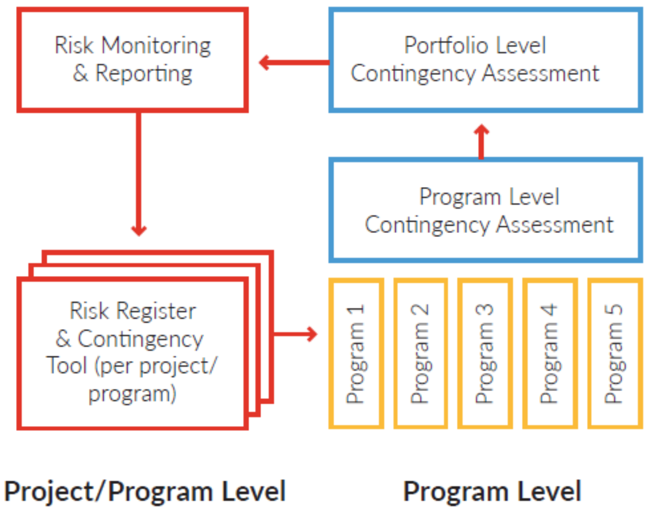

Figure 10: Contingency management at project, program and portfolio levels

RES Tips & Tricks: this Guideline also highlights the importance of identification and removal of any buried or above-the-line contingency within the Base Estimate or Base Schedule. In order to keep a project on track, buried cost and time contingencies are sometimes concealed within the Bases in case the explicit contingency is underestimated or written out of the project. Buried contingencies can lead reviewers to believe that the budget has been raised due to inappropriate allowances or decreasing productivity. RES does **not** recommend the use of buried contingency.

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Contingency management at the project level is often focused on inherent risks from the project point of view and individual risks that, should they occur, will require funds or time in excess of the allowance provided in the bases for management. At a program level – from the point of view of the program business sponsor and director – there are likely to be added or secondary risks resulting from interaction and/or compounding of the component projects. These risks need to be assessed, and unique contingency established for their management by the program director or a similar authority. Such contingencies need to be assessed and managed in conjunction with other relevant information to determine whether new investment can be added to the portfolio while the organisation is comfortably below its risk appetite.

RES Recommendation: this Guideline recommends the following approaches when managing contingencies at the program or portfolio levels:

- Develop and implement a standard risk policy for scheduling, estimation, issues, and risk registers, and implement reporting cycles to ensure appropriate contingencies for the project while also considering program and portfolio objectives
- Implement a consistent approach to consolidate and integrate reports from projects to programs and portfolio (note: from a statistical viewpoint, be aware that only the mean value of distributions is additive in a program or portfolio, e.g. P50s are not additive)
- Assess interdependencies such as milestones and resources between projects
- Plan the consolidation of multiple projects using interface relationships (integrated schedule)
- Assess secondary risks (e.g. complexity) that may occur at the program and portfolio level
- Develop and implement a transparent view of issues, risks and change control at the project, program and portfolio levels.

The additional information and interaction risks to be assessed at the portfolio or program level can include: risks which affect multiple projects through the project's interdependencies (e.g. shared resources); the level of existing risk in the portfolio or program; the level of over-programming; requirements to make provision for potential project cost overruns; and constraints for sharing funds between projects (e.g. Federal funds).

The decision to invest in a new project should also take into account the fact that the potential savings offered by a project will not become actual savings until the project is completed. Figure 11 shows the interrelationship of risks at the project, program and portfolio levels.

Figure 11: Interrelationship between risks from project to portfolio

The key to portfolio and program risk management is to assess all the risks at the appropriate level and centralise risk reporting, centralise (but separate) the project, program and portfolio risks and their allocated contingencies and devise effective and applicable metrics and matrices across all levels. Then the required overall contingency at the program level for desired confidence level should be assessed. Any surplus between the required overall contingency and the sum of available project contingencies can be utilised for other beneficial initiatives.

It should be also noted that internal projects for capability development may be best dealt with at the portfolio level (e.g. the Project Management Office and project management maturity improvement project).

3.4 Program Portfolio Effect

It is theoretically possible to optimise the forecast portfolio return – or keep the risk as low as possible for a given return – by selectively allocating resources. This is known as Modern Portfolio Theory (MPT).

The Program Portfolio Effect results from the fact that most organisations manage a number of projects concurrently. The confidence level of each project, as well the degree of correlation between projects, can influence the level of confidence of the parent program. For sufficiently diversified programs, the combined risk tends to be less than for individual projects.

To take advantage of the Program Portfolio Effect, the budgeted contingency allowances should be managed at the program/portfolio level. When projects do not need to use their entire contingency, the remaining amount should be reallocated to other projects. By combining an active Program Portfolio Effect with an efficient contingency management process, it is possible for organisations to maintain a high confidence level at the program or portfolio level even if individual project confidence levels are low.

Table 3 presents an example of the portfolio probability for various numbers of projects, project probabilities, and two levels of project correlation.

		Portfolio Probability	
# Projects	Project Probability	No Correlation	0.25 Correlation
5	50%	38%	40%
5	60%	61%	59%
5	70%	80%	78%
5	80%	94%	92%
10	50%	32%	36%
10	60%	62%	61%
10	70%	87%	83%
10	80%	98%	96%
20	50%	24%	32%
20	60%	65%	61%
20	70%	94%	86%
20	80%	99%	98%

Table 3: Portfolio probabilities for different levels of project correlation (AFCAA, 2007)

One point to note from Table 3 is that the portfolio for individual project probability of 60% is also around 60% probability for both '25% Correlation' and 'No Correlation' regardless of number of projects. This is because there is no Program Portfolio Effect if projects are funded at the mean. With skewed distributions, the mean is generally greater than P50 – P60 being typical. This also highlights that the P50 (median) is not risk neutral, it is aggressive because the median does not address skewed reality.

Also important is the effect of reducing the probability of individual projects on the portfolio probability. A drop from 60% to 50% project probability for portfolios containing 10 or 20 projects results in a reduction of portfolio probability of 25% and 29% respectively. This demonstrates that increasing the project risk exposure by small amounts can markedly decrease the likelihood that funding levels will be met at the portfolio level.

According to the US Airforce *Cost Analysis Agency (AFCAA) Handbook* (2007), the mean is greater than the median for (approximate) lognormal uncertainty distributions – which results in low portfolio probabilities for 50% project probability. Therefore, increasing project probability to 60% (which is usually close to or greater than the mean) can increase portfolio probabilities about the 50% level. The median is always lower than the mean, and for that reason, funding projects at 50% result in weak portfolio probabilities. RES suggests that funding projects at 60% (generally near or above the mean) bring portfolio success to above 50%. Raising project probability above 70% can deliver better portfolio probabilities, but is costly. The AACEi definition of contingency is "expected to be expended" – and the expected value is the mean. (see Hamaker's paper in the Further Reading section for more information).

Figure 12 shows that the program confidence level increases above individual project confidence levels when the project have a probability greater than 50%, which increases with the number of projects in the program.

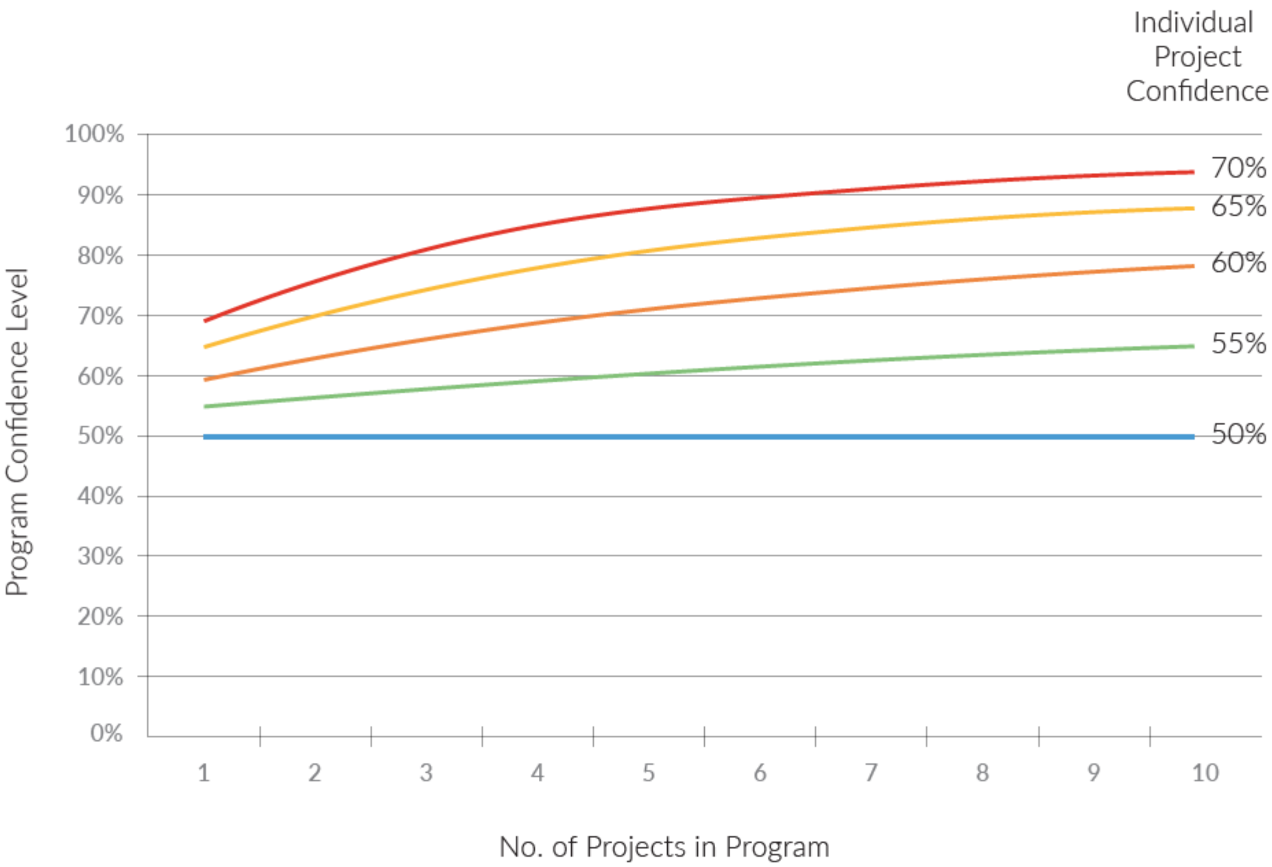

Figure 12: Portfolio probabilities for multiple projects (AFCAA, 2007)

RES Example: ABC, a government agency, is currently managing its portfolio of 20 projects, under four separate programs. While allocated funding can be moved between the projects under each program, it cannot be transferred between programs. The latest progress reports are highlighted below:

- Program 1: including 10 projects, remaining P80 contingency for each project is $2m (total of $20m)
- Program 2: including five projects, remaining P80 contingency for each project is $1m (total of $5m)
- Program 3: including two projects, remaining P80 contingency for each project is $5m (total of $10m)
- Program 4: including three projects, remaining P80 contingency for each project is $2m (total of $6m).

Hence, the summation of required contingencies suggests the P80 contingency of $41m. However, to maximise opportunities for additional projects, ABC developed an integrated risk and contingency assessment platform across the whole profile rather than the summation of project contingencies. The assessment revealed that a contingency of $37m would be enough for a confidence level of 80%, i.e. P80, at the portfolio level.

This assessment supported ABC management to proactively plan to utilise this surplus contingency of $4m, (i.e. $41m minus $37m), to bring one additional project forward into Program 3. Hence, the Program 3 will have three projects.

3.5 Further Reading

- AACEi RP No. 17R-97 – *Cost Estimate Classification*
- AACEi RP No. 18R-97 – *Cost Estimate Classification System – As applied in engineering, procurement, and construction for the process industries*
- AACEi RP No. 27R-03 – *Schedule Classification System*
- AACEi RP No. 40R-08 – *Contingency Estimating – General Principles*
- AACEi RP No. 46R-11 – *Required Skills and Knowledge of Project Cost Estimating*
- AACEi RP No. 62R-11 – *Risk Assessment: Identification and Qualitative Analysis*
- AACEi RP No. 63R-11 – *Risk Treatment*
- AACEi RP No. 67R-11 – *Contract Risk Allocation As Applied in Engineering, Procurement and Construction*
- AACEi RP No. 70R-12 – *Principles of Schedule Contingency Management – As Applied in Engineering, Procurement and Construction*
- AACEi RP No. 71R-12 – *Required Skills and Knowledge of Decision and Risk Management*
- AACEi RP No. 72R-12 – *Developing a Project Risk Management Plan*
- AACEi RP No. 75R-12 – *Schedule and Cost Reserves within the Framework of ANSI EIA-748*
- AACEi PGD 01 – *Guide to Cost Estimate Classification Systems* <library.aacei.org/pgd/pgd01.shtml>
- AACEi PGD 02 – *Guide to Quantitative Risk Analysis* <web.aacei.org/resources/publications/professional-guidance-documents>
- AFCAA, *Cost Risk Analysis Handbook*, 2007
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Spreadsheets, Cambridge University Press, 2003

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- Department of Infrastructure, Regional Development and Cities, *National PPP Guides Volume 4*: PSC Guidance
- Department of Treasury and Finance, Victoria, *Investment Lifecycle and High Value/High Risk Guidelines – Victoria*, 2012 and updates
- Hamaker, Joseph "NASA Risk Adjusted Cost Estimates"; NASA Headquarters Cost Analysis Division; International Society of Parametric Analysts Annual Conference, May 23-26, 2006
- IEC/ISO 31010 *Risk management – Risk assessment techniques*
- ISO 31000:2018 *Risk management – Guidelines (principles, framework and process)*, 2018
- New South Wales Government Treasury, *Guidelines for Economic Appraisal*, 2007
- PMI, *Project Management Body of Knowledge (PMBOK)*, Project Management Institute
- PMI *Practice Standard for Project Estimating*, Project Management Institute
- PMI, *Practice Standard for Project Risk Management*, Project Management Institute
- PMI *Practice Standard for Work Breakdown Structures*, Project Management Institute
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4. Contingency Management Framework

4.1 Structure of Content

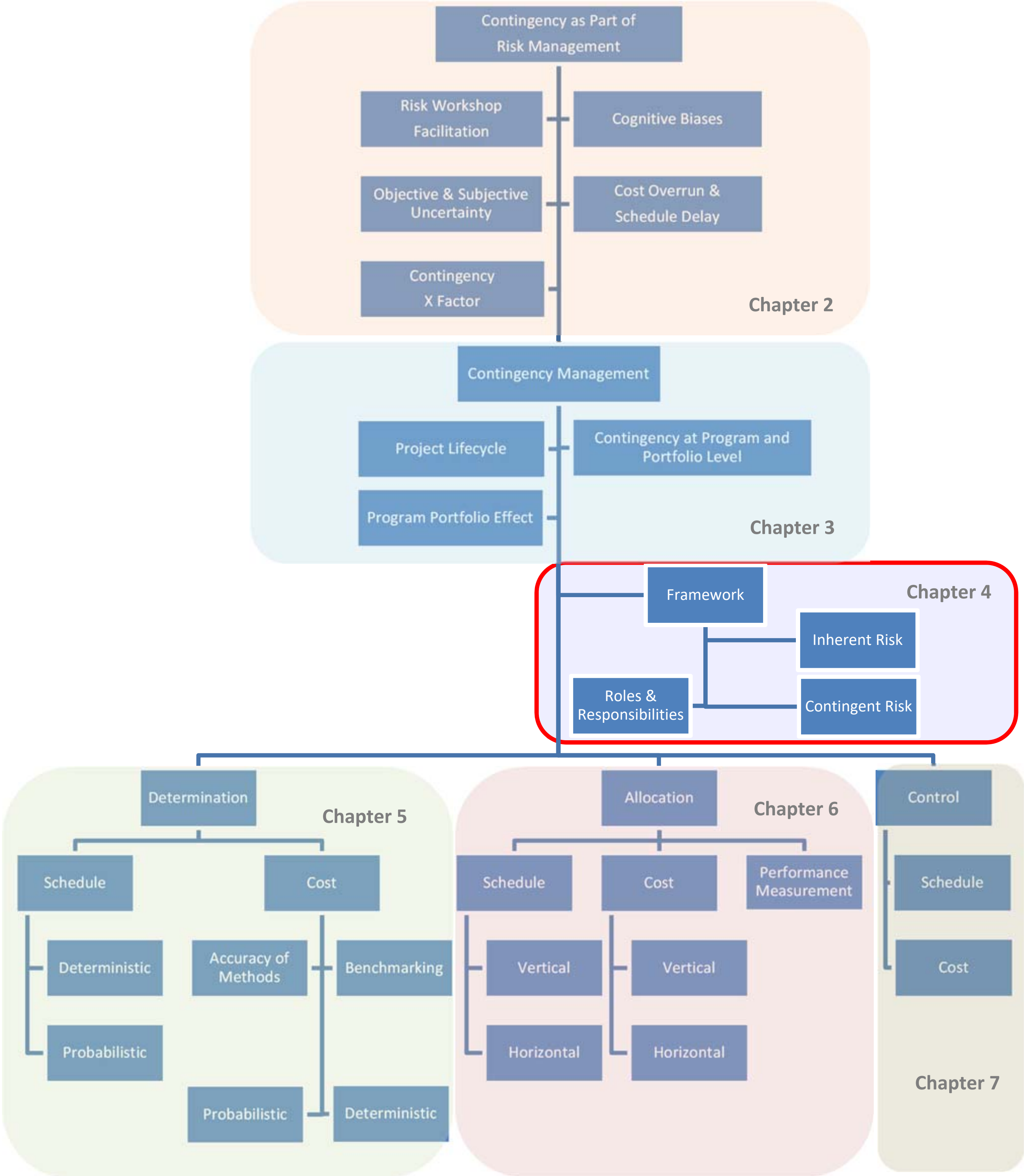

Figure 13: RES Contingency Guideline – Structure of Content

4.2 Overview

The main purpose of the contingency management framework is to provide a reference document for a consistent approach to analysing, determining, allocating and managing the most appropriate and reasonable contingency allowance (time and cost) at different stages of the project lifecycle. The risks facing the project as well as the organisation's risk tolerance and Delegation of Authority (DoA) at different levels of the organisation will also be discussed. The framework establishes a consistent approach and methodology to aggregate contingency data from projects up to the program level and consolidation into the portfolio level.

RES Recommendation: for an effective contingency management framework, within an overall risk management framework RES recommends that the key sections below are included within the framework:

a) Objectives
b) Scope, e.g. specific project, program/department or across the organisation
c) Key Definitions, including inherent and contingent risks
d) Internal and external constraints and requirements, e.g. funding allocation, reporting, assurance gates, contingency accessibility and Delegation of Authority (DoA)
e) Scope/Cost/Schedule/Risk/Change Integration Process
f) Roles and responsibilities (Responsible, Accountable, Consulted, Informed (RACI) Matrix)
g) Contingency Determination
h) Contingency Allocation
i) Contingency Controls
j) Monitoring and reporting
k) Tools and infrastructure.

Any decision for selecting a preferred contingency management approach or methodology should consider a wide range of matters, including the key factors below:

- complexity of the project or program
- level of investment assessment (e.g. the project or program level)
- past performance of the organisation and availability of reliable historical data
- project and risk management maturity level of the organisation
- delivery strategy and type of contract (e.g. managing contractor; early contractor involvement; design and construct or construct only; public private partnership; alliance; or joint venture)
- type of project (e.g. defence; communications; events; organisational change; infrastructure projects; or facility management projects including decommissioning, demolition or maintenance)
- project classifications, for example:
    - minor projects (value less than $10 million)
    - major projects (value more than $10 million)
    - complex projects (exceptional projects with unique risk profiles)
    - mega projects (value greater than $1 billion).
- stage of the investment lifecycle (e.g. strategic, final business case, delivery, or finalisation)
- level of investment (e.g. project, program, or portfolio).

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4.3 Inherent & Contingent Risks

For the purposes of this Guideline, inherent and contingent risks are defined according to the NASA Cost Estimating Handbook (Version 4, Appendix G). Different risk types mean different risk quantification methods for optimal outcomes – so it is important for risk practitioners to distinguish between them in order to ensure that the risk model and plan incorporate appropriate assessments for risk and uncertainty.

Inherent risks also include systemic risks which recognise the system nature of projects and their management. A system – including processes, people, tools and resources – is only as strong as its component parts, and how well they are tied together. If a system is weak, it can fail in multiple ways and it is difficult to effectively allocate contingency.

Many of the cost impacts of risk events on large and complex projects arise from the cost consequences of delays or disruptions. In particular, the trading of cost for schedule can be problematic – for example spending money so that the schedule does not slip. When modelling the uncertainty of project schedule and cost it is important to bring together all possible drivers – including risks that impact schedule – and assess cost and schedule risks together. Project cost drivers may be grouped into five types:

a) uncertainty (i.e. inherent risk or planned risk) around time-independent costs
b) uncertainty (i.e. inherent risk or planned risk) around time-dependent costs
c) uncertainty (i.e. systemic risks) of the project system with non-attributable cost and time impacts
d) risk event (i.e. contingent risk or unplanned risk) with cost impacts
e) risk event (i.e. contingent risk or unplanned risk) with time impacts that drive costs.

Inherent risks stem from the inability to be certain about the nature and behavior of the project system and its interaction with external economic, political and other systems. The likelihood of occurrence of inherent risk is 100%.

Practitioners should determine probability distributions used to model inherent uncertainty by considering the prior experiences of comparable teams on similar projects – combined with historical data. Fortunately, much of what drives inherent risks (e.g. the level of scope definition and team development) is commonly generic between projects, and the uncertainty resulting from these drivers has been shown to be fairly predictable (e.g. comparable poor team development results for similar uncertainty conditions across projects).

In the early phases of the project lifecycle, the use of empirically based models of inherent risks can be more reliable than the judgment of the team, or a limited database (if a risk database is available).

Examples of inherent risks are non-uniform construction techniques, pricing and scope uncertainties, and uncertainty over the amount of resources and their cost per unit in the Base Estimate. These are identifiable technical causes, but more importantly, there is uncertainty about how the system will behave, particularly when presented with an accumulation of weak practices, skills, and knowledge – and subjected to the stress of risk events.

Figure 14 presents two probability distributions (Normal and Triangular) representing point estimates of individual project Work Breakdown Structure (WBS) cost elements. Marked on the distributions are the mean (50^{th} percentile), median (expected value) and mode (most likely value).

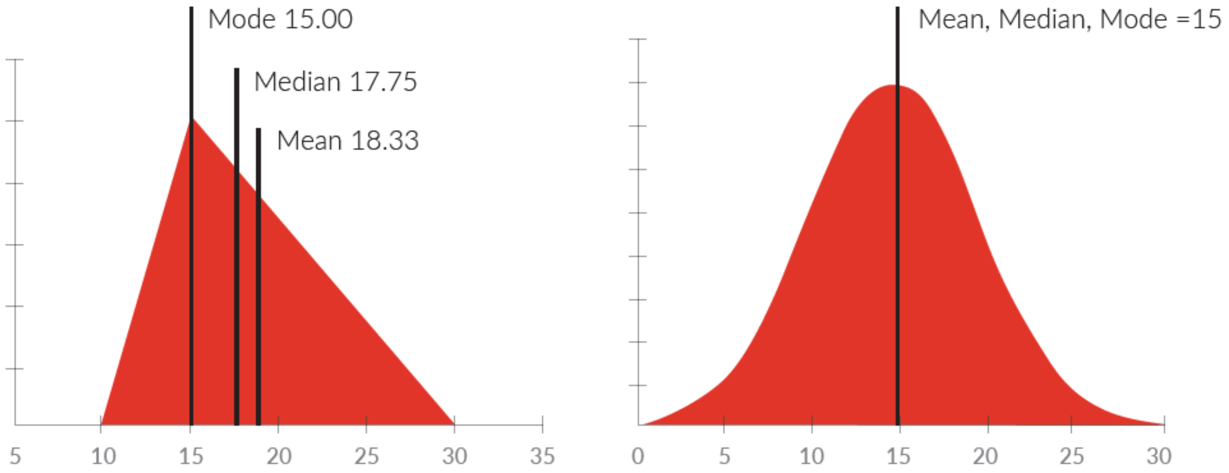

Figure 14: Statistics of Triangle and Normal distributions (NASA Cost Estimating Handbook)

The Central Limit Theorem (CLT) states that when the sum large amount of random independent variables is averaged, it converges to a normal random variable (as long as the mean and variances are finite). Therefore, the probability distribution for the combined cost of an increasing number of WBS items can be approximated by the normal distribution, as shown in Figure 15.

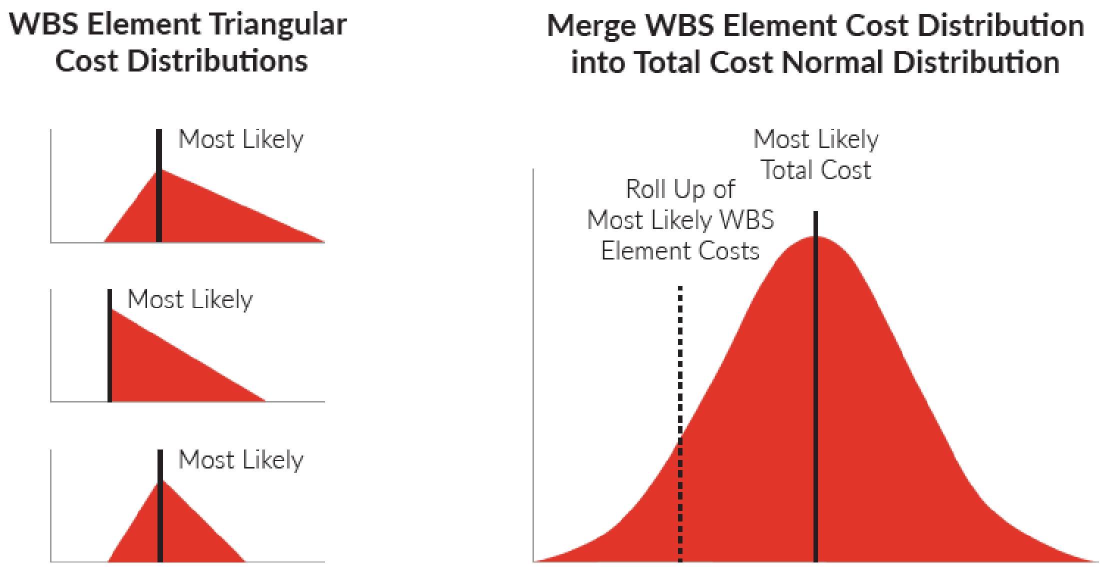

Figure 15: Central Limit Theorem (NASA Cost Estimating Handbook)

Three of the more commonly used probability distributions for assessing inherent risks are Triangular, Normal, Pert and Lognormal (or their Alt format) distributions. Both Triangular and Pert can be defined with three-point estimates, so are most widely used in practical risk analysis. In the Monte Carlo Simulation technique, a Triangular distribution requires three inputs to be defined: best case or lowest; most likely; and worst case or highest. These inputs can be generated either objectively or subjectively. The objective method defines a probability distribution for each WBS element using the three cost elements, while subjective inputs can be based on elicitation by SMEs (see Section 2.3.2).

It should be noted that many risk analysts prefer to use the Alt format of Triangular and Pert distributions to address overestimation of the best-case numbers and underestimation of the worst-case estimates.

To increase the number of possible outcomes represented, risk practitioners can vary the extremes of Pert or Triangular distributions. In the case where the standard deviation and mean are known, practitioners prefer to use Normal and Lognormal distributions (shown in Figure 16). This approach does not require the best or worst case inputs.

The lognormal distribution, which cannot go below zero and is nonsymmetrical, is generally preferred over the normal distribution by many risk analysts. This is because many risks are bounded at zero. For example, if the Base Estimate assumes three lost days per month due to rain – the best case is zero. However, the 3 lost days of rain per month, the best is 0, but worst case could be 30, which is skewed in a similar way to the lognormal distribution.

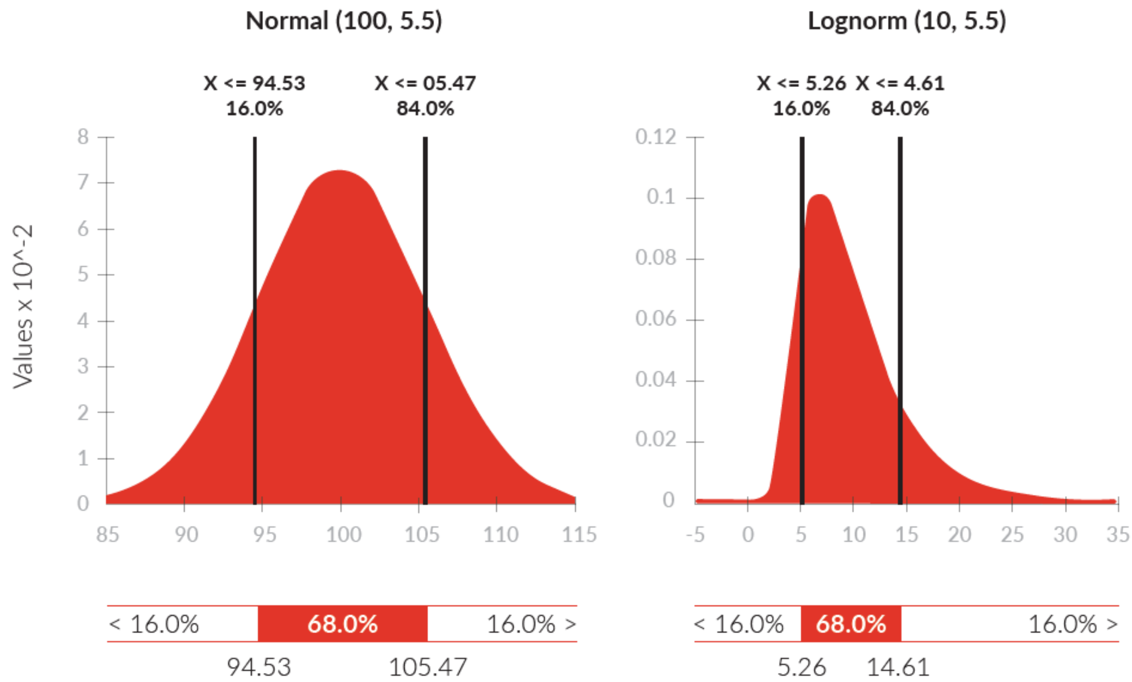

Figure 16: Normal and Lognormal distributions (NASA Cost Estimating Handbook)

As opposed to inherent risks, contingent risks are generally caused by events or conditions not included in the Base Estimate or Schedule. Unlike inherent risks, which have a 100% likelihood of occurrence, contingent risks may or may not occur. Therefore, their likelihood of occurrence is always less than 100%. Examples of contingent risks are delays or cost increases due to bad weather and other incidents which have not been predicted, industrial action, planning approvals, scope variations, or unexpected site conditions detected by geotechnical engineers. Potential unsubstantiated claims from contractors, which do not result of from risk events or conditions, are also contingent risks.

To realistically assess the various drivers of cost and schedule uncertainty, these drivers should be integrated into a single model – or integrated set of models that best address each type of risk. This allows all effects to be simultaneously modelled and the drivers identified and ranked to enable risks to be managed. Selection of the most appropriate approach depends on a number of factors including, but not limited to:

a) project phase
b) contract type
c) delivery strategy (e.g. self-delivery or subcontracting)
d) internal and external requirements

e) constraints
f) project risk profile
g) risk appetite, risk and contingency management maturity of the organisation.

RES Tips & Tricks: If all random variables have the same distribution and are perfectly correlated (i.e. they always take the same random value) then the percentile of the sum (e.g. sum of P90s) of each individual project, will be exactly the same as the sum of percentiles (e.g. P90 of all projects together as a program). It is obvious that, in practice, this is not common at all. Hence, we generally expect the sum of P90s to be greater than the overall P90. This is also true when modelling inherent and contingent risks. For assessing an optimum amount of contingency allowance, RES recommends assessing both inherent and contingent risks together to determine the optimum overall contingency.

In addition to definitions of inherent and contingent risks, there are a number of other relevant definitions being used in industry – including 'unknown unknowns' or unidentified risks. While unknown unknowns have conventionally been outside the scope of project risk management, this guideline recommends the definitions in Table 4 to consistently integrate these risks into the organisation's risk management framework. RES also acknowledges that some practitioners believe there are no unknown unknown risks – as all risks have eventuated in the past. These practitioners believe unknown unknowns are just risks which the project team have chosen not to quantify.

Identification \ Certainty	**Known (i.e. certain)**	**Unknown (i.e. uncertain)**
Known (i.e. identified)	Known Known (i.e. identified knowledge)	Known Unknown (i.e. identified inherent & contingent risks)
Unknown (i.e. unidentified)	Unknown Known (i.e. unidentified knowledge)	Unknown Unknown (i.e. unidentified risk)

Table 4: Combination of known and unknown uncertainties

		Base Estimate	**Inherent Risk**	**Contingent Risk**	**Contingency Reserve (CR)**	**Management Reserve (MR)**	**Examples**
Known	**Known**	X					Cost estimation of a foundation excavation by measuring its size using concept design and current productivity rate assumptions
	Unknown	X*	X	X	X		Volume of rock due to lack of geotechnical information. It should be noted that some allowances may be included with the Base Estimate to represent uncertain, but specific items
Unknown	**Known**			X	X		Possibility of hitting a live electrical cable due to lack of as-built drawings and brownfield nature of project
	Unknown					X	Hurricane Katrina in 2005

Table 5: Addressing known and unknown uncertainties at different locations

From the contingency perspective, the approach in Table 5 (above) can be used to address both identified and unidentified risks while assessing and managing optimum contingency. While management reserve can be allocated to manage unknown unknowns, RES recommends that the team should aim to convert unknown unknowns to known unknowns through the characterisation of relevant unknown unknowns. This allows these risks to be incorporated in the organisation's established risk and contingency management processes.

RES Example: contractor W2F is preparing its submission for a lump sum tender. All packages will be delivered using external subcontractors. In addition to obtaining a number of market quotes, W2F is also using its own internal benchmark data from previous similar projects. As part of the estimate development, W2F assessed and quantified the inherent and contingent risks as per the table below.

Discipline Package	Quote 1	Quote 2	Quote 3	Internal Benchmark	Final Decision
Design	$500k	$1m	-	$600k	$600k @ Base Estimate with the inherent risk below: Best Case = $500k Most Likely = $600k Worse Case = $1m
Civil Works	$15m	$16m	$20m	$15m	$16m @ Base Estimate with the inherent risk below: BC = $15m ML = $16m WC = $20m
Structural Works	$10m	$12m		Not Available	$10m @ Base Estimate, with possible contingent risk for claim, 50% probability with $2m cost
Mechanical Works	$5m	$7m	$10m	$12m	$12m @ Base Estimate, with possible contingent opportunity for saving, 70% probability (because all three quotes are less) with $2m-$5m-$5m saving. Considering the scope of works, Quote 1 is unrealistic and was excluded.
Electrical Works	$5m	-	-	$7m	$5m @ Base Estimate, with possible contingent risk for claim, 50% probability with $2m additional cost
Internal Resources				$1m	$1m @ Base Estimate with the inherent risk below: Best Case = $$800k Most Likely = $1m Worse Case = $1.5m
Contingency				?	All inputs above should be used to assess the required contingency allowance

As the project progresses through its lifecycle, it is quite common to see changes in the size of the respective contributions of inherent and contingent risks to the required contingency allowance. In the early stages of development, the inherent risks are key drivers (e.g. 60-70%) of required contingency, while contingent risks will be the key drivers at the delivery stage.

4.4 Contingency Management Process Overview

As assessment and management of contingency is integral to planning and execution of risk treatment, alignment of the two through the project lifecycle enhances the value of project risk management.

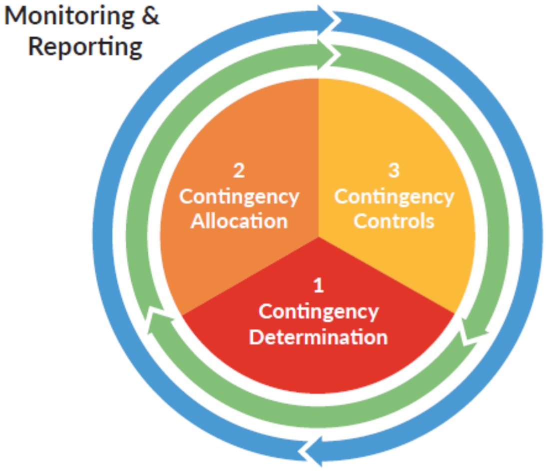

Figure 17: The overall process of the contingency management framework

The overall process has three key areas, which are applied at various stages throughout project lifecycle:

a) Contingency determination – how much contingency is enough for the desired confidence level?
b) Contingency allocation – providing guidance about delegation and allocation of available contingencies both within the project and at different levels of the project/organisation
c) Contingency control – providing guidance about contingency control measures

Figure 18 represents an example of a high level integrated approach to the contingency management process during the project development and delivery phases.

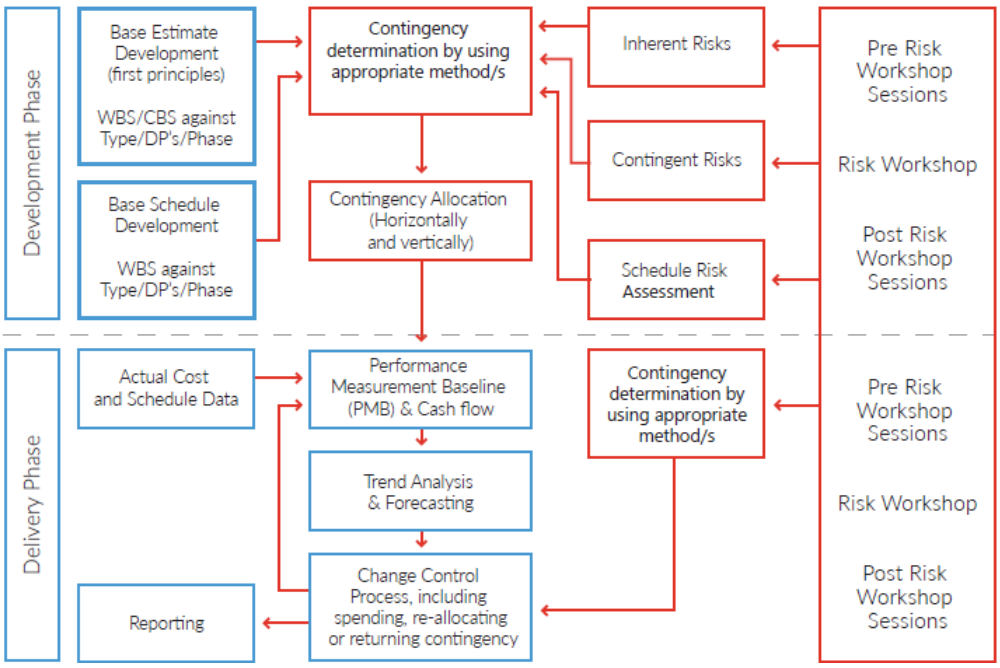

Figure 18: A typical high level contingency management process

4.5 Roles & Responsibilities

Similar to other integrated processes, the contingency management process has many inputs and outputs from different teams – as well as interfaces with internal and external stakeholders. To achieve an effective and transparent contingency management process, RES recommends a RACI Matrix (Responsible, Accountable, Consulted and Informed) to be developed and communicated within the project's contingency management framework.

For the purpose of this Guideline, the red highlighted boxes and interfaces in Figure 18 are the responsibilities of the risk practitioner, including capturing data as required; facilitating risk and contingency workshops; developing risk models; and reporting.

4.6 Relevant Qualifications and Certificates

There are a wide range of qualifications and certificates enabling the risk analyst to undertake the required roles and responsibilities, as highlighted in the previous section. Some of these relevant qualifications and certificates are:

a) Chartered Professional Engineer (CPEng – Risk Engineering), Engineers Australia
b) Chartered Professional Engineer (CPEng – Cost Engineering), Engineers Australia
c) Certified Cost Technician (CCT), AACEi
d) Certified Scheduling Technician (CST), AACEi
e) Certified Cost Professional (CCP), AACEi
f) Certified Estimating Professional (CEP), AACEi
g) Earned Value Professional (EVP), AACEi
h) Planning & Scheduling Professional (PSP), AACEi
i) Certified Forensic Claims Consultant (CFCC), AACEi
j) Decision & Risk Management Professional (DRMP), AACEi
k) Project/Program/Portfolio Management Professional (PMP, PgMP, PfMP), PMI
l) Certified Associate in Project Management (CAPM), PMI
m) PMI Risk Management Professional (PMI-RMP), PMI
n) PMI Scheduling Professional (PMI-SP), PMI
o) International Certificate in Financial Services Risk Management, Institute of Risk Management
p) IPMA (International Project Management Association) Levels A, B, C and D
q) PRINCE2 Foundation and Practitioner
r) PRINCE2 Agile Foundation and Practitioner
s) 10131NAT Certificate IV in Compliance & Risk Management
t) 10184NAT Graduate Certificate in Compliance & Risk Management
u) International Certificate in Enterprise Risk Management, IRM
v) International Diploma in Enterprise Risk Management, IRM
w) Digital Risk Management Certificate, IRM
x) PMI Agile Certified Practitioner (PMI-ACP), PMI
y) Certified Associate in Project Management (CAPM)

5. Contingency Determination

5.1 Structure of Content

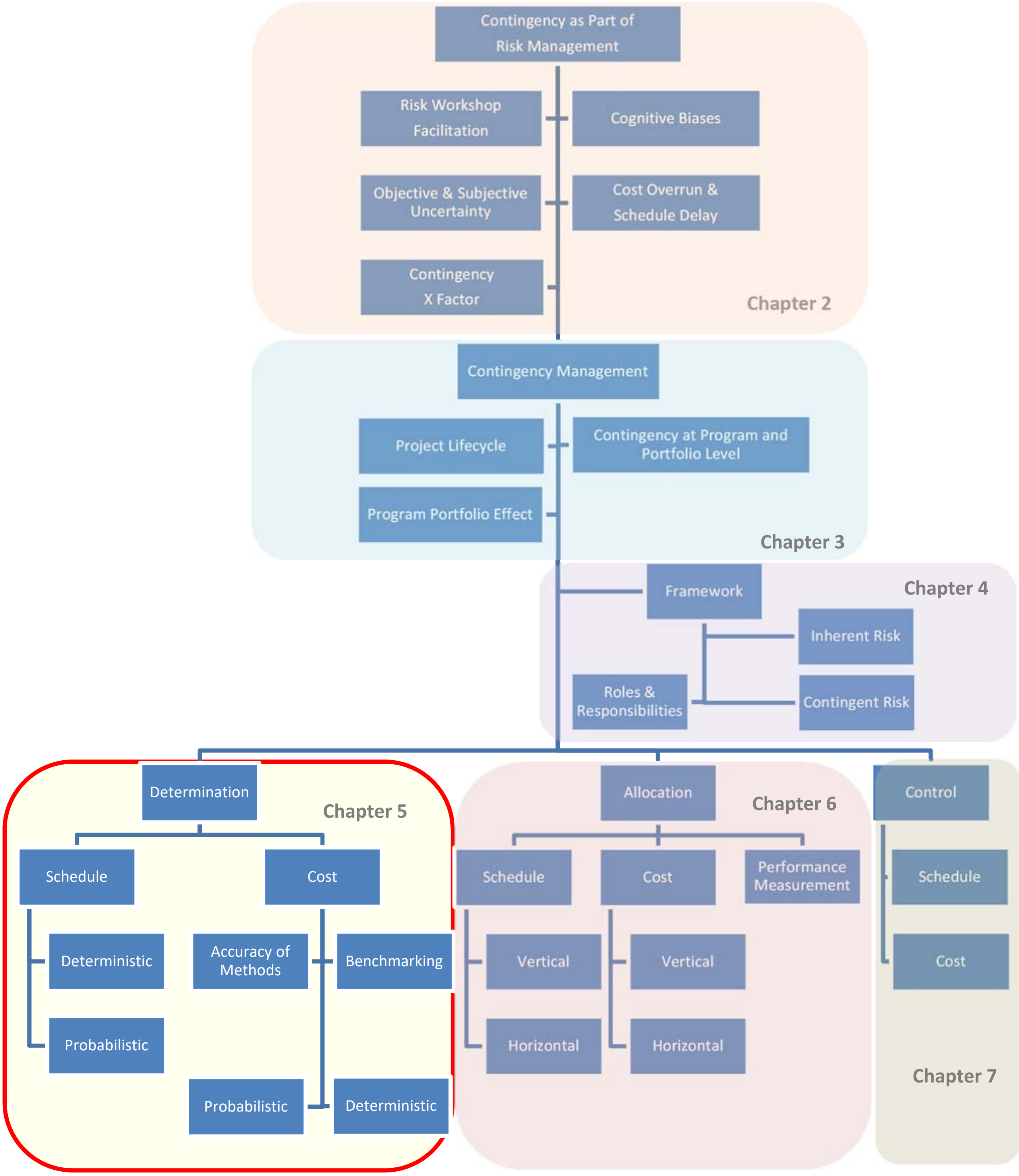

Figure 19: RES Contingency Guideline – Structure of Content

5.2 Overview

Contingency is not a substitute for proper cost estimating or project planning and scheduling. It should not be added to the Base Estimate in budgets, cost plans, forecasts or the Base Schedule as an alternative to sound, properly founded cost estimating and planning or scheduling.

Contingencies must be consistent with the residual risks in the estimated project solution as well as the method of project cost estimation and schedule development. They should be as specific as possible, and should be consistent with the level of project definition and solution development at each decision gate. Ultimately at the point of approval, that definition should be well defined with appropriate and thorough cost and schedule planning. The primary objective of any contingency management framework is to develop procedures that apply to the governance, assessment, allocation and release of contingency.

Even if the contingency determination was based on empirically derived models, any assessed contingency should be also checked against appropriate internal and external benchmarks where possible. There are a number of risk based approaches for assessing contingency. These approaches are of varying degrees of difficulty and the appropriate method should be selected based on a wide range of internal and external factors including those listed below:

a) external requirements (e.g. regulations and investment criteria)
b) stage of the investment lifecycle
c) project value and risk profile
d) extent of development of design and scope definition
e) project complexity
f) organisation’s strategic objectives
g) organisation’s project, risk and contingency management maturity
h) project portfolio and the current risk exposure against the risk appetite, tolerance and capacity
i) organisation’s record on similar projects
j) market conditions and level of competition.

If the organisation selects the most appropriate method of quantitative risk analysis for each set of circumstances, it should be able to address the following five sources of risk:

a) inherent risks associated with the cost estimating and scheduling methodologies
b) inherent risks associated with the technical and programmatic aspects of the system or project being developed,(i.e. systemic risks)
c) contingent risks associated with the key internal and external interfaces
d) inherent risks in the correlation between WBS elements or contingent risks, and
e) specific risks for the project.

RES Recommendation: to improve efficiency, risk and uncertainty data should be collected and assessed for contingency determination. This allows time for modifications and improvements to the plans, and to conduct re-assessments before the decision gate. However, bias in the Base Estimate (which is always present to some extent) must be assessed and addressed using estimate and schedule validation. Hence, RES recommends that the bases should be fully documented and completed before the risk and contingency assessment can be finalised and completed.

5.3 Schedule Contingency Determination

As illustrated in Figure 20, the most common methods for schedule contingency determination are divided into two groups: deterministic and probabilistic. Note that RES **does not recommend** calculating the schedule contingency determination separately to cost contingency. Analysis should always be integrated. This makes it easier to read the discrepancies and correlations between the schedule and cost contingency determination methods. It should be noted that there are also hybrid approaches (i.e. combination of multiple methods or parametric or other to address some deficiencies of various individual methods).

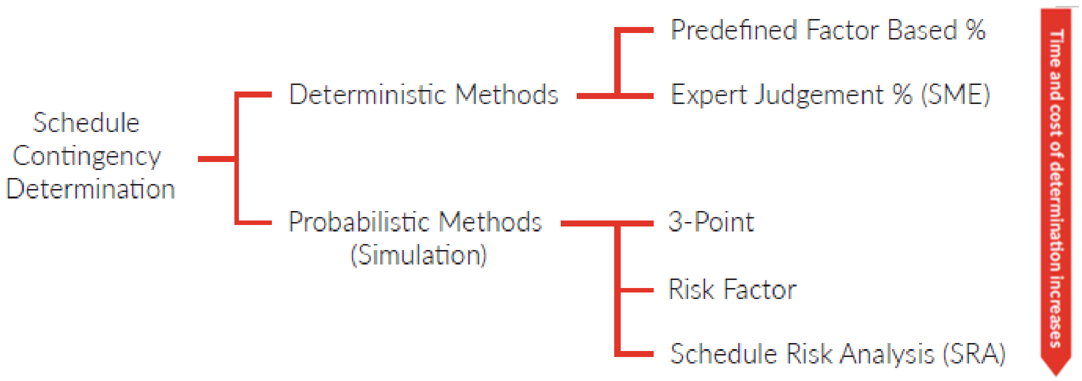

Figure 20: The most common methods of schedule contingency determination

5.3.1 Deterministic Methods

Deterministic methods are the easiest approaches to schedule contingency determination and are mostly used during the early stages of the project lifecycle, or for small projects. During the early stages of project development, insufficient data and time or resource constraints may limit a team's ability to undertake a more detailed schedule contingency assessment. Using appropriate factors for the desired confidence levels facilitates this approach. There are a number of different applications of deterministic methods for determination of schedule contingency, including predefined factor based percentage or expert judgment percentage.

Predefined Factor Based Percentage

In this method, a predetermined percentage of the project Base Schedule (e.g. 10%) will be added to the project Base Schedule across the board. Some organisations have their own set of guidelines for contingency percentages in addition to the Base Schedule to concurrently address both inherent and contingent risks. Alternative applications may include:

a) predefined percentages of the Base Schedule for different types (or sizes) of projects
b) predefined percentages of the Base Schedule for different project phases
c) predefined percentages of the Base Schedule for different confidence levels (e.g. 10% for P50 and 30% for P90).

Using this technique, practitioners set a single overall contingency allowance for combined inherent and contingent risks for the whole project – or a number of different key areas. This allowance is based on the organisation's exposure to multiple projects, its experience, and historical project performance. These predetermined percentages will be used consistently across the organisation. An example of the predefined factor based method is illustrated in Table 6, note that RES **does not recommend** the percentages in Table 6, or any other specific contingency values.

Work Breakdown Structure (WBS)	Project Value (incl. contingency) PV <= $1m	Project Value (incl. contingency) $1m < PV <= $5m	Project Value (incl. contingency) PV > $5m
	% of Base	% of Base	% of Base
Whole scope	5%	10%	20%

Table 6: An example of predetermined contingency percentages for different project sizes

Expert Judgment Percentage (SME)

The method of expert judgment percentage (SME) is similar to the predefined factor based percentage method. However, instead of using predetermined percentages, for the Base Schedule, a group of Subject Matter Experts (SME) determine percentages for each project – after considering the project specific risks and uncertainties as well as contractual and organisational requirements, stakeholder expectations, and other relevant factors.

5.3.2 Probabilistic Methods (Simulation)

The probabilistic methods of schedule contingency determination generate a probability distribution of project schedule duration. The critical path method using the Monte Carlo simulation does this by simulating schedule components and their likely ranges using computer software. Regression based parametric modeling does this inherently through the probabilistic attributes of the model algorithm.

Probabilistic methods are a form of Quantitative Risk Analysis (QRA). To estimate contingency at the desired level of confidence, common techniques include computer-based Latin Hypercube or Monte Carlo simulations. According to the NASA *Cost Estimating Handbook,* the simulation process will generally produce steady state results after 2,500 to 10,000 iterations. Simulations allow risk practitioners to quantify project risks and provide them with a range of possible outcomes expressed as statistical distributions. For parametric modeling, the algorithm generates the distribution based on the risk factor ratings entered in the model. This is the only viable probabilistic method when there is no Critical Path Model (e.g. at Class 5 as described in Section 3.2).

Three-Point

The process for the most common approach to this method is represented in Figure 21.

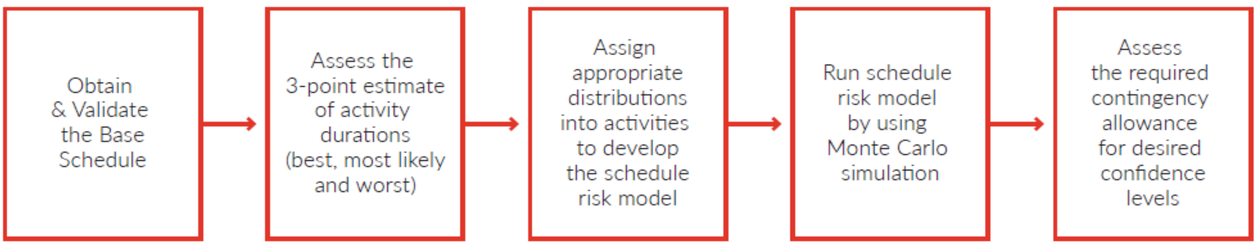

Figure 21: Common process of three-point schedule contingency determination method

A three-point schedule includes three estimates: optimistic, most likely, and pessimistic duration. Commonly, a Monte Carlo simulation provides a probability distribution for the entire project schedule based on SME estimations of range and probability distributions for components of the WBS. Some of the key challenges associated with this method of schedule contingency determination are:

a) selection of an appropriate level of WBS and schedule activities for allocating three-point ranges (i.e. number of schedule items and inputs)
b) determining which risks directly drive crucial activities
c) optimising effective use of the risk register and available contingent risks
d) determination of probability distributions for each activity
e) determination and modelling of the correlations and relationships between inputs
f) visibility of key schedule risk drivers and their rankings
g) accurate estimation of contingent risks (e.g. access delay, wet weather, accidents)

Due to these challenges, the three-point schedule contingency determination method may result in inconsistent and unpredictable results, depending on the level of modelling and its quality. The resulting distribution is almost always too tight, due to inadequate treatment of correlations.

Risk Factor

To address some of the gaps within the three-point method (e.g. correlations, narrow ranged outcomes, or identification of key risk drivers) the risk factor top-down approach was introduced to drive the schedule risk with risks previously defined in the risk register. During the early stages of project development, the risk factor method can identify and use a number of key factors – generally between five to 20 items – representing uncertainties that may affect the Base Schedule. These key factors are often aligned with key scheduling assumptions (e.g. productivity rates and quantities). The key aspects of this method are:

a) set risk factors (e.g. 0.8 for optimistic; 1.0 for most likely; and 1.4 for pessimistic)
b) assign the risk factors to one or more activities and multiply the activity duration by the applicable risk factor
c) if the activity duration is impacted by one or more risk factors, all applicable risk factors should be used to multiply the activity duration.

Schedule Risk Analysis (SRA)

This method is underpinned by a Critical Path Method (CPM) schedule which incorporates risk drivers as elements of the model (i.e., it is risk driven). The key elements of a realistic and reliable SRA in determination and allocation of a reasonable schedule contingency for different desired confidence levels are:

a) undertake a schedule health check against contractual factors, integrity and structure
b) undertake required rectification of deficiencies (e.g. constraints, missing links, broken logic)
c) for large schedules, create a manageable study schedule
d) allocate the inherent and contingent risks into the rectified schedule model (i.e. determine which activities each risk may impact)
e) assess and model key correlations
f) assess and model key possible scenarios, e.g. directed changes and changes to deal with risk occurrence (i.e. probabilistic branching)
g) run a Monte Carlo Simulation
h) review, validate and finalise the results
i) using results for cost Contingency Determination, if required.

The process for the most common approach of this method is represented in Figure 22.

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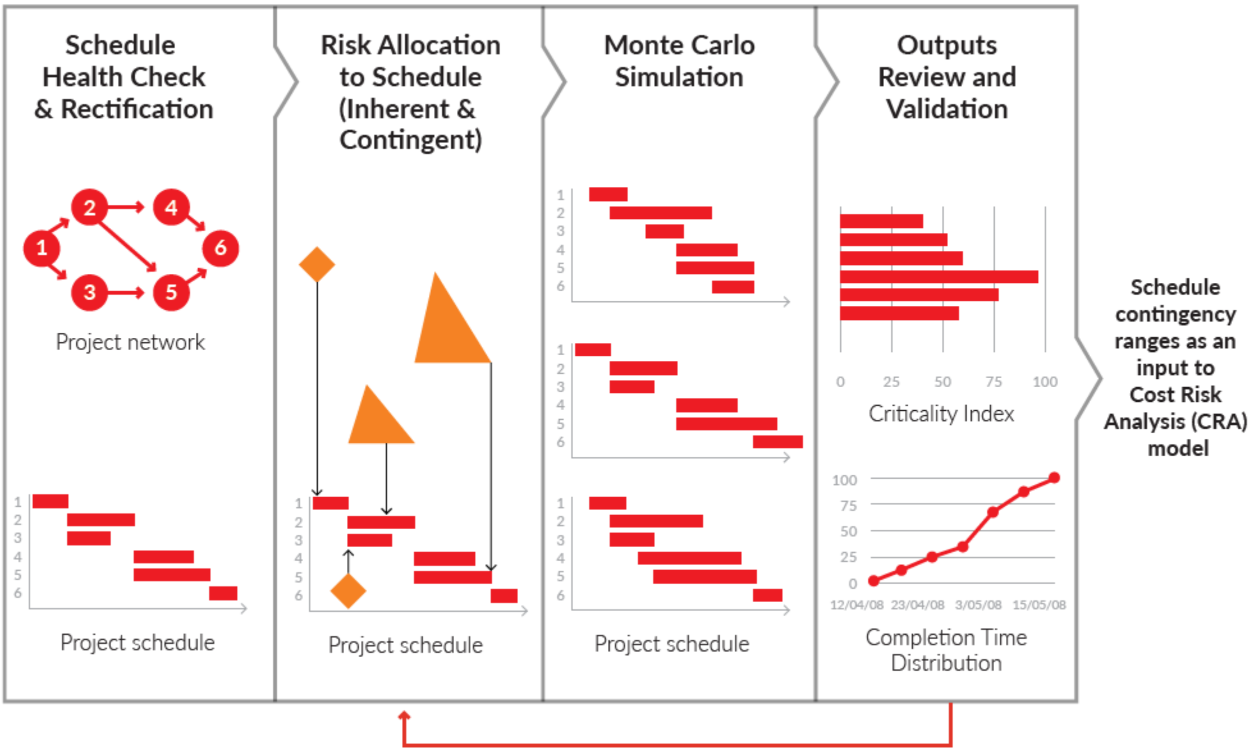

Figure 22: A typical process map for the probabilistic Schedule Risk Analysis (SRA)

Further details about this method are included at Appendix C.

5.4 Cost Contingency Determination

As illustrated in Figure 23, common methods for cost contingency determination are divided into two groups: deterministic and probabilistic. RES strongly recommends that practitioners employ the good practice of assessing cost and schedule contingency together using an integrated approach. However, to make this Guideline easier to read, schedule and cost contingency calculations have been explained in different sections.

This Guideline also notes that mathematical methods including fuzzy techniques or artificial neural networks, as well as systems dynamics models have been introduced by researchers – mainly for academic purposes. There are also hybrid approaches (i.e. combination of multiple methods or parametric or other to address the deficiencies of various methods).

RES Recommendation: while contingency is a form of risk treatment which can be used to mitigate uncertainty or realised risks, it should only be used when incorporated with a comprehensive risk management approach.

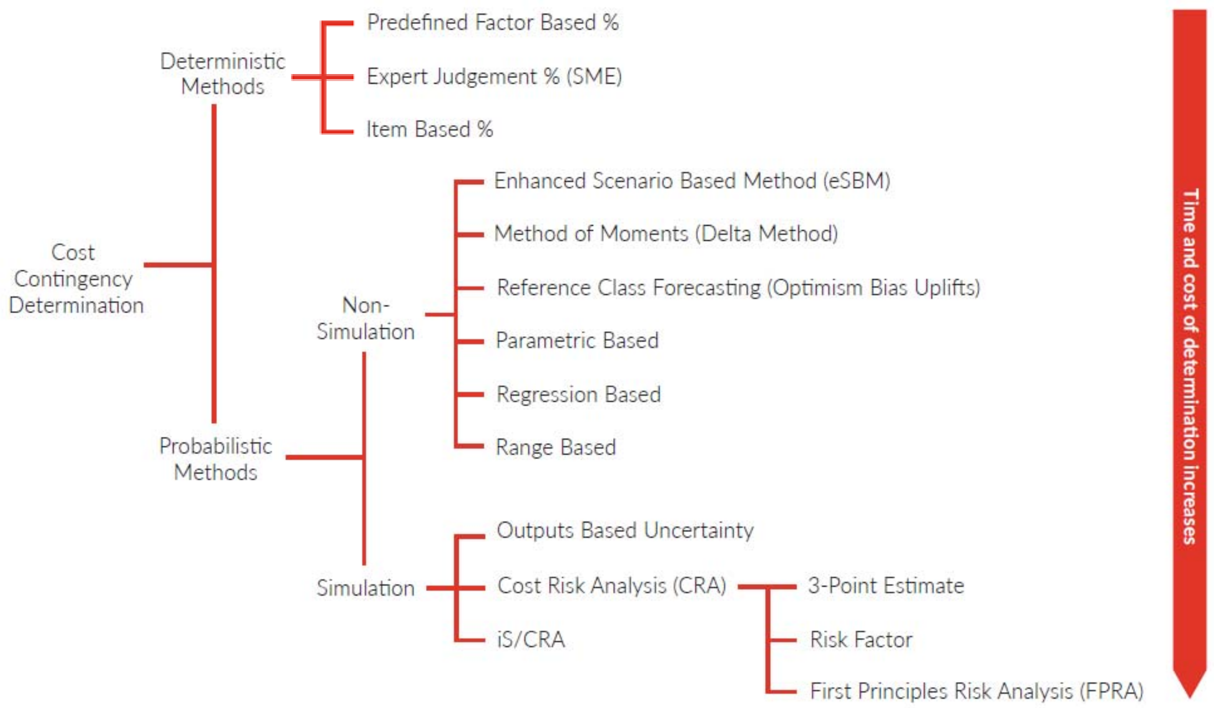

Figure 23: The common methods of cost Contingency Determination

5.4.1 Reliability of Methods

Both deterministic and probabilistic methods can be reasonably used to determine a realistic contingency allowance for projects – depending on the phase of the investment lifecycle, availability and quality of project data, historical information, the organisation's maturity, and project specific requirements. While some approaches are more acceptable in the early stages of the project lifecycle, bottom-up probabilistic methods of contingency determination are recommended wherever possible at every decision gate of the phase gate system – particularly at the full funds approval gate. For projects with a value of more than $10m this Guideline recommends simulation or hybrid methods, when practical, at these final decision making stages.

RES recommends that practitioners use the following evaluation criteria to select an appropriate cost contingency determination method:

a) strength, supporting data and nature of assumptions required
b) ability of the practitioner and project team to understand the technical complexity of the method
c) computational overheads, availability of software, and training required for computational methods
d) consistency, reliability and range boundaries of the method, and its ability to support decision-makers in assisting decision-makers
e) ability and possibility to use a combination of methods to support decision making

The evaluation criteria above can assist practitioners and their organisations to develop an overarching strategy for contingency determination by deciding which method or combination of techniques best fit their internal and external requirements.

The criteria can also help practitioners determine the ability of each of the methods discussed in the Guideline to provide reliable and realistic results for specific needs. This depends on several factors, including the quality and availability of information to support the process.

The Guideline generally recommends the application of MCS, due to its potential capability for consistent and reasonably reliable predictions. It should be noted that there are associated challenges, including: whether historical data is validated; the consistency of probability density functions, their tail shapes, and interdependency; and the relevant risk function.

If a large number of supporting observations are available, practitioners should be able to closely estimate the data with a probability density function which should improve the accuracy of the MCS predictions. While they still depend on the model used, and accurate programming, simulations with a sizeable body of relevant supporting data generally provide the most accurate risk forecasts.

The most common methods of cost contingency determination are explained in this section. The other methods – except the new mathematical methods due to the small number of current practical applications – have been explained in the Appendix D.

5.4.2 *Deterministic Methods*

Predefined Factor Based Percentage

The factor based approach is the easiest method of cost contingency determination. It is mostly applicable at the early stages of the project lifecycle or for smaller projects – where time, data and resource constraints make a more comprehensive assessment difficult. Using appropriate factors for the desired confidence levels facilitates this approach.

This technique adds a predetermined, across the board, percentage of the project Base Estimate (e.g. 10%) to the project estimate. Individual organisations have frameworks to determine which percentages best suit their needs. The most common application of this methodology is to set a single overall percentage of the project Base Estimate which incorporates both inherent and contingent risks. Other ways may include:

a) predetermined percentages of base for different types (or sizes) of projects
b) predetermined percentages of base for different key phases of a project
c) predetermined percentages of base for different confidence levels (e.g. 10% for P50, 30% for P90).

Instead of calculating separate contingency for inherent and contingent risks, this technique determines an overarching contingency allowance range for the whole project or a number of different key areas. This is based on the organisation’s exposure to multiple projects, experience, and historical performance of projects. These predetermined percentages are used consistently across the organisation. A few examples are illustrated in Tables 7 and 8. Note RES **does not recommend** these, or any other specific values of contingency. It is best to benchmark chosen values against actual company projects.

Work Breakdown Structure (WBS)	Low confidence level e.g. P10	Reasonable confidence level e.g. P50	High confidence level e.g. P90
	% of Base Estimate	% of Base Estimate	% of Base Estimate
Whole scope	20%	30%	40%

Table 7: An example of a predetermined contingency percentages for different confidence levels

Work Breakdown Structure (WBS)	Project Value (incl. contingency) < = $1m	Project Value (incl. contingency) < = $5m	Project Value (incl. contingency) > $5m
	% of Base Estimate	% of Base Estimate	% of Base Estimate
Whole scope	10%	20%	30%

Table 8: An example of predetermined contingency percentages for different project sizes

RES Example: the predefined factor based method is a common method, especially at the early stages of project development, both in Australia and globally. For example, in the US, the factors below are used by Virginia Department of Transportation to estimate transport projects for different regions.

State	Factor
Delaware	5% of estimated construction cost
Kentucky	10% of estimated construction cost
Pennsylvania	10 to 20% of estimated construction cost
Tennessee	10% of estimated construction cost

Expert Judgment Percentage (SME)

The method of expert judgment percentage (SME) method is very similar to the factor based percentage method. Instead of predetermined levels, percentages are obtained from the Base by a group of experts for each project – after specifically considering its risks and uncertainties. The accuracy of results depends on the experience of the SMEs and their consideration of specific circumstances and risks – and tends to vary from project to project.

Item Based Percentage

The deterministic item based approach to quantifying contingencies aims to improve the expert judgment approach by applying the deterministic method for a number of items across the project scope – including the inherent and contingent risks – rather than percentages of the Base Estimate and Base Schedule. The structure of items is based on the WBS or Risk Breakdown Structure (RBS). Some applications of this method have been illustrated in Tables 9, 10 and 11.

Work Breakdown Structure (WBS)	Base Estimate <= $5m	Base Estimate > $5m
	% of Base Estimate	% of Base Estimate
Civil Design	1% of Civil Design $	2% of Civil Design $
Structure Design	1% of Structure Design $	2% of Structure Design $
Soft Soil Treatment	5% of SST $	10% of SST $
Excavation	5% of Excavation $	7% of Excavation $
Structures	5% of Structures $	8% of Structures $
Line Marking	1% of Line Marking $	2% of Line Marking $
Landscape	1% of Landscape $	2% of Landscape $
TOTAL – contingency	**To be calculated**	**To be calculated**

Table 9: An example of the item based percentage using WBS

Work Breakdown Structure (WBS) / Risk Breakdown Structure (RBS)	Low confidence level e.g. P10	Reasonable confidence level e.g. P50	High confidence level e.g. P90
	% of Base Estimate	% of Base Estimate	% of Base Estimate
Project scope	2%	3%	5%
Status of design	3%	4%	5%
Site information	1%	2%	3%
Constructability	1%	2%	3%
Project schedule	1%	2%	3%
Interface Management	2%	3%	5%
Approval processes	1%	2%	4%
Utility adjustments	1%	2%	4%
Properties	2%	3%	5%
Other inherent & contingent risks	1%	2%	3%
TOTAL – Contingency	**15%**	**25%**	**40%**

Table 10: An example of the item based percentage using 10 key aspects

As with pre-defined factors, research has found that this method is generally optimistic as may not be risk-driven and tends to focus on the estimator's view of the quality of their estimate as opposed to a combination of inherent and contingent risks. It is not usually based on empirical analysis of a company's data.

Values from books and external references generally do not apply well to any specific company or project. Values based on historical projects or benchmarked against actual company projects is best.

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RES Example: Table 11 presents an example of the item based percentage method against WBS and different project confidence levels while approaching the inherent and contingent risks separately. The details presented in Table 11 can be interpreted as described below:

a) Base Estimate of $5,000k
b) Base Schedule of 80 working days
c) For a confidence level of 50%, cost contingency of approximately $720k (14% of Base Estimate) and schedule contingency of an additional 21 working days (26% of Base Schedule) is recommended
d) For a confidence level of 90%, cost contingency of $1,475k (30% of Base Estimate) and schedule contingency of an additional 30 working days (38% of Base Schedule) is recommended. Note that adding P90 values implies all risks are 100% correlated – a very conservative assumption.

WBS / RBS	P(x) (%)	Base Estimate ($)	Schedule (day)	Low confidence level e.g. P10		Reasonable confidence level e.g. P50		High confidence level e.g. P90	
				% of Base Estimate of Item		% of Base Estimate of Item		% of Base Estimate of Item	
INHERENT									
Earthworks	100	$1,000k	20	2%	$20k	3%	$30k	4%	$40k
Pavement	100	$300k	20	1%	$3k	2%	$6k	5%	$15k
Bridge 1	100	$1,000k	20	5%	$50k	10%	$100k	30%	$300k
Bridge 2	100	$2,000k	20	5%	$100k	15%	$300k	40%	$800k
Misc.	100	$700k	-	3%	$21k	5%	$35k	10%	$70k
		$5,000k	**80**						
CONTINGENT									
Extreme weather	30	$500k	20	30% x $500k	$150k	30% x $500k	$150k	30% x $500k	$150k
Extra soft soil treatment	20	$500k	-	20% x $500k	$100k	20% x $500k	$100k	20% x $500k	$100k
Approval & site access	20	-	20						
TOTAL – Contingency				**9%**	**$444k**	**14%**	**$721k**	**30%**	**$1,475k**

Table 11: An example of the item based percentage method

5.4.3 *Probabilistic Methods – Simulation*

Probabilistic simulation methods generate distributions of possible outcomes. There are two types of practical probabilistic (inferential statistics) methods: regression based and Monte Carlo simulation. Some regression based methods are discussed in the Appendix D.

Simulation creates distributions by sampling from a range of inputs to a model and capturing the iteratively generated outputs. A well-developed model, using quality assumptions validated against historical data, can reasonably reflect the behavior of real projects subject to risks of various types.

The simulation methods start with a model of the project. It may be the estimate with its line items, or a Critical Path Method (CPM) schedule with its activities and logic, or some combination or variation. Note that none of the simulation models depict how a project behaves under the dynamic nature of risks. For example, the CPM network as usually applied is static or fixed. The model is made probabilistic by replacing fixed input values with ranges and probabilistic methods in order to produce a probability distribution that approximates project schedule and costs. To do this, practitioners need to set a probable range for each identified element of cost and schedule, and conduct an iterative sampling process to simulate the distribution using computer software to capture the outputs of the many iterations.

As discussed in Section 5.4.2, probabilistic methods are a form of Quantitative Risk Analysis (QRA).

The quality of simulation methods depends on how realistically the underlying model represents how the project will behave when subject to risk. For example, as a principle, it should be “risk-driven; i.e., we model the occurrence of each risk and its impact, not just a range of impact without modeling the risk driving that range. When undertaken properly, the method optimally generates all possible scenarios modeled by the analysis and the likelihood of the occurrence of each outcome. Building a realistic yet practical underlying model is the main challenge.

In order to determine the values of possible outcomes, the simulation calculates which values are reasonably possible for each model variable. If they are included in the model, the simulation includes the risk drivers' occurrence probability. The results for Monte Carlo simulations and other probabilistic techniques results also encompass the confidence levels able to be assigned to each possible value of project cost and duration.

Simulation has an advantage over empirical models in that risk drivers and behaviors not captured in the actual data can be factored into the model. This is particularly relevant to significant contingent risks for which the occurrence and/or impact is specific to the project. However, empirical models have an advantage over simulation models in their objectivity and credible consistency in analysing inherent risks – especially at very early stages of project development. Using empirical and simulation methods together can capitalise on each of their advantages.

RES Recommendation: in the absence of objective data (and unless there is evidence to do otherwise) RES recommends all subjective bounds (i.e. SME opinions) are modelled with confidence intervals of 80% between best case and worst case (e.g. 10% best case and 90% worst case). When using – and when using Triangular, Uniform or Beta-Pert distributions, these confidence intervals should be adjusted for skew

The Guideline provides details for the following common probabilistic methods below (less common methods are explained in Appendix D):

- Cost Risk Analysis (CRA)
    - Three-Point Estimate
    - Risk Factor
    - First Principles Risk Analysis (FPRA)
- Integrated Schedule Cost Risk Analysis (iSCRA).

Cost Risk Analysis (CRA)

CRA generates a cost cumulative distribution (CDF), or S-curve for projects and also for various elements of the estimate as needed for allocation purposes. The key activities of CRA are:

a) Ensure Base Estimate represents the cost strategy established – considering specific circumstances and assumptions
b) Determine the project's cost drivers and risks, using input from key stakeholders and historical data (this method is not integrated with SRA, so care must be taken to ensure alignment in risks considered)
c) Determine the bias in the estimate by developing the probability of occurrence distributions and correlations for the schedule and technical cost drivers
d) Develop impact distributions and correlations for uncertainties in the cost model
e) Run the cost risk model
f) Generate the probabilistic cost distribution
g) Recommend sufficient contingency for the desired confidence level.

CRA allows practitioners to pinpoint and analyse a project's critical risks according to set technical criteria, key interfaces, and limitations for schedule and costs. It also helps the project team to document and proactively manage the project budget – capturing uncertainty in methodology, systemic factors to shift from a deterministic to probabilistic contingency calculation. CRA methods can be run in conjunction with empirically based methods to address inherent risks more objectively.

This guideline provides details for three different methods of CRA:

a) 3-Point Estimate
b) Risk Factor
c) First Principles Risk Analysis (FPRA)

The following sections will provide further details about these methods as well as recommendations regarding the most appropriate phases of the project lifecycle to put them into action.

Three-Point Estimate

In this method, the underlying risk model is the cost estimate with the risk drivers added. It is essential that a risk driven approach is used. For inherent risk, practitioners should replace fixed values with distributions that can be defined with three-point inputs.

For contingent risk, the risk is connected to the impacted estimate items, and the probability of each risk occurring – and its correlation to other risks – is quantified. Note that this is only meaningful when the estimate is reasonably detailed. For Class 5 estimates, this takes the nature of deterministic methods. This method is generally applied to a bottom-up estimate, which is obtained by analysing individual work packages. The process for the most common approach to this method is represented in Figure 24 below.

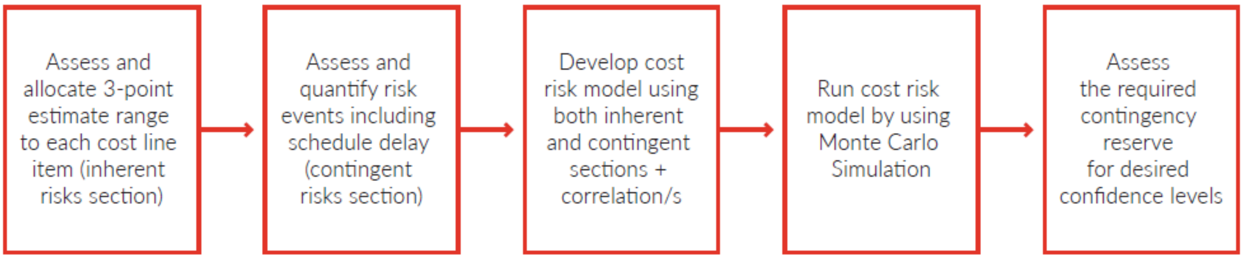

Figure 24: Common process of CRA 3-Point Estimate methodology

This technique can be used to analyse the costs of multiple projects, with the WBS as a basis. As the WBS includes a breakdown of the project's work packages, components, facilities and services, practitioners can just allocate a cost to each component and calculate the sum for an overall project cost.

For a CRA 3-point estimate, SMEs are asked to use elicitation to set a range and probability distribution for each WBS element, which is then input into a Monte Carlo Simulation for total cost calculation. As discussed in Section 5.3.2, variations in the elicitation process can affect results. Some of the key challenges associated with this method of contingency determination are:

a) selection of an appropriate level of WBS for allocating three-point ranges (i.e. number of cost items and inputs)
b) determination of probability distributions for each cost element
c) determining the correlations and relationships between model inputs and understanding them clearly
d) accurate assessment of schedule delays
e) narrow range of possible cost outcomes, which increases the likelihood of underestimating the required contingency.

Due to these challenges, the CRA three-point estimate may result in inconsistent and unpredictable results, depending on the level of modelling and its quality. It is **not recommended** by this Guideline, especially at the key investment decision making points, e.g. Final Business Case.

Risk Factor

To address some of the gaps within the three-point estimate method (e.g. correlations or narrow ranged outcomes) the top-down approach of risk factor was introduced by some practitioners. At the early stages of project development, the risk factor method can identify and use a number of key factors – generally between five and 20 items – that represent uncertainties and the cost items which they may affect across the Base Estimate. These key factors are often aligned with key estimating assumptions.

Across different sectors, there are several ways this method can be used – depending on the project requirements and the availability of data. The process for the most common approach to this method is represented in Figure 25.

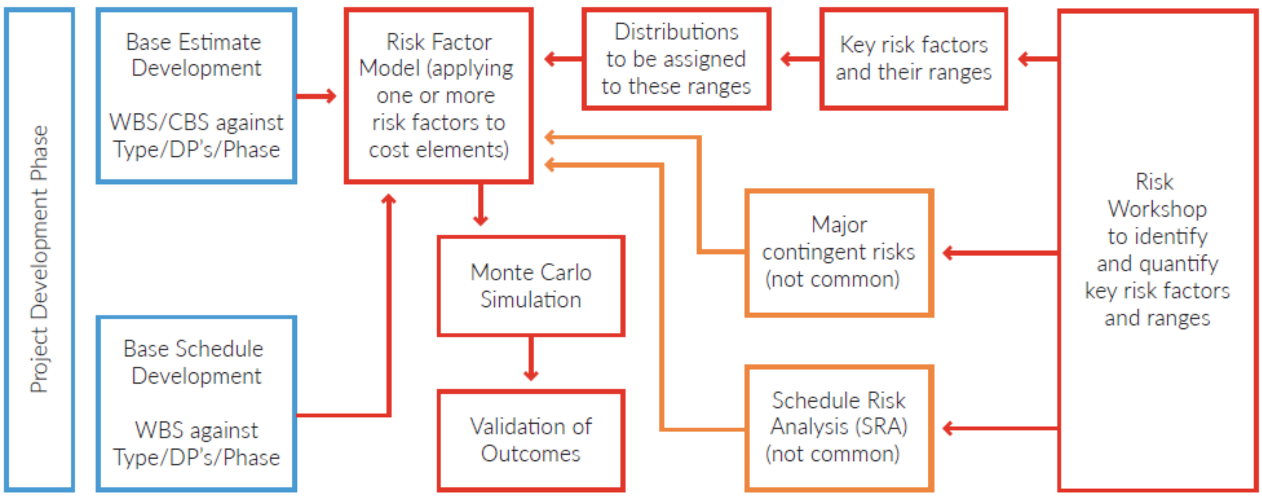

Figure 25: The process for the most common approach to the risk factor method

In practice, organisations generally develop and use predetermined key risk factors for different types of projects to facilitate quantification during risk workshops. For example, the common key factors for a fly-in-fly-out (FIFO) resource project can be office cost rate ($/month), provisions, schedule, heavy machinery rate ($/month), site accommodation rate ($/month), labour productivity, equipment rate, material quantity, staff rate, productivity, and FIFO rate.

Correlation between risk factor distributions should also be considered, as a single uncertainty factor may affect multiple risk factors.

Like any high-level, top-down approach, the risk factor method may be adequate for projects that are relatively self-contained or at the early stage of development (e.g. projects within the resource sector or at the initiation or Optioneering phase). It may not pass the scrutiny required at key investment decision points (e.g. Final Business Case) particularly in terms of governments demonstrating the best value for public money.

The risk factor method may not fully address all requirements of infrastructure projects due to the nature of infrastructure cost uncertainties. The HM Treasury Infrastructure UK *Guidance of Cost Estimate* also states that cost contingency estimates should include:

a) uncertainties around the estimate which are defined but unmeasured
b) specific risks that are measured uncertainties
c) uncertainties that are currently unknown or not entirely understood (e.g. interface risks).

RES, as well as a number of other key references including the UK *Guidance of Cost Estimate*, affirms that (a) and (b) above are the main drivers of contingency for primarily self-contained projects. Point (c) comes into play as a significant risk exposure factor in the early phases of major infrastructure projects – and can result from complex interfaces of the project with the surrounding area, or unexpected stakeholder reactions and needs.

First Principles Risk Analysis (FPRA)

As a bottom-up risk-based cost contingency determination approach, FPRA aims to improve the quality of CRA and address some of the key deficiencies of the three-point estimate and risk factor methodologies, while capturing and validating uncertainties and risks at the lowest meaningful level of the WBS.

The key elements of a realistic and reliable FPRA in the determination and allocation of a reasonable cost contingency for different desired confidence levels are:

a) quality of the Base Estimate: preferably a first principles, rigorous, structured and detailed cost estimate – representing the most likely assumptions – structured against equipment, labour, material and sub-contracts
b) quality of the Base Schedule: preferably a logic or resource based CPM schedule – representing the current strategies and assumptions
c) bias of the base estimate
d) alignment and consistency of assumptions between the Base Estimate and Base Schedule
e) identification and quantification of inherent and contingent risks including schedule risks
f) allocation of the inherent and contingent risks into the cost risk model
g) assessment and modelling of key correlations
h) Monte Carlo Simulation (MCS)
i) review, validation and finalisation of the results.

The process for the most common approach to this method is represented in Figure 26. The quality of the method can be improved by validation through an explicit empirical foundation.

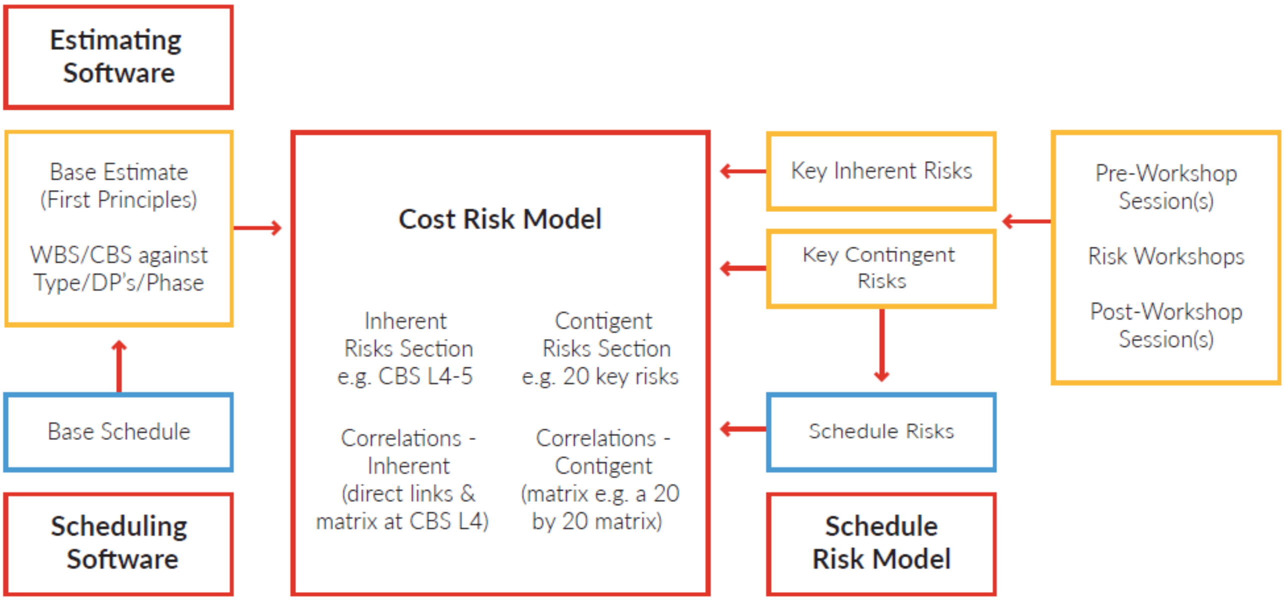

Figure 26: A typical process map for the probabilistic Cost Risk Analysis (CRA) method

Where possible, especially at key decision points (e.g. Preliminary and Final Business Case), RES recommends the use of FPRA. Further details for this method are included at Appendix E.

Integrated Schedule Cost Risk Analysis (iS/CRA)

This method is based on a risk-driven, cost loaded, CPM schedule model. As mentioned earlier, the project cost drivers may be grouped into four types:

a) uncertainty (i.e. inherent risk or planned risk) around time-independent costs
b) uncertainty (i.e. inherent risk or planned risk) around time-dependent costs
c) risk event (i.e. contingent risk or unplanned risk) with cost impacts
d) risk event (i.e. contingent risk or unplanned risk) with time impacts that drive costs.

When attempting to consolidate these four drivers of project cost within one model (i.e. a logic based or resource based CPM schedule), the Integrated Schedule Cost Risk Analysis (iS/CRA) methodology assesses the range of possible outcomes from one model to increase the quality of outcomes. This can be achieved using a resource loaded project schedule, where the project Base Estimate is assigned to schedule activities or its summary schedule. An important advantage of this model is that the cost and risk impacts of a given risk are assessed together which helps address the cost-schedule tradeoff uncertainty.

The quality of the method can be improved by validation through an explicit empirical foundation. The process for the most common approach to this method is presented in Figure 27.

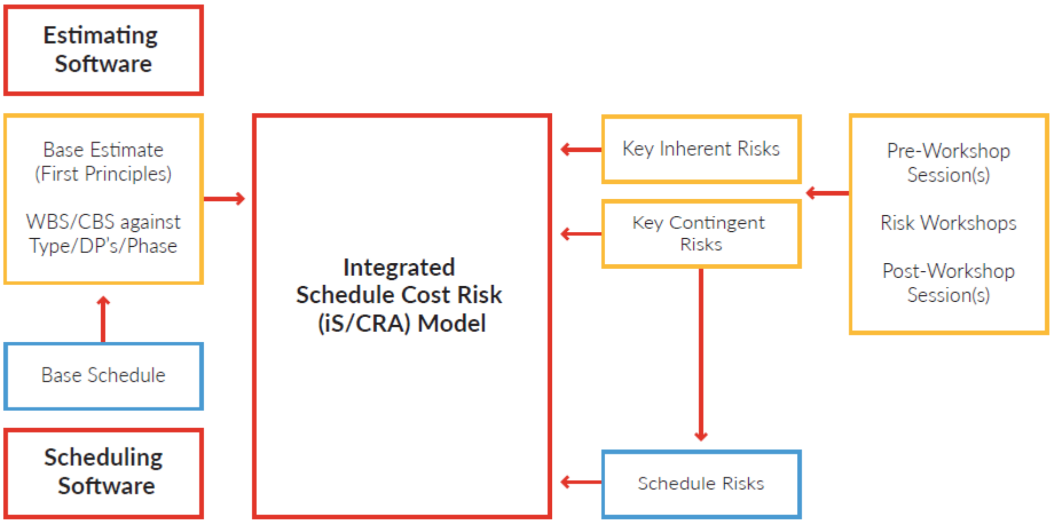

Figure 27: A typical process map for the Integrated Cost Schedule Risk Analysis (iSCRA) model

Further details for this method are included at Appendix F.

5.4.4 Uncommon Probabilistic Methods

The probabilistic cost contingency determination methods below, which are not common within the infrastructure sector and government funded major projects, have been explained in Appendix D:

a) Enhanced Scenario Based Method (eSBM)
b) Method of Moments (Delta Method)
c) Reference Class Forecasting (RCF)
d) Parametric Based
e) Regression Based
f) Ranged Based
g) Outputs Based Uncertainty.

5.5 Contingency Determination Tools & Software

Commercial risk assessment tools provide a range of technical capabilities and features – and can assist in developing risk-adjusted estimates and schedules as well as risk analysis and management. Table 12 describes some of the most popular risk assessment software packages at the time this Guideline was published.

It should be noted that RES does not have any commercial arrangement with any of these software providers and **does not** recommend any of these platforms. Inclusion of this list within this Guideline is intended to help organisations and individuals by providing a wide range of available options. However, RES strongly recommends organisations undertake a detailed analysis against specific requirements before selecting and implementing any risk analysis or management tool. This will ensure the product provides the best fit for their internal and external requirements.

#	Tools Reference / Software	Reference
1	AACEi - excel versions of The Hackney and the Rand Corp parametric models	<web.aacei.org>
2	ACEIT	<www.aceit.com>
3	Barbecana – Full Monte	<www.barbecana.com>
4	Booz Allen Hamilton – Polaris	<www.boozallen.com/consulting/products/polaris>
5	Crystal Ball	<www.palisade.com>
6	Deltek Acumen	<www.deltek.co.uk/products/ppm/risk/acumen-risk>
7	JACS: Joint Analysis of Cost and Schedule	www.aceit.com
8	John Hollmann – excel versions of parametric cost and schedule models	Project Risk Quantification, Probabilistic Publishing, 2016
9	Microsoft Office Excel	
10	Oracle – Primavera Risk Analysis	<www.oracle.com/applications/primavera/products/risk-analysis.html>
11	Palisade - @Risk and the DecisionTools Suite	<www.palisade.com/risk>
12	PRICE Integrated Models & Standalone Models	<www.pricesystems.com>
13	Project Cost Estimating Capability (PCEC)	<www.oncedata.com>
14	Risk Decisions – Predict! Risk Analysis	<www.riskdecisions.com/predict-risk-management-software>
15	Safran Software Solutions	<www.safran.com/products/safran-risk>
16	SEER	<www.galorath.com>
17	Spider Project	<www.spiderproject.com>
18	Sword Active Risk Manager (ARM)	<www.sword-activerisk.com/products/active-risk-manager-arm>
19	Trigo White – White Box	<www.trigowhite.com/Pages/RiskManagementPages/WhiteBoxRM.aspx>
20	True Planning	<www.pricesystems.com>
21	Vose Software – Pelican, Tamara, ModelRisk, ModelRisk Cloud, StopRisks	<www.vosesoftware.com>

Table 12: List of common risk analysis tools and software

5.6 Validation and Benchmarking

While this Guideline appreciates the value of historical data, it highlights that this data should be carefully gathered (including deciding what to include and exclude) and managed. Practitioners should analyse historical data in a consistent manner designed to support risk management objectives (and other uses). Optimally, the practitioner will embed the learnings from historical data directly into the methods used.

Regardless of the method used to determine the contingency, it is also critical to assess the historical performance of risk assessment – this has usually been underestimation for large projects, and overestimation for small projects. Practitioners should also look for evidence of contingency being spent on additional scope, or other inappropriate uses. The following steps contribute not only to calibrating risk assessment procedures, but also to improved performance of organisational and project risk management.

In the absence of any internal and external contingency historical data – and for a top-down benchmarking purposes only – Table 13 provides some guidance on the percentage above the Base Estimate that could represent the common P50 and P90 approximation for different types of transport projects.

Project Phase	Type of estimate	P50 Range	P90 Range
Initiation and Strategic Assessment	Preliminary Business Case	20% to 40%	30% to 70%
Concept	Full Business Case	10% to 15%	25% to 40%
Delivery Readiness	Pre-Tender	5% to 10%	10% to 20%
Delivery	Construction	Up to 5%	Up to 10%

Table 13: Common benchmarking of P50 and P90 contingency allowance (Transport Projects)

RES Recommendation: it should be noted that there is not enough empirically based and validated historical data (including researched-based evidence) to support the contingency ranges provided in Table 13.

To mitigate and minimise the risk of bias during contingency determination, RES strongly recommends that these ranges only be used at the end of the process. Any inconsistencies can then be reviewed, validated and documented. This benchmarking and guidance on contingency ranges should not be a replacement for appropriate and sound cost estimating, project scheduling or contingency determination. These ranges should be only used for cross-checking and comparison purposes.

5.7 Further Reading

- AACEi, RP No. 41R-08 – *Risk Analysis and Contingency Determination using Range Estimating*
- AACEi, RP No. 42R-08 – *Risk Analysis and Contingency Determination using Parametric Estimating*
- AACEi, RP No. 43R-08 – *Risk Analysis and Contingency Determination using Parametric Estimating – Example Models as Applied for the Process Industries*
- AACEi, RP No. 43R-08 – *Risk Analysis and Contingency Determination using Expected Value*
- AACEi, RP No. 57R-09 – *Integrated Cost and Schedule Risk Analysis Using Monte Carlo Simulation of a CPM Model*
- AACEi, RP No. 64R-11 – *CPM Schedule Risk Modelling and Analysis: Special Considerations*
- AACEi, RP No. 65R-11 – *Integrated Cost and Schedule Risk Analysis and Contingency Determination using Expected Value*
- AACEi, RP No. 66R-11 – *Selecting Probability Distribution Functions for use in Cost and Schedule Risk Simulation Models*
- AACEi, RP No. 68R-11 – *Escalation Estimating Using Indices and Monte Carlo Simulation*
- AACEi, RP No. 70R-12 – *Principles of Schedule Contingency Management – As Applied in Engineering, Procurement and Construction*
- AACEi, RP No. 75R-12 – *Schedule and Cost Reserves within the Framework of ANSI EIA-748*
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6. Contingency Allocation

6.1 Structure of Content

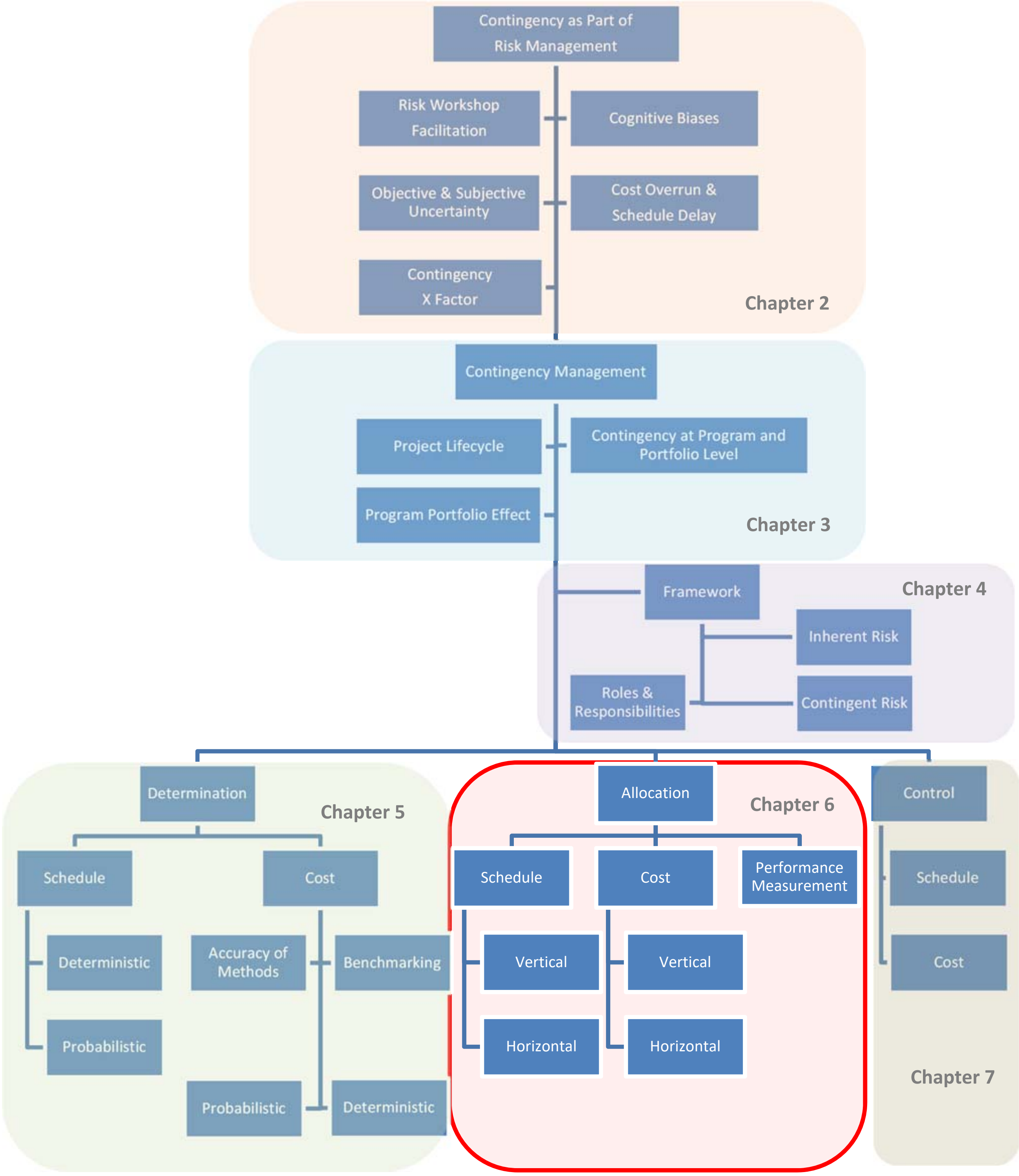

Figure 28: RES Contingency Guideline – Structure of Content

6.2 Overview

For major infrastructure projects, in the absence of any specific contractual arrangement, a party should take a risk where:

a) its likelihood and/or consequences are within the party's control – noting that 'control' means the party should be able to assess, and treat (e.g. accept, avoid, mitigate or transfer) the risk
b) it leads to a greater benefit of the party controlling the risk for any key objective. For example economic or reputational benefits
c) if the risk occurs, the consequence stays with that party and it is not practical and/or reasonable to try to transfer the loss to another party
d) it leads and incentivises the desired behaviour and culture for the project such as risk-based decision making, efficiency, innovation, value engineering, or optioneering.

In 2005, Engineers Australia and the Chamber of Commerce and Industry of Western Australia conducted a study of effective risk allocation in major construction contracts. It found that risks were not according to which party was best able to manage the risk. Another study by the Queensland University of Technology highlighted that risk reduction is the most frequently used risk response method, with the use of contingencies and contractual transfer preferred over insurance.

Contingency allocation and control should be planned and managed in alignment with risk allocation agreements as well as broader project performance measurement strategies. For these purposes, proactive planning for contingency allocation and control should enable:

a) establishment of a contract, project or program baseline risk profile and consistent basis for planning
b) establishment of an integrated view of the allocation of contingency for the contract, project or program and the desired confidence levels (or other statistical measure) at each level
c) development of a process for change control, to manage proposed changes to the contingency included within the contract, project or program baseline
d) development of a process to control progressive elaboration of the scope, or rolling wave planning – and the associated transfer of contingency within the contract, project or program baseline
e) monitoring of the contract, project or program risk and contingency profile, measuring deviations from the plan
f) planning and forecasting by the users of the performance management strategies for assessment of contingency resources (e.g. time, human resources, and money), availability and demand.

6.3 Contingency and Project Performance Measurement

Projects need a structured performance measurement strategy to assessing progress against the latest approved plan and support accurate forecasting. This is especially important for projects that have significant risks associated with their cost and/or schedule objectives.

The appropriate performance metrics will enable informed decisions about the management of the contract, project or program. Leading indicators may also be incorporated into the performance management strategies. Examples include: Earned Value; safety metrics such as lost time injuries; quality metrics such as non-conformance report (NCR); defects; deviations; and waivers. Monitoring these metrics may provide early warning about whether risk and contingency provisions are sufficient.

The relationship between contingency and project performance measurement can be multifaceted, and can provide opportunities as well as risks and uncertainties which can adversely affect a project's goals.

RES acknowledges that there are a wide range of project performance measurement techniques, strategies and standards. For the purpose of this Guideline, "*Australian Standard AS 4817-2006, Project performance measurement using Earned Value*" is explained and recommended. Earned Value Performance Measurement (EVPM) is a method for measuring and reporting project performance, and forecasting future performance based on past performance. The EVPM method allows risk practitioners to:

a) measure the performance and status of projects
b) compare project progress to the original plan
c) predict future performance using historical performance data
d) use metrics to measure project performance within an organisation, and against external projects

AS 4817-2006 describes three keys to success when using EVPM:

a) plan work to allow achievements to be measured
b) select objective techniques to guage 'achievement' for each project component
c) integrate the cost, schedule and technical factors of achievement aspects in a single management system.

The steps below outline the process of applying the EVPM method to a project. For the purpose of this Guideline, steps 1 to 5 have an impact on contingency determination while contingency allocation should be addressed in step 6, as explained in the following section. Contingency control is a key element of EVPM during steps 7 to 11 and will be explained in Chapter 7.

1. Decompose the project scope
2. Assign RACI (Responsible, Accountable, Consulted and Informed) Matrices
3. Schedule the work packages
4. Develop time-phased budget
5. Assign objective measures of performance
6. Set the Performance Measurement Baseline (PMB)
7. Authorise and perform the work packages
8. Accumulate and report project performance data
9. Analyse project performance data
10. Take management action
11. Maintain the baseline.

6.4 Contingency allocation in setting PMB

To establishing the PMB, practitioners should create a project baseline which incorporates scope, schedule and cost. This single baseline should be used as a basis to control and manage performance throughout the project lifecycle. As far as possible, the PMB should provide the team with an accurate time-based model of the planned project budget and schedule. Three approaches to contingency allocation for PMB setting purposes are:

1. PMB excludes both Contingency Reserve (CR) and Management Reserve (MR)
2. PMB includes both CR and MR
3. PMB includes CR but excludes MR.

RES Recommendation: the third approach above is preferred in this Guideline – the CR should be a reserve within the PMB managed by the project manager for incorporation of realised risks, while the MR is withheld to cover unforeseen risk events.

CR is used for risks which have been identified and accepted, or which for which contingency responses are planned. They are used to finance the implementation of contingency plans or necessary risk responses when a risk eventuates. The main methods to distribute and allocate the CR within the PMB for cost and schedule estimates are explained in Sections 6.5 and 6.6 respectively.

The PMB is designed to provide a realistic, time-phased schedule and budget which includes contingency reserves. As discussed earlier, this Guideline recommends allocation of contingency to relevant risks or project phases for creation of the PMB, although contingency may be removed from the PMB, reallocated and then managed at the project level during project execution.

The MR is not part of the cost baseline. However, it is a component of the project budget, and can be added to the PMB to cover the costs of unforeseen work in accordance with the organisation's change management process.

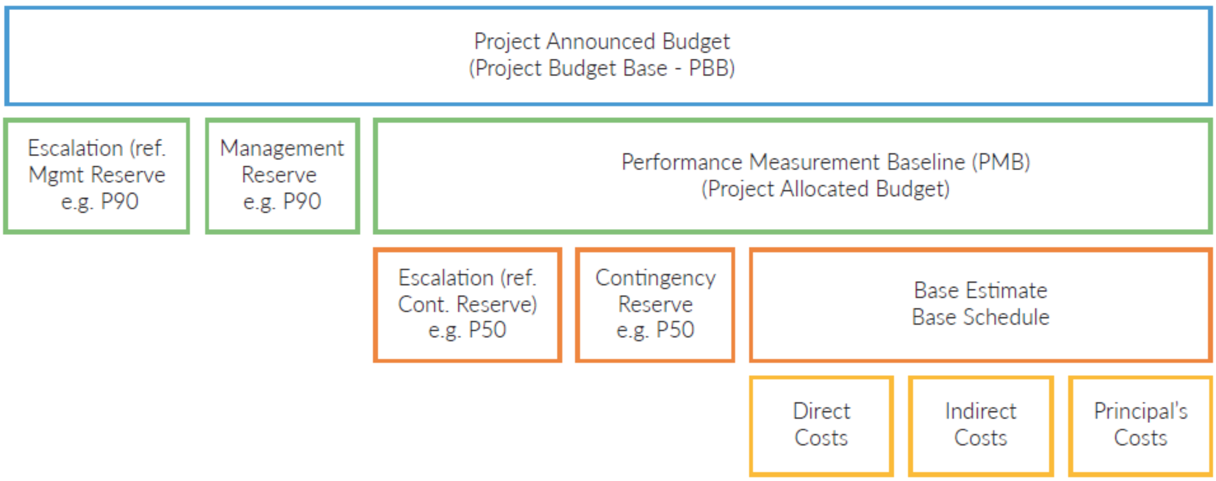

Figure 29: The structure of the project budget base and its elements

To prepare the PMB, this Guideline recommends the process below:

a) Calculate the required cost contingency for the desired confidence level (e.g. P50 cost)
b) Calculate the required schedule contingency for desired confidence level (e.g. P50 schedule):
   - Create additional contingency activities – one before the project Practical Completion (PC) Date and others before the key contractual or critical milestones across the Base Schedule
   - Split and distribute the schedule contingency allowance among these contingency activities
c) Allocate the P50 cost to the P50 schedule to generate the expenditure cost plan (i.e. PMB)
d) Note that additional schedule and/or cost management reserves can be managed as separate 'buckets'
e) To set a tight target PMB, allocate all available schedule contingency before the PC Date, and monitor and compare actual progress against the two cash flows.

This has been illustrated in Figure 30.

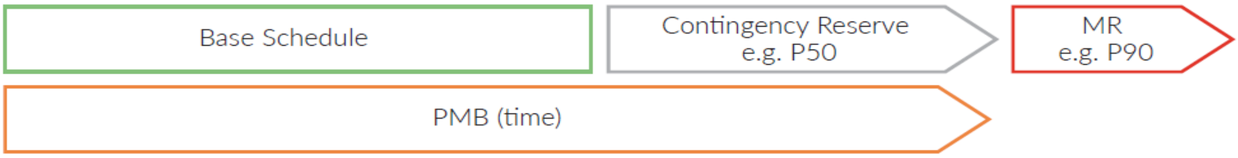

Figure 30: Allocation of schedule contingency for establishment of PMB

For further details regarding project performance measurement, RES recommends *Australian Standard AS 4817-2006, Project performance measurement using Earned Value*.

RES Example: a head contractor, Crown Contractors, has recently won a $300m lump sum Design and Construct (D&C) road project.

Key details are below:

- Base Estimate: $250m
- six-month design, 2.5-year construction, overall schedule duration of three years
- key risks: soft soil treatment, wet weather, availability of import material
- key contractual milestones: SP1 bridge A, SP2 road X and SP3 project Completion Date
- three months of schedule contingency for P70 confidence level.

To maximise the efficiency of contingency control during construction, the management decided to split the available contingency of three months into two buckets as described below:

- allocate two months of available three months schedule contingency, as CR, for the P50 confidence level at the project level. This contingency will be owned and managed by the project manager
- allocate the remaining one month contingency, as MR, owned and controlled by the general manager.

To establish a reasonable cash flow and the PMB, and considering the associated risks for each key milestone, the project manager created three contingency activities before each contractual milestone and then distributed the available two months contingency between them as shown below:

- two weeks contingency activity prior to SP1
- three weeks contingency activity prior to SP2
- three weeks contingency activity prior to SP3

The cost risk analysis recommended a P50 contingency allowance of 10% ($25m) and P70 contingency of 20% ($50m). To achieve reasonable and effective contingency control, the contractor decided to allocate P50 contingency ($25m) as the CR, and the remaining $25m (P70 minus P50 contingency) as the MR.

To establish a reasonable PMB and cash flow, and considering the risk profile across the scope and schedule, $25m CR was then distributed to WBS sections (as below) within the project schedule. In summary:

- 10% of $25m, i.e. $2.5m, to be allocated to design activities
- 50% of $25m, i.e. $12.5m, to be allocated to soft soil treatment activities
- 20% of $25m, i.e. $5m, to be allocated to bridge construction activities
- 10% of $25m, i.e. $2.5m, to be allocated to cut and fill activities
- 10% of $25m, i.e. $2.5m, to be allocated across the schedule (on a pro-rata basis for the direct expenditure cost) for other identified risks.

The remaining $25m MR will be kept and controlled as a bucket by the general manager.

For effective and efficient contingency allocation in setting the PMB, it is critical to assess and allocate contingencies appropriately and in accordance with applicable contracts and their terms and conditions as well as Delegation of Authority and funding requirements. To facilitate these considerations, this Guideline discusses two directions of contingency allocation:

a) vertical allocation: the objective of vertical contingency allocation is to appropriately delegate control of contingency for different levels of delegation (e.g. the client, delivery agency, general manager and project manager)
b) horizontal allocation: the objective of horizontal contingency allocation is to appropriately set indicative distribution of contingencies at any level of delegation (e.g. at the project level this would be between different project areas, including procurement, design, and human resources).

The following sections will provide further details on the vertical and horizontal allocation of schedule and cost contingencies.

6.5 Schedule Contingency Allocation

6.5.1 Vertical Allocation

Good practice in vertical schedule contingency allocation is achieved through a combination of contingency allocations at different levels of delegation where appropriate. This allows contingency owners, in accordance with their Delegation of Authority (DoA), to effectively manage an allocation that most closely matches their capability and proximity to manage the risks.

RES Example: a head contractor, Crown Contractors, has recently won a $300m lump sum D&C road project. Key details are listed below:

a) six-month design, 2.5-year construction, overall schedule duration of three years
b) key risks: soft soil treatment, wet weather, availability of import material
c) three months of schedule contingency for P70 confidence level.

To maximise the efficiency of contingency control during construction, management decided to split the available contingency of three months into two buckets as described below:

a) allocate two months of available three months schedule contingency, for the P50 confidence level at the project level. This contingency will be owned and managed by the project manager
b) allocate the remaining one month contingency, owned and controlled by the general manager.

To establish a reasonable cash flow and the PMB, the project manager then needs to allocate or distribute his two months of schedule contingency across the project schedule. This is the horizontal allocation of contingency (see Section 6.5.2).

6.5.2 Horizontal Allocation

Schedule contingency allowance can be allocated according to lifecycle phase, risk categories, or other methods – or to the overall project schedule. This means schedule contingency can be distributed throughout the schedule, or represented by an activity close to the completion date. The available options for horizontal schedule contingency allocation across the schedule include, but are not limited to:

a) distributing the available contingency between critical activities on a pro-rata basis
b) allocating non-working days within the project calendar
c) representing schedule contingencies as a lag between two activities
d) creating a single activity just before the project PC Date
e) creating multiple activities just before key milestones (i.e. contractual and/or critical milestones) across the project schedule, and then distributing available contingency between those activities depending on the associated risks for each key milestone.

RES Recommendation: subject to contractual and project specific requirements, RES recommends a combination of methods (d) and (e) above – as allocating a large portion of contingency to a single activity close to the PC Date is generally preferable. This is because distributing contingency between a number of activities in advance can be problematic because risk practitioners do not know which risks will eventuate, or the magnitude of their outcomes. In addition, dispersing contingency to many activities may cause it to be prematurely or superfluously consumed.

If practitioners choose to distribute contingency between several activities, they should ensure that this does not affect critical path calculations. The allocation of a portion of contingency to key interim milestones should be kept to a minimum – as they should not be associated with scope or resources – or cause a practical delays to successive activities.

The five methods of horizontal schedule contingency allocation are illustrated in Figure 31.

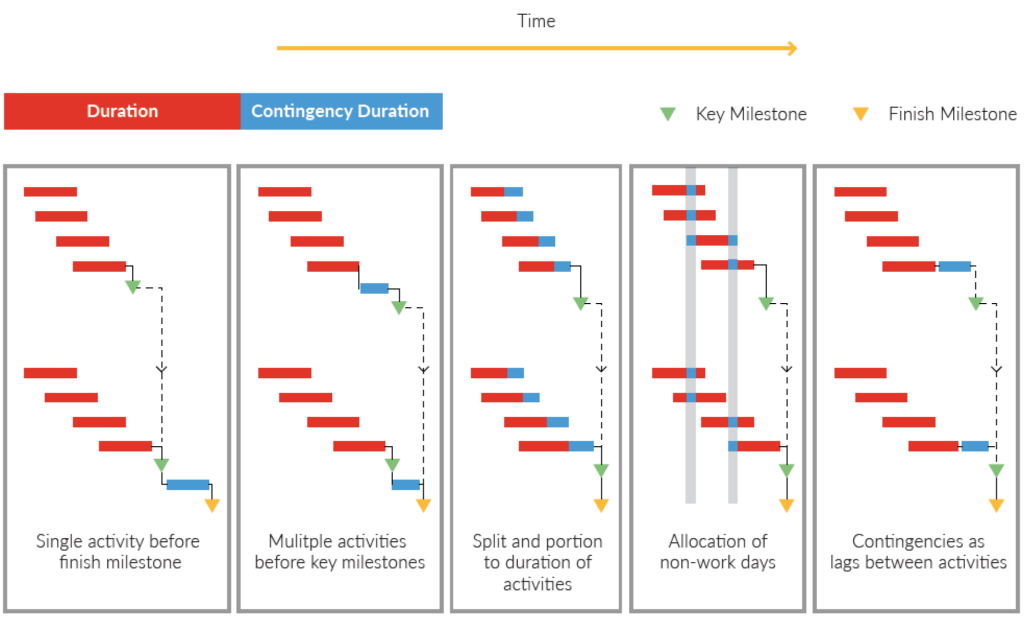

Figure 31: Approaches for horizontal allocation of schedule contingency

RES Recommendation: for practical application of methods (d) and (e) in horizontal allocation of schedule contingency – and depending on contractual and project specific requirements – RES recommends 60-70% of the available schedule contingency is captured as a bucket before the project PC Date. The remaining 30-40% contingency allowance should be distributed and allocated prior to interim key contractual or critical milestones – preferably to less than five milestones – based on their associated risks.

6.6 Cost Contingency Allocation

6.6.1 Vertical Allocation

Vertical allocation of cost contingency should follow the same principles as schedule contingency – that is, separating the contingency allocation into a CR (to be managed at the project level), and an MR (managed at the program or portfolio level). RES acknowledges that across different sectors and organisations there are diverse views and approaches to defining, differentiating, assessing, allocating and controlling the CR and MR.

In this Guideline, the CR is defined (Section 6.4) as the contingency within the PMB for risks which have been identified and accepted, or which for which contingency responses are planned. The MR is defined as a portion of the Project Base Budget (PBB) withheld for management control purposes. Depending on the specific requirements of each organisation and its stakeholders, the MR might represent the budget for unexpected work that falls within the scope of the project, or activities outside the planned scope which have been authorised by decision makers. In special circumstances, the MR might be used to cover items outside the project scope, in order to achieve greater benefits for the customer.

However, the Guideline also acknowledges that the MR may be defined as being outside of the project funding for some owners, especially within the private sector. In the private sector, the MR is often regarded as the additional amount that may be required to complete the project if outcomes turn out to be even more pessimistic than the overall contingency reserve allows.

The MR enables the project owners to assess how much extra funding they might be called upon to contribute – beyond the allocated budget (including the CR). This can enable management to decide the amount of equity they are prepared to hold in a project while protecting their balance sheet from excessive exposure. This can determine the maximum percentage of a major project an equity partner may be prepared to own.

RES Example: as a head contractor, Crown Contractors, has recently won a $300m lump sum D&C road project. Key details are below:

a) six-month design, 2.5-year construction, overall schedule duration of three years
b) key risks: soft soil treatment, wet weather, availability of import material
c) key contractual milestones: SP1 bridge A, SP2 road X and SP3 PC Date
d) three months of schedule contingency for P70 confidence level.

To maximise the efficiency of contingency control during construction, management decided to split the available contingency of threee months to two buckets:

a) allocate two months of schedule contingency, as CR, for the P50 confidence level (at the project level) to be owned and managed by the project manager
b) allocate the remaining one month of contingency, as MR, owned and controlled by the general manager.

To establish a reasonable cash flow and the PMB (considering the risks associated with each key milestone) the project manager created three contingency activities before each contractual milestone and then distributed the available two months of contingency between them as below:

a) two weeks of contingency activity prior to SP1
b) three weeks of contingency activity prior to SP2
c) three weeks of contingency activity prior to SP3.

The MR is estimated based on the organisation's policies; the overall uncertainty and unknowns associated with the project scope; internal and external stakeholders; the organisation's culture and risk appetite; market conditions; and many other factors. An estimation of MR can be made using an independent deterministic method for the total cost or time of the project (e.g. 5–15%), or probabilistic methods.

This determination can be carried out as an additional step after assessing CR – or even as part of the same contingency assessment with a higher confidence level, using one of the options below:

a) selecting CR from a lower confidence level (e.g. P50) and then MR from a higher confidence level (e.g. P90). This method is more common with government organisations, asset owners or investors
b) selecting a portion of the allocated contingency for the desired confidence level, (e.g. 80% of P50), for CR and then the remaining contingency as MR, (e.g. 20% of P50). This method is more common with contractors – especially for lump sum and D&C contracts.

RES Recommendation: in practice, while MR is widely used by government agencies for budgeting purposes, it is rarely set aside in the private sector as many consider the organisation would provide extra funding at the request of the project management team if circumstances require. However, this is **not recommended** by RES. For more effective contingency management, RES recommends a separate MR bucket is reasonably and practically assessed, allocated and managed.

In a government environment, the vertical contingency allowance up to the 'allocated budget' level will be controlled by the Government Agency and any access to further funding up to the 'announced budget' level will need approval from the client (e.g. Treasury or the Federal Government).

In a private sector context for a D&C project – allocated budget (e.g. P50 budget) can be allocated to the project manager – and the remaining contingency (e.g. P70 or P90 contingency) could be allocated and controlled by the project director or general manager as the MR.

Figure 32 shows an example of project cost and schedule contingency allocation.

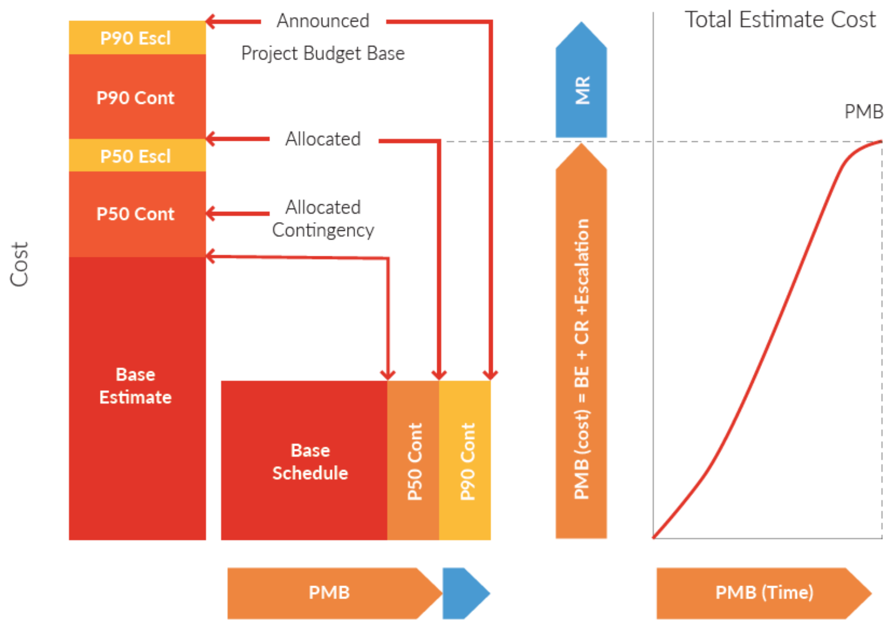

Figure 32: An example of time and cost contingency vertical allocation

RES Example: ABC, a government agency, has prepared a Final Business Case for delivering a major road project with its cost estimate as below:

a) Base Estimate for D&C Contractor: $90m (using the First Principle Estimate methodology)
b) Base Estimate (total including client's costs): $100m
c) P50 Contingency bucket: $20m (using a probabilistic estimation methodology)
d) P90 Contingency bucket: $15m (using a probabilistic estimation methodology
e) no escalation allowance is required.

For budgeting purposes, the P50 Contingency bucket will be allocated within PMB, as the CR. While the additional estimated P90 Contingency bucket (i.e. $15m) will be funded to this project by Treasury, as the MR. This will not be directly accessible by the government agency. A special control process including justification of needs and evidence of proactive risk management is needed as part of accessing this additional funding. Hence, $120m will be allocated to ABC to deliver this project. With this funding approval, ABC progresses with the procurement of a D&C contract through a selective tender.

DEF, as a tier 1 contractor, has prepared and submitted its response to this tender opportunity. For this lump sum contract and considering all internal and external circumstances as well as market conditions, the senior management of DEF decided to proceed with the lump sum tender submission as below:

a) Base Estimate $85m
b) P50 Contingency bucket: $17m
c) Lump Sum submission: $102m.

DEF was selected as the preferred tenderer following a comprehensive tender evaluation including a risk and contingency comparison between the different tenderers. At the commencement of the project, DEF management decided to allocate 80% of the $17m available contingency (i.e. $13.6m) as CR and the remaining 20% (i.e. $3.4m) as MR. As recommended by RES, the CR will be controlled and used by the project manager when establishing the PMB for project performance measurement and Earned Value assessment. MR will be allocated out of PMB and will be controlled and released by senior management, if required.

6.6.2 Horizontal Allocation

The objective of horizontal cost contingency allocation is to appropriately set the indicative distribution of contingencies between different areas of a project or program so a reasonable and achievable PMB can be established. In a D&C project, examples of project areas could include approvals, design and human resources. Cost contingency can be linked to the cost expenditure curve in several ways, including the three approaches below:

1. CR is global to the overall project and will be allocated at the project timeline:
   a) at the beginning of the project
   b) at the end of the project
   c) distributed along the timeline (e.g. linearly).
2. CR is allocated by the project lifecycle phase or risk categories
3. CR is distributed by using a pro-rata approach of cost expenditure per month.

This Guideline recommends that the cost contingency be managed as a single 'bucket' (at the project level). However, indicative distribution to different project areas will improve the effectiveness and transparency of contingency control as well as creating a more realistic project cash flow and PMB. An example of some project areas or subgroups is presented in Table 14.

Approvals	Legal & Commercial
Constructability	Occupational Health and Safety
Community	Procurement
Design	Project Management
Earthworks	Property
Environment, Noise and Heritage	External Stakeholders
Funding	Structures
Government	Utilities
Human Resources	Miscellaneous

Table 14: Some examples of project areas or subgroups

Another approach is to run full, sequential simulations when single (or grouped) costs and tasks – or uncertainty classes – are removed. When each element is taken out of the equation, the simulation models the results of its removal for the probability levels chosen. This process can help organisations decide how best to set priorities to optimise the project's risk response.

6.7 Further Reading

- AACEI, RP No. 67R-11 – *Contract Risk Allocation As Applied in Engineering, Procurement and Construction*
- AACEI, RP No. 72R-12 – *Developing a Project Risk Management Plan*
- APM, *Project Risk Analysis and Management Guide*, APM Publishing, 2nd Edition, 2004
- AS 4817 – 2006, *Project performance measurement using Earned Value*
- Australian Government Treasury, *Charter of Budget Honesty Policy – Policy Costing Guidelines* <www.treasury.gov.au/PublicationsAndMedia/ Publications/2012/charter-of-budget-honesty>
- Australian Government, *National PPP Guides Volume 4: PSC Guidance*
- Boardman, A.E., Greenberg, D.H., Veining, A.R. and Weimer, D.L., *Cost-Benefit Analysis: Concepts and Practice*, Prentice Hall, 1996
- CIOB, *Guide to Good Practice in the Management of Time in Complex Projects*
- Commonwealth Department of Infrastructure and Transport, *National Alliance Contracting Policy and Guidelines*, 2011
- ISO-31000: 2018 *Risk Management – Principles and Guidelines*
- Lyons, Terry and Skitmore, Martin (2004) Project risk management in the Queensland engineering construction industry: a survey. International Journal of Project Management 22(1):pp. 51-61
- PMI, *Practice Standard for Project Risk Management*
- PMI, *Practice Standard for Earned Value*
- PMI, *Project Management Body of Knowledge (PMBOK)*
- Raydugin, Y., *Project Risk Management*, Wiley, 2013
- United Kingdom Government, HM Treasury, *The Green Book, Appraisal and Evaluation in Central Government*, 2003 <www.hm-treasury.gov.uk/d/ green_book_complete.pdf>
- United Nations, *UN Industrial Development Organization, Guidelines for Project Evaluation*, Project Formulation and Evaluation Series, No. 2, UNIDO, 1972

7. Contingency Control

7.1 Structure of Content

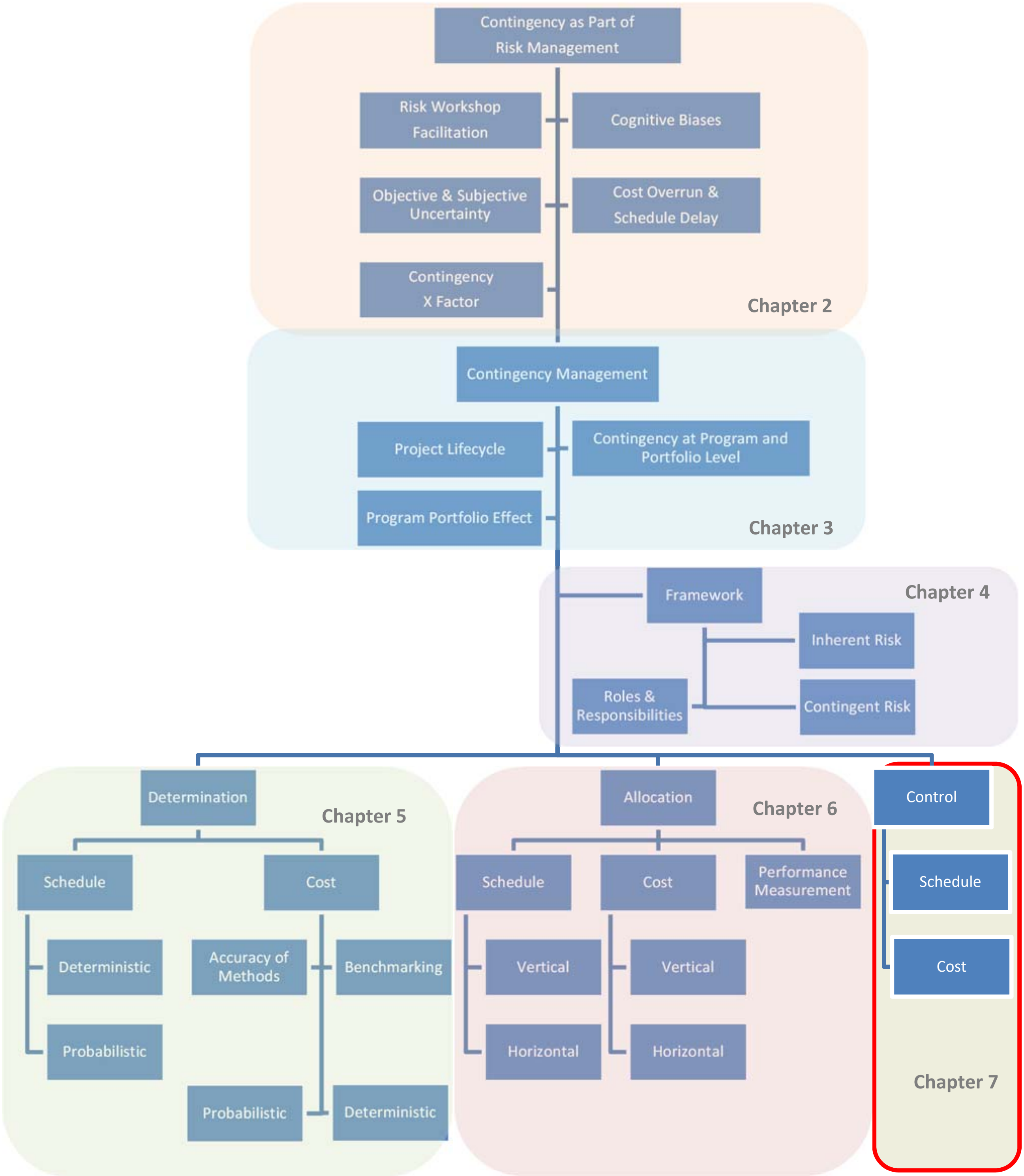

Figure 33: RES Contingency Guideline – Structure of Content

7.2 Overview

As highlighted in Chapter 6, the steps below outline the process of applying the EVPM method to a project. For the purpose of this Guideline, steps 1 to 5 have an impact on contingency determination while contingency allocation should be mainly addressed in step 6, as explained in Chapter 6. Contingency control (both schedule and cost in an integrated management system) is a key element of EVPM during steps 7 to 11 and is explained in this chapter.

1. Decompose the project scope
2. Assign RACI (Responsible, Accountable, Consulted and Informed) Matrices
3. Schedule the work packages
4. Develop time-phased budget
5. Assign objective measures of performance
6. Set the performance measurement baseline (PMB)
7. Authorise and perform the work packages
8. Accumulate and report project performance data
9. Analyse project performance data
10. Take management action
11. Maintain the baseline.

7.3 Schedule Contingency Control

RES recommends that schedule contingency control should be planned and managed as part of a larger schedule change control plan – which incorporates both Baseline Schedule and current schedule. This ensures that contingency use is documented and transparent, and any variances can be measured. The subject of schedule change control, as part of EVPM, is not the subject of this Guideline, but the section below highlights a few critical aspects of this topic.

7.3.1 Schedule Change Control

A schedule change control process manages the components of the current Updated Schedule, as well as the criteria for applying program and technical changes, and improvements to the Baseline Schedule. This assists organisations to maintain an accurate and reliable current schedule and base. Defining and communicating schedule change measurement criteria to the team ensures that they do not deliberately or unconsciously adjust the planned schedule to correspond with actual or planned performance. This can distort decision-makers' oversight of true performance, reducing the likelihood of project success.

Accurate measurement of performance against the original Baseline Schedule and PMB is not possible when changes are uncontrolled or undocumented. Performance measurement, schedule data, and inconsistent versions of the plan can be generated by different project teams or stakeholders.

RES Tips & Tricks: organisations should define the degree to which their project schedules are governed by the schedule change control process. This may be influenced by factors such as complexity, size, scope and risk. For less complex projects, it may be appropriate to restrict the change control process to key contract milestones or high-level WBS components. For complex projects, the level of risk increases, meaning that it may be necessary to manage schedule network dependencies and activities at a lower WBS level under established change management processes.

Management should a use a unique version number for each approved iteration of the current Updated Schedule, and communicate it with relevant stakeholders. Consistent version numbers will help management keep track of updates and make sure all parties are referring to a single Updated Schedule.

Generally, the Baseline Schedule should not be changed except to accommodate limited scope variations or formal re-planning. One exception is in cases where decision-makers determine that the current Baseline Schedule no longer provides a reasonable estimation to measure performance. Examples of this case include an instructed Variation Order or award of an Extension of Time.

In addition to meeting contractual requirements, re-baselining can also provide a more reasonable basis for performance management to help decision-makers regain control. The updated Baseline Schedule generally discards historical variances in order to efficiently identify and measure new variances. For most projects, there should not be the need for more than two to three baselines over the project duration. Factors leading to more frequent re-baselining can include poor understanding of scope, managers who do not exercise enough discipline to realistically estimate the schedule. In both of these scenarios, further assessment is urgent in order to mitigate future risks.

RES Recommendation: for complex projects, schedule contingency control is more efficient and effective if it is being managed as part of a broader schedule change control process. RES recommends that appropriate schedule change control criteria should be defined, implemented and monitored regularly. For example, the criteria below may be used:

a) any change in total number of activities more than 10%
b) any change in original activity duration more than 10%
c) any change in the Schedule Criticality Index (SCI)
d) monitor the Baseline Execution Index (BEI) – the ratio of the number of completed detail activities, compared to those expected to be complete at a point in time. Generally,:
    i) the project is performing according to plan if a BEI is equal to 1
    ii) the number of completed activities is less than that planned if the is BEI less than 1
    iii) the number of completed activities is greater than that planned if the BEI is greater than 1.
e) Conduct trend analysis to investigate the effects of mitigation measures (e.g. reducing contingency or decreasing total float).

7.3.2 Schedule Recovery and Acceleration

There are a number of strategies and options available to address undesired variances in relation to the latest Baseline Schedule to get the project schedule back on track. In order to identify and increase understanding of how individual schedule variances affect the baseline, risk practitioners should analyse several strategies. Variances relate directly to the reliability of the project schedule – so underdeveloped, unrealistic or incomplete schedules may lead to unreliable outputs when measuring them against the Base Schedule.

The list below summarises common general techniques that can be used to reduce (accelerate) the schedule duration, or correct schedule variances (interruptions to the original plan) through schedule recovery.

There are two types of schedules being developed using the CPM technique:

a) logic driven schedules – CPM uses the longest path through the activity network to calculate the shortest project duration or PC Date from events linked by physical relationships

b) resource driven schedules – CPM uses the longest path through the activity network to calculate the shortest project duration or PC Date from the physical relationships of activities; availability of critical resources, and activity priorities.

For logic driven schedules, schedule recovery and acceleration should focus on realistic and achievable critical activities – particularly those with long durations. For resource driven schedules, focus should shift to accurate resource allocation.

Some strategies for schedule recovery and acceleration may have contractual or commercial implications. Therefore, any recovery and/or acceleration action should be entirely discussed, assessed and agreed between the project controls, commercial team and project management. Strategies include:

a) reviewing and assessing schedule delays and the causes for possible variations and/or EOTs – any approved EOT may result in schedule re-baselining rather than recovery or acceleration
b) varying construction methodology or logic (e.g. bringing fill material from a closer source)
c) reviewing and adjusting the working calendar (e.g. carrying out activities over the weekend)
d) 'crashing' by increasing the resources to time-dependent critical activities
e) performing activities concurrently
f) fast-tracking by substituting partial dependencies between activities with partial dependencies (e.g. reducing Finish-to-Start logic to Start-to-Start plus lag logic)
g) splitting long activities, and undertaking the shorter activities in parallel
h) reviewing schedule logic on critical (and near critical) activities for any improvement
i) reviewing activity durations
j) reviewing any critical constraints and lag/lead assumptions
k) decreasing scope to reduce both duration and costs
l) using available schedule contingency, in accordance with formal change management processes.

7.4 Cost Contingency Control

7.4.1 Key Objectives

The key objective of contingency control is to manage the expenditure of contingency funds to enable effective project delivery – in the event that risks identified in the project plan are realised or additional funding is required for unexpected events. Effective governance should be implemented to ensure that the contingency spend remains within approved limits for its intended purpose.

Change control is a core part of effective cost contingency management. Contingency funds should not be released for any materialising risk or issue without passing through a gated change control process. Risks and issues that materialise on a project should be reviewed under the change control process to confirm and validate that the item is covered under contingency.

The key objective of contingency monitoring is to consistently and regularly review performance and utilisation of contingency against the approved provision, to enable management action and risk mitigation as required. This should be carried out monthly for qualitative assessment and no longer than quarterly for quantitative assessment.

The regular and consistent reassessment of contingency requirements and performance throughout the project lifecycle provides assurance and confidence at all levels of governance and enables proactive risk identification. The objective of regular contingency reporting is to provide consistent and transparent disclosure of contingency management performance information across all levels of governance to enable optimal fund management across the program and portfolio.

7.4.2 Overall Process

Reviewing performance of cost contingency against initial estimates is a means to identify potential and realised risks and issues early – enabling effective responses and optimising contingency performance across the project and organisation.

For effective and efficient contingency control, change control processes for individual activities should be fully integrated into the project's overall change control process. Any use of contingency should be clearly tracked and categorised under one of the groups below (as illustrated in Figure 34):

a) Scope Change
b) Unforeseen Event
c) Identified Risk (Inherent or Contingent).

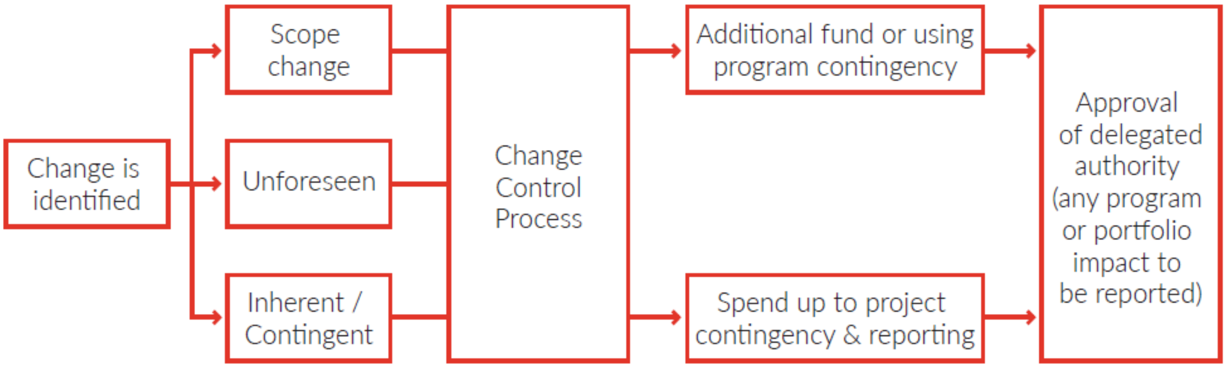

Figure 34: Interface between change control and contingency controls

7.4.3 Delta Contingency

This Guideline recommends the terminologies defined below:

a) allocated (or budgeted) contingency (i.e. P50 contingency)
b) remaining contingency (allocated contingency minus realised contingency minus returned contingency)
c) desired contingency (the contingency needed for the desired confidence level)
d) delta contingency (available contingency minus desired contingency).

After considering factors such as the amount of delta contingency; desired confidence level; stage of the project; and delegation level of contingency – decision-makers should select from the following actions:

a) retain the contingency
b) reallocate the contingency
c) spend the contingency
d) return the contingency.

Three potential decisions based on the amount of delta contingency are illustrated in Table 15 below.

Scenario	Recommended Decision/s
Delta contingency = 0 (available contingency = desired contingency)	Retain and/or reallocate
Delta contingency < 0 (available contingency < desired contingency)	Retain and/or request for additional contingency (report to the next level of authority)
Delta contingency > 0 (available contingency > desired contingency)	Retain and/or potential return to portfolio (report to the next level of authority)

Table 15: Scenarios for contingency control decisions based on delta contingency

RES Tips & Tricks: considering the subjective nature of contingency determinations and associated uncertainties, for practical use of Table 15, RES recommends the contingency performance indicators below:

a) - 20% =< Delta Contingency / Available Contingency =< +20% – retain and/or reallocate
b) Delta Contingency / Available Contingency > +20% –retain and/or potentially return to portfolio (report to the next level of authority)
c) Delta Contingency / Available Contingency < -20% – retain and/or request for additional contingency (report to the next level of authority).

7.4.4 Return of Contingency

The key objective of return of contingency is to manage the availability of any surplus contingency funds to enable optimal use of available capital at higher levels. The preferred option to return contingency is to review the delta contingency (see Section 7.3.3 above).

RES Recommendation: return of contingency reviews should be conducted at least every three months throughout the project lifecycle, allowing contingency funds to be released as determined by the delegated authority.

7.5 Further Reading

- AACEi RP 82R-13 *Earned Value Management (EVM) Overview and Recommended Practices consistent with EIA-748-C*
- APM, *Earned Value Management Guideline*
- APM, *Earned Value Management Handbook*
- APM, *Interfacing Risk and Earned Value Management*
- APM, *The Earned Value Management Compass*
- AS 4817 – 2006, *Project performance measurement using Earned Value*
- PMI, *Practice Standard for Earned Value*
- PMI, *Practice Standard for Project Estimation*

8. Appendix A – Key definitions

Term	Definition / Description
Acceleration	AACEi: Conduct by the owner or its agent (either in a directed or constructive manner) in which a contractor is required to complete performance of a contracted scope of work earlier than scheduled. A directed acceleration occurs when the owner formally directs such acceleration completion. A constructive acceleration generally occurs when a contractor is entitled to an excusable delay; the contractor requests a time extension from the owner; the owner declines to grant a time extension or grants one in an untimely manner; the owner or its agent either expressly orders completion within the original performance period or implies in a clear manner that timely completion within the original performance period is expected; and the contractor gives notice to the owner or its agent that the contractor considers this action an acceleration order.
Accuracy	AACEi: "Correctness that the measured value is very close to the true value."
Allocate	1. Assign contingency funds and associated risks to defined contingency owner or risk categories. 2. AACEi: (i) In planning and scheduling, the process of distributing or assigning work on an activity to specific resources (ii) In cost estimating and budgeting, the process of distributing or assigning cost of an item or activity (often an overhead or indirect cost) to specific cost or budget accounts.
Allowances	1. Queensland Government: Specific allocation of known but undefined resources included in the Base Estimate or Base Schedule to cover a most likely scope that has not yet been fully defined and quantified. The inclusion of these allowances in duration and cost estimates will ensure both the Base Estimate and Base Schedule are presenting the scenario for current strategies and assumptions. 2. AACEi: (i) For estimating, resources included in estimates to cover the cost of known but undefined requirements for an individual activity, work item, account or sub-account (ii) For scheduling, dummy activities and/or time included in existing activities in a schedule to cover the time for known, but undefined requirements for a particular work task, activity, account or subaccount.

Accountability	1. Queensland Government: "Final responsibility for completion of tasks and achievement of results within delegated authority and to established performance standards." 2. AACEi: "Answerable, but not necessarily charged personally with doing the work. Accountability cannot be delegated but it can be shared."
Authority	AACEi: (i) Power of influence, either granted to or developed by individuals, that leads to others doing what those individuals direct. (ii) Formal conferment of such influence through an instrument such as a project charter.
Base Estimate	1. Estimated cost of a project that can be reasonably (i.e. current strategies and assumptions) expected if the project materialises as planned. 2.Queensland Government: "the estimator's best prediction in terms of the quantities and current [productivity] rates which are likely to be associated with the delivery of a given scope of work prior to the addition of inherent and contingent risk values or escalation allowances." 3. AACEi: "Estimate excluding escalation, foreign currency exchange, contingency and management reserves."
Base Schedule	1. Expected duration of a project that can reasonably (i.e. current strategies and assumptions) be expected if the project materialises as planned. 2. Queensland Government: "the [scheduler's] best prediction in terms of the quantities, current [productivity] rates and delivery strategy that are likely to be associated with the delivery of a given scope of work prior to the addition of inherent and contingent risk values. 3. AACEi: Schedule excluding risks (i.e., excluding contingency).
Baseline	1. US Department of Energy: A quantitative definition of cost, schedule, and technical performance that serves as a standard for measurement and control during the performance of an activity; the established plan against which the status of resources and the effort of the overall program, field programs, projects, tasks, or subtasks are measured, assessed, and controlled. Once established, baselines are subject to change control discipline. 2. AACEi: (i) In project control, the reference plans in which cost, schedule, scope and other project performance criteria are documented and against which performance measures are assessed and changes noted. (ii) The budget and schedule that represent approved scope of work and work plan. Identifiable plans, defined by databases approved by project

	management and client management, to achieve selected project objectives. It becomes basis for measuring progress and performance and is baseline for identifying cost and schedule deviations. (iii) In earned value management systems, the general term to refer to the contractual baseline. See contract budget baseline and performance measurement baseline for the typical earned value management (EVM) definitions of the different baseline levels within the EVM baseline plan.
Baseline Schedule	1. PMI: "the approved time phased plan (for a project, a work breakdown structure component, a work package, or a schedule activity), plus or minus approved project scope, cost, schedule, and technical changes." 2. AACEi: (i) A fixed project schedule that is the standard by which project performance is measured. The current schedule is copied into the baseline schedule that remains frozen until it is reset. Resetting the baseline is done when the scope of the project has been changed significantly, for example after a negotiated change. At that point, the original or current baseline becomes invalid and should not be compared with the current schedule. (ii) Version of schedule that reflects all formally authorised scope and schedule changes.
Basis of Estimate (BoE)	A document which records the evidence used to develop the key elements of the project cost estimate. It includes factors such as assumptions, reference analyses, availability of resources and personnel. BoE and Basis of Schedule (below) should be developed and aligned together.
Basis of Schedule (BoS)	A document which records the evidence used to develop the key elements of the project schedule. It includes factors such as delivery strategy, productivity rate estimates, long lead times, deviations and assumptions, and reference analyses. BoE and Basis of Schedule (below) should be developed and aligned together.
Benchmark	1. US Department of Energy: "A standard by which performance may be measured." 2. AACEi: A measurement and analysis process that compares practices, processes, and relevant measures to those of a selected basis of comparison (i.e., the benchmark) with the goal of improving performance. The comparison basis includes internal or external competitive or best practices, processes or measures. Examples of measures include estimated costs, actual costs, schedule durations, [and] resource quantities.
Best Practices	AACEi: "Practical techniques gained from experience that have been shown to

	produce best results."
Bias	1. US Department of Energy: "A repeated or systematic distortion of a statistic or value, imbalanced about its mean." 2. AACEi: Lack of objectivity based on the enterprise's or individual's position or perspective. Systematic and predictable relationships between a person's opinion or statement and his/her underlying knowledge or circumstances. Note: There may be "system biases" as well as "individual biases".
Bid	AACEi: "To submit a price for services; a proposition either verbal or written, for doing work and for supplying materials and/or equipment."
Brainstorming	1. US Department of Energy: "Interactive technique designed for developing new ideas [within a group]." 2. AACEi: [Process in which] a group of people, selected for their creativity and knowledge, are brought together to seek solutions to particular problems or simply to find better ways of meeting objectives. Suggestions, however outlandish, are encouraged and pursued during a creativity session. From this, many ideas, some entirely new, are brought forward for analysis and ranking.
Budget	1. Amount of money available for spending that is based on a schedule for how it will be spent. 2. PMI: "the approved estimate for the project or any work breakdown structure component or any schedule activity." 3. AACEi: "A planned allocation of resources. The planned cost of needed materials is usually subdivided into quantity required and unit cost. The planned cost of labor is usually subdivided into the work-hours required and the wage rate (plus fringe benefits and taxes)."
Budgeting	AACEi: "A process used to allocate the estimated cost of resources into cost accounts (i.e., the cost budget) against which cost performance will be measured and assessed. Budgeting often considers time-phasing in relation to a schedule or time-based financial requirements and constraints."
Buried contingency	US Department of Energy: Costs that may have been hidden in the details of an estimate to protect a project from the removal of explicit contingency and to ensure that the final project does not go over budget. To reviewers, buried contingency often implies inappropriately inflated quantities, lowered productivity, or other means to increase project costs. Buried

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	contingency should not be used.
Business Case	AACEi: Defines a project's or other investment's justification for business decision making purposes. Depending upon the business' decision making criteria, it typically includes an outline of objectives, deliverables, time, cost, technical, safety, quality and other attributes in respect to how the project or investment addresses the objectives and requirements of the business. May include information on project risks (either threats or opportunities), competitive impact, resource requirements, organizational impacts, key performance indicators (particularly profitability) and critical success factors.
Calendar	1. AACEi: "Defined work periods and holidays that determine when project activities may be scheduled. Multiple calendars may be used for different activities, which allows for more accurate modeling of the project work plan e.g. 5-day work week calendar vs. 7-day work week." 2. PMI: a table or register of dates containing the days of each month and week in one or more years. In project management, each date may be identified as a time span for performing work (work period) or as a time span for not performing work including designated holidays (non-working period) and each date may be further subdivided into segments such as shifts, hours, or even minutes that may be designated as work periods or non-work periods.
Cash Flow	AACEi: "Inflow and outflow of funds within a project. A time-based record of income and expenditures, often presented graphically."
Client	Accountable entity for the successful selection, approval and delivery of the projects to be funded. The client is the owner of the completed asset.
Change	Alteration or variation to the cost and schedule baseline. For business, scope change is limited to changes to the basic premises of the business case.
Change Control	1. The system for managing alterations to a project's baselines. 2. US Department of Energy: "a process that ensures changes to the approved baseline are properly identified, reviewed, approved, implemented and tested, and documented." 3. PMI: "identifying, documenting, approving or rejecting, and controlling changes to the project baseline." 4. AACEi: (i) Process of accepting or rejecting changes to the project's baselines. Lack of change control is one of the most common causes of scope

	creep. (ii) Process of implementing procedures that ensure that proposed changes are properly assessed and, if approved, incorporated into the project plan. Uncontrolled changes are one of the most common causes of delay and failure. (iii) Risk abatement process of accepting or rejecting changes to the project's baselines, based on predetermined criteria or "trigger points."
Confidence Interval	Probability that the value of a parameter e.g. project actual cost or completion date falls within an expected or specified or expected range.
Confidence level	1. US Department of Energy: "Confidence level is the probability that a cost estimate or schedule can be achieved or bettered. This is determined from a cumulative probability distribution." 2. AACEi: The probability: (i) That results will be equal to or more favorable than the amount estimated or quoted; or (ii)) That the decision made will achieve the desired results; or (iii) That the stated conclusion is true. Note: Confidence level may also be expressed as "equal to or less favorable". If that is the case, it should so be noted. Without such a note, the definition shown is assumed. 3. PMI: a measure "of how reliable a statistical result is, expressed as a percentage that indicates the probability of the result being correct."
Consequence	1. The outcome of a contingent risk. (Normally includes scope, schedule, and cost.) 2. AACEi: "In risk management, the impact or effect of a risk event or condition."
Contingency	1. Specific allocation of resources (capital cost, resources, and time) required in addition to the Base Estimate or Base Schedule as a provision for inherent and/or contingent risks for the desired confidence level. 2. AACEi: (1)An amount added to an 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. Typically estimated using statistical analysis or judgment based on past asset or project experience. Contingency usually excludes: 1) Major scope changes such as changes in end product specification, capacities, building sizes, and location of the asset or project; 2) Extraordinary events such as major strikes and natural disasters; 3) Management reserves; and 4) Escalation and currency effects. Some of the items, conditions, or events for which the state, occurrence, and/or effect is uncertain include, but are not limited to, planning and estimating errors

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	and omissions, minor price fluctuations (other than general escalation), design developments and changes within the scope, and variations in market and environmental conditions. Contingency is generally included in most estimates, and is expected to be expended. (2) In earned value management (based upon the ANSI EIA 748 Standard), an amount held outside the performance measurement baseline for owner level cost reserve for the management of project uncertainties is referred to as contingency.
Contingency Allocation	Appropriately delegating control of contingency between the client, delivery agency and project manager.
Contingency Controls	Controls to effectively and efficiently manage the movement of contingency, based on delegated authority.
Contingency Determination	Quantification and assessment of required contingency funds or time for inherent and contingent risks to achieve desired confidence level.
Contingency Management Framework	Establishes how the contingency management process (i.e. determination, allocation and controls) is to be performed at project, program and portfolio levels.
Contingency Owner	Governance authority responsible for the use or return of contingency (or part thereof) throughout the project lifecycle.
Contingency Plan	AACEi: "A risk response plan made to address identified residual risks if they occur."
Contingency Reserve (CR)	1. Allowance incorporated in the Performance Measurement Baseline (PMB) to fund management of accepted risks, or risks with planned contingency responses. 2. PMI: "budget within the performance management baseline that is allocated for identified risks that are accepted and for which contingent or mitigating responses are developed."
Contingent Risk	Type of risk caused by unmeasured items outside the Base Estimate, which may or may not materialise. Examples of contingent risks are delays or cost increases due to bad weather and other incidents which have not been predicted, industrial action, planning approvals, scope variations, or unexpected site conditions detected by geotechnical engineers. The likelihood of occurrence of a contingent risk is always less than 100%.
Control Gate	AACEi: "A major project milestone at which the project client has the opportunity to exercise a 'go/no-go' decision upon continuation into the succeeding phase."

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Correlation	1. US Department of Energy: “relationship between variables such that changes in one (or more) variable(s) is generally associated with changes in another. Correlation is caused by one or more dependency relationships. Measure of a statistical or dependence relationship existing between two items estimated for accurate quantitative risk analysis.” 2. AACEi: “The measure of the relationship between two or more quantitative elements.”
Cost Estimate and Schedule Classification System	AACEI: recommends classification catergories are primarily defined according to the project level. For projects, the estimate class designations that follow below are labeled Class 1, 2, 3, 4, and 5. A Class 5 estimate is based upon the lowest level of project definition, and a Class 1 estimate is closest to full project definition and maturity. This “countdown” approach considers that estimating is a process whereby successive estimates are prepared until a final estimate closes the process. CLASS 5 ESTIMATE – (Typical level of project definition required: >0% to 2% of full project definition.) CLASS 4 ESTIMATE – (Typical level of project definition required: 1% to 15% of full project definition.) CLASS 3 ESTIMATE – (Typical level of project definition required: 10% to 40% of full project definition.) CLASS 2 ESTIMATE – (Typical level of project definition required: 30% to 75% of full project definition.) CLASS 1 ESTIMATE – (Typical level of project definition required: 65% to 100% of full project definition.)
Cost to Complete (CTC)	1. Forecast costs to complete the project in addition to actual cost already spent or accrued. 2. AACEi: “The amount that an in-progress activity or group of activities will cost to complete."
Critical Path	1. US Department of Energy: A logically related sequence of activities in a critical path schedule having the longest duration. The total float is zero. A delay in any activity will have a corresponding impact on the completion date of the project. 2. PMI: “generally, but not always, the sequence of schedule activities determining the duration of the project. Generally, it is the longest path through the project. However, a critical path can end, as an example, on a schedule milestone that is in the middle of the schedule model and that has a finish-no-later-than imposed date schedule constraint.” 3. AACEi: “longest continuous chain of activities (may be more than one path) which establishes the minimum overall project duration. A slippage or delay in completion of any activity by one time period will extend final completion

	correspondingly. The critical path by definition has no 'float'."
Cumulative Distribution Function (CDF)	US Department of Energy: A statistical function based on the accumulation of the probabilistic likelihood of occurrences. In the case of the DOE risk analysis, it represents the likelihood that at a given percentage the project cost or duration will be at or below a given value. As an example, the x-axis might represent the range of potential project cost values evaluated by the Monte Carlo simulation and the y-axis represents the project's probability of completion.
Direct costs	1. Expenses specifically attributable to a project cost object, such as materials or labour. 2. US Department of Energy: "Costs identified with a particular project or activity; includes salaries, travel, equipment, and supplies directly benefiting the project or activity." 3. AACEi: Costs of completing work that are directly attributable to its performance and are necessary for its completion. 1) In construction, the cost of installed equipment, material, labor and supervision directly or immediately involved in the physical construction of the permanent facility. 2) In manufacturing, service, and other non-construction industries: the portion of operating costs that is readily assignable to a specific product or process area.
Duration	1. AACEi : The amount of time estimated to complete an activity in the time scale used in the schedule (hours, days, weeks, etc.). Planned production rates and available resources will define the duration used in a given schedule. The following four types of duration are used: 1) Original duration: Duration input by the planner; 2) Current duration: Duration based on latest progress date for in-progress activities. Calculated rate of progress provides a new completion estimate; 3) Actual duration: Duration based on activity's actual start and actual finish. Applies only to completed activities; and 4) Remaining duration: The expected time required to complete an activity. It is calculated as the difference between the data date and the expected finish date for in-progress activities. (Equal to the original duration for non-progressed activities. Equal to zero for completed activities). 2. PMI: "the total number of work periods (not including holidays or other nonworking periods) required to complete a schedule activity or work breakdown structure component or project. Usually expressed as work-hours, workdays or workweeks. Sometimes incorrectly equated with elapsed time."

Escalation	1. Queensland Government: Anticipated increase in project costs over time as a result of various factors such as inflation or market conditions. It is the provision in actual or estimated costs for an increase in the cost of equipment, material, labor, etc., due to price level changes over time. Inflation may be a component of escalation, but non-monetary policy influences, such as supply-and-demand, are often components. 2. AACEi: "A provision in costs or prices for uncertain changes in technical, economic, and market conditions over time. Inflation (or deflation) is a component of escalation."
Estimate	1. Queensland Government: "Document recording the calculated cost prediction to undertake a specific amount of work. It is prepared in a systematic manner appropriate to the size and complexity of the work, and to a level of accuracy commensurate with the available information and the intended use of the information developed." 2. AACEi: "A prediction or forecast of the resources (i.e., time, cost, materials, etc.) required to achieve or obtain an agreed upon scope (i.e., for an investment, activity, project, etc.)." 3. PMI: "A quantitative assessment of the likely amount or outcome. Usually applied to project costs, resources, effort, and durations and is usually preceded by a modifier (i.e. preliminary, conceptual, feasibility, order-of-magnitude, definitive). It should always include some indication of accuracy (e.g., +- % percent)."
Estimate at Completion (EAC)	1. PMI: The expected total cost of completing all work "expressed as the sum of the actual cost to date (AC) and the estimate to complete (ETC). EAC = AC + ETC" 2. AACEi: "Estimate of the total cost an activity or group of activities will accumulate upon final completion."
Estimate to Complete (ETC)	1. PMI: "The estimated cost of completing the remaining work." 2. AACEi: (1) In general terms, the estimated resources (i.e., work hours, costs, time, and/or materials) required to complete a scope of work. (2) In earned value management, an estimate of the remaining costs required to complete an activity or group of activities. ETC = estimate at completion (EAC) – actual cost (AC), is often used to calculate the estimated cost to complete the project or program under discussion.
Estimate uncertainty	US Department of Energy: The accuracy of a cost or schedule estimate. Represents a function of the level of project definition that is available, the resources used (skill set and knowledge) and time spent to develop the cost estimate and

	schedule, and the data (e.g., vendor quotes, catalogue pricing, historical databases, etc.) and methodologies used to develop the cost estimate and schedule.
Expected Value Method	AACEi: "In quantitative risk analysis and contingency estimating, a method that employs the product of a risk's probability times its impact as the primary approach to quantifying risks."
External Risk	Risk related to factors external to an organisation, including: the political and physical environment; the general public and other external stakeholders; and global influence.
First Principles Estimate	Method of preparing a cost estimate at the lowest level of first principles estimate, i.e. material, labour, equipment and sub-contractor for each cost code within the Work Breakdown Structure.
Indirect Costs	1. Queensland Government: Costs "not directly attributable to work items. For construction activities these costs include on-site overheads (such as site supervision) and off-site overheads (such as contractor's corporate and business costs)." 2. AACEi: Costs not directly attributable to the completion of an activity, which are typically allocated or spread across all activities on a predetermined basis. (1) In construction, (field) indirects are costs which do not become a final part of the installation, but which are required for the orderly completion of the installation and may include, but are not limited to, field administration, direct supervision, capital tools, startup costs, contractor's fees, insurance, taxes, etc. (2) In manufacturing, costs not directly assignable to the end product or process, such as overhead and general purpose labor, or costs of outside operations, such as transportation and distribution. Indirect manufacturing cost sometimes includes insurance, property taxes, maintenance, depreciation, packaging, warehousing and loading.
Inherent Risk	1. Inherent risks stem from the inability to be certain about the nature and behavior of the project system and its interaction with external economic, political and other systems or any other project or organisation system element or attribute. The likelihood of occurrence of inherent risk is 100%. Inherent risks may also include systemic risks. 2. "AACEi: A risk that exists (but may or may not be identified) due to the very nature of the asset, project, task, element, or situation being considered."

Internal Risk	Internal risks are related to factors within the organisation such as employees and internal stakeholders, governance policies, contract management, and organisational culture.
Issue	AACEi: "In risk management, a risk that has occurred or an unplanned question or decision that needs to be addressed by a process other than risk management."
Known Unknown	Uncertainties whose cause and nature are reasonably known and quantifiable. AACEi: "An identifiable quantity or value having variability or an identifiable condition lacking certainty."
Management Reserve (MR)	1. PMI: "An amount of the project budget base (PBB) withheld for management control purposes. These are budgets reserved for unforeseen work that is within scope of the project. The management reserve is not included in the performance measurement baseline (PMB)." 2. AACEi: (1) An amount added to an estimate to allow for discretionary management purposes outside of the defined scope of the project, as otherwise estimated. May include amounts that are within the defined scope, but for which management does not want to fund as contingency or that cannot be effectively managed using contingency. (2) In earned value management according to the ANSI EIA 748 standard, an amount held outside the performance measurement baseline to handle unknown contingency at the total program level. Management reserve has no scope, is not identified to specific risks, and is not time-phased. It is typically not estimated or negotiated and is created in the budget development process. Note: The MR is not included in the Performance Measurement Baseline (PMB).
Monte Carlo Simulation	AACEi: "A computer sampling technique based on the use of "pseudo-random numbers" that selects samples for a simulation of a range of possible outcomes."
Opportunity	AACEi: "Uncertain event that could improve the results, or improve the probability that the desired outcome will happen."
Optimism bias	Queensland Government: "Tendency for people to be overly optimistic regarding project costs and planned durations."
Out-turn dollars	Queensland Government: Value in dollars of the project cost at the end of the "period in which the work will be performed. Estimates prepared at a particular date can be converted to out-turn dollars by applying the appropriate escalation rates to the project's planned cash flow."

Parametric Estimate	AACEi: In estimating practice, describes estimating algorithms or cost estimating relationships that are highly probabilistic in nature (i.e., the parameters or quantification inputs to the algorithm tend to be abstractions of the scope). Typical parametric algorithms include, but are not limited to, factoring techniques, gross unit costs, and cost models (i.e., algorithms intended to replicate the cost performance of a process of system). Parametric estimates can be as accurate as definitive estimates.
Parametric Risk Analysis	AACEi: "Methods using parametric estimating wherein the input parameters are risk drivers and the outputs are a quantification of risk. Typically applied for systemic risks."
P(x) estimate	Estimate of the project cost based on a percentage of x% (e.g. P50 for 50% or P90 for 90%) probability that the cost will not be exceeded at project completion.
P(x) schedule	Estimate of the project schedule based on an x% probability that the schedule will not be exceeded (e.g. P50 for 50% or P90 for 90%).
Performance Measurement Baseline (PMB)	1. AS 4817-2006: The total time-phased BUDGET plan against which project performance is measured. It is the schedule for expenditure of the resources allocated to accomplish project scope and schedule objectives and is formed by the BUDGETS assigned. The PERFORMANCE MEASUREMENT BASELINE also includes BUDGET for future scope assigned to UNDISTRIBUTED BUDGET. MANAGEMENT RESERVE is not included in the PMB as it is not yet designated for specific work scope. 2. AACEi: (1) The time-phased budget plan against which contract performance is measured. (2) In earned value management according to the ANSI EIA 748 standard, the assignment of budgets to scheduled segments of work produces a plan against which actual performance can be compared. The PMB is the time-phased project execution plan against which performance is measured. It includes direct and indirect costs and all cost elements. It also contains undistributed budget. PMB + management reserve (MR) = contract budget base (CBB) unless an over target baseline (OTB) has been implemented.

PERT	AACEi: "Project Evaluation and Review Technique, Along with CPM, PERT is a probabilistic technique for planning and evaluating progress of complex programs. Attempts to determine the time required to complete each element in terms of pessimistic, optimistic, and best-guess estimates."
PERT Analysis	AACEi: "A process by which you evaluate a probable outcome based on three scenarios: 1) Best-case; 2) Expected-case; and 3) Worst-case. The outcome in question may be duration of a task, its start date, or its finish date."
Portfolio	AACEi: "An array of assets—projects, programs, or other valuable and often revenue-producing items—that are grouped for management convenience or strategic purpose. When strategically combined, the portfolio assets serve to create synergies among and otherwise complement one-another."
Portfolio Management	AACEi: (1) Direction and oversight of an array of assets grouped together for strategic purpose or convenience. (2) In total cost management (TCM), this is considered an aspect of strategic asset management (SAM).
Portfolio Risks	Project and program risks that cannot be effectively managed at their originating level may be also escalated to the portfolio level if they require responses unavailable at the project or program level. The capital portfolio management process itself may be a cause of risk to the projects and programs. These risk may seriously degrade the organisation's operations.
Principal	Also known as "delivery agency", is the body that will generally deliver a project.
Principal's Costs	Queensland Government: Costs that the principal (i.e. the delivery agency) "incurs to conceptualise, develop, deliver and finalise a project. These may include community consultation, environmental assessment, design planning, services relocation, resumptions, accommodation, site investigations and principal supplied material."
Probabilistic Estimating	Queensland Government: "Method of generating estimates which takes into consideration the fact that quantities measured (or allowed for) can change, rates assumed can vary and risk with a probable outcome can materialise."
Probability Distribution Function (PDF)	A representation of the probability of specific project costs or durations (i.e. the number of times particular outcomes are likely to be achieved). Also known as a probability density function.
Program of Works (PoW)	1. Queensland Government: Group of related projects, or projects within the same program office, "managed in a coordinated way in order to obtain benefits and control not possible when managing them individually."

	2. AACEi: (1) A grouping of related projects usually managed using a master schedule. (2) A set of projects with a common strategic goal. (3) In Europe and elsewhere, the term 'program' or 'programme' may be used to mean a network schedule.
Program risks	Risks that should be managed at the program level. These may include: resource allocation, project interactions, cumulative project risks, and quality of change management processes.
Project	1. Queensland Government: Temporary endeavor "undertaken to create a unique product, service or result. It has a clearly defined scope, start and end time, a structured set of activities and tasks, a budget and a specified business case." 2. AACEi: "A temporary endeavor with a specific objective to be met within the prescribed time and monetary limitations and which has been assigned for definition or execution."
Project Control	AACEi: A management process for controlling the investment of resources in an asset where investments are made through the execution of a project. Project control includes the general steps of: 1) Project planning including establishing project cost and schedule control baselines; 2) Measuring project performance; 3) Comparing measurement against the project plans; and 4) Taking corrective, mitigating, or improvement action as may be determined through forecasting and further planning activity.
Project lifecycle	Queensland Government: "The activities necessary for a project throughout its life – from beginning to end – normally dissected into a number of sequential phases."
Project Manager	1. Queensland Government: "Person responsible for managing a project and achieving its objectives to the required quality standard and within the time and cost constraints." 2. AACEi: "An individual who has been assigned responsibility and authority for accomplishing a specifically designated unit of work effort or group of closely related efforts established to achieve stated or anticipated objectives, defined tasks, or other units of related effort on a schedule for performing the stated work funded as a part of the project. The project manager is responsible for the planning, controlling, and reporting of the project." 3. PMI: "The person assigned by the performing organisation to achieve the

	project objectives.”
Project risks	Individual risks that, should they occur, will affect the project’s objectives.
Project schedule	PMI: “Model used in conjunction with manual methods or project scheduling software to perform schedule network analysis to generate the schedule for use in managing the execution of a project.”
Quantitative Risk Analysis (QRA)	1. Method of risk analysis used to numerically assess the nature, sources, and impact of the identified risks, and to assess and quantify the overall impact of uncertainties. 2.AACEi: “Risk analysis used to estimate a numerical value (usually probabilistic) on risk outcomes wherein risk probabilities of occurrence and impact values are used directly rather than expressing severity narratively or by ranking as in qualitative methods.”
RACI	AACEi: “Acronym for a chart or matrix indicating which individuals on a team responsible, accountable, consulted and informed are regarding identified project deliverables.”
Requirement	AACEi: (1) An established requisite characteristic of a product, process, or service. A characteristic is a physical or chemical property, a dimension, a temperature, a pressure, or any other specification used to define the nature of a product, process, or service. (2) A negotiated set of measurable customer wants and needs.
Residual risk	1. IBM Centre for the Business of Government: “Risk remaining after risk treatment. Residual risk can contain unidentified risk and can also be known as ‘retained risk’”. 2. AACEi: “That portion of risks that remain after risk responses are implemented in full or in part.” Note: Residual risk present at the time of the gate review is typically the risk being quantified.
Returned contingency	Refund of unutilised contingency funds, preferably not in a way to diminish the project confidence level.
Risk	1. ISO 31000:“Effect of uncertainty on objectives.” 2. AACEi: (1) An ambiguous term that can mean any of the following: a) All uncertainty (threats + opportunities); or b) Undesirable outcomes (uncertainty = risks + opportunities); or c) The net impact or effect of uncertainty (threats – opportunities). The convention used should be

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	clearly stated to avoid misunderstanding. (2) Probability of an undesirable outcome. (3) In total cost management, an uncertain event or condition that could affect a project objective or business goal.
Risk Allocation	AACEi: "In risk treatment, the process of transferring threats or sharing opportunities between parties, most commonly expressed in association with the contracting process."
Risk Appetite	AACEi: "A component of the risk management plan that expresses the risk management objective in terms of a confidence interval or level for selected outcome measures."
Risk Breakdown Structure (RBS)	AACEi: "A framework or taxonomy to aid risk identification and for organizing and ordering risk types throughout the risk management process."
Risk event	Refer to "contingent risk".
Risk Response	AACEi: "Strategies or actions identified and planned in the risk treatment process to address risks."
Schedule	AACEi: (1) A description of when each activity in a project can be accomplished and must be finished so as to be completed timely. The simplest of schedules depict in bar chart format the start and finish of activities of a given duration. More complex schedules, general in CPM format, include schedule logic and show the critical path and floats associated with each activity. (2) A time sequence of activities and events that represent an operating timetable. The schedule specifies the relative beginning and ending times of activities and the occurrence times of events. A schedule may be presented on a calendar framework or on an elapsed time scale.
Schedule Contingency	AACEi: (1) Duration added to a schedule activity to allow for the probability of possible or unforeseen events. Use in this manner is not recommended as the contingency is hidden and may be misused. (2) A unique activity used to model specific float available to a project phase. Used in this manner gives ownership of float to those activities and or responsibility entity. (3) The amount of time added to specific activities of a project (or program) schedule to mitigate (dampen/buffer) the effects of risks or uncertainties identified or associated with specific elements of that

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	schedule.
Scope	1. PMI: "The sum of the products, services, and results to be provided as a project." 2. AACEi: The sum of all that is to be or has been invested in and delivered by the performance of an activity or project. In project planning, the scope is usually documented (i.e., the scope document), but it may be verbally or otherwise communicated and relied upon. Generally limited to that which is agreed to by the stakeholders in an activity or project (i.e., if not agreed to, it is "out of scope"). In contracting and procurement practice, includes all that an enterprise is contractually committed to perform or deliver.
Severe Weather	AACEi: A weather event, which is in itself severe and can be of violent nature. If the average weather over time is significantly different from the normal then it is said to be other than normal. In either case, if such weather affects the job and causes a delay, it may be excusable and form the basis for a contract adjustment for time and possibly money once all relevant contract clauses are considered.
Spend of contingency	Approval to use contingency.
Systemic Risks	AACEi: "Uncertainties (threats or opportunities) that are an artifact of an industry, company or project system, culture, strategy, complexity, technology, or similar over-arching characteristics."
Total Outturn Cost (TOC)	Department of Infrastructure, Regional Development and Cities: Sum of the price-escalated costs for each year of a Project's duration. Outturn Cost calculation requires the non-escalated Project Cost 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 often referred to as Real costs while Outturn Costs are often referred to as Nominal costs.
Trend Analysis	AACEi: "Mathematical methods for studying trends based on past project history allowing for adjustment, refinement or revision to predict cost. Regression analysis techniques can be used for predicting cost/schedule trends using historical data."

Uncertainty	AACEi: (1) The total range of events that may happen and produce risks (including both threats and opportunities) affecting a project. (Uncertainty = threats + opportunities.) (2) All events, both positive and negative whose probabilities of occurrence are neither 0% nor 100%. Uncertainty is a distinct characteristic of the project environment.
Unknown unknowns	1. Events whose probabilities of occurrence and effect are not foreseeable by the project team at the time of risk assessment. Unknown unknowns are typically averse to a program or project's objectives. 2. AACEi: "A quantity, value or condition that cannot be identified or foreseen, otherwise referred to as unknowable."
Unplanned risk	Refer to "contingent risk".
Validation	AACEi: "Testing to confirm that a product or service satisfies user or stakeholder needs. Note difference from verification."
Work	1. PMI: "Sustained physical or mental effort, exertion, or exercise of skill to overcome obstacles and achieve an objective." 2. AACEi: Any and all obligations, duties, responsibilities, labor, materials, equipment, temporary facilities, and incidentals, and the furnishing thereof necessary to complete the construction which are assigned to, or undertaken by the contractor, pursuant to contract documents. In addition, the entire completed construction or various separately identifiable parts thereof required to be furnished under the contract documents. Work results from performing services, furnishing labor, and furnishing and incorporating materials and equipment into the construction, all as required by contract documents.
Work Breakdown Structure (WBS)	1. AACEi: "A hierarchical structure by which project elements are broken down, or decomposed." 2. PMI: A deliverable-oriented hierarchical decomposition of the work to be executed by the project team to accomplish the project objectives and create the required deliverables. It organises and defines the total scope of the project. Each descending level represents an increasingly detailed definition of the project work. The WBS id decomposed into work packages. The deliverable orientation of the hierarchy includes both internal and external deliverables.

For more definitions, the Guideline recommends AACEi Recommended Practice No. 10S-90, Cost Engineering Terminology – http://library.aacei.org/terminology/

9. Appendix B – Risk Workshop Facilitation

9.1 Phase 1 – Before Risk Workshop

Establishing the risk context is a critical first step in developing the risk register and facilitating conversations between the project stakeholders prior to any risk workshop. This will ensure the appropriate stakeholders and subject matter experts will attend and/or contribute to the risk management process. Some key actions of the workshop facilitator are listed below:

a) Contact and discuss the requirements with key stakeholders and attendees as early as possible
b) Clearly understand and confirm the key objectives of the risk workshop – running a strategic risk workshop at the Preliminary Business Case stage has a totally different objective to running a quantitative risk workshop to assess cost contingency for an Engineering, Procurement and Construction (EPC) bid submission. These may encompass risk identification for project activities and mitigation controls, or providing risk analysis to support a project submission
c) Review existing relevant information and documents including the Risk Management Policy or Framework, any relevant guidelines, the latest risk register (if available), Organisational Chart, Project Management Plan (PMP), Basis of Estimate, Basis of Schedule, and Work Breakdown Structure (WBS)
d) Capture key risks and areas of uncertainty and concerns during meetings or conversations with key stakeholders and individuals, and try to understand their expectations of the risk workshop exercise. These details can be also shared with the team prior to the workshop
e) Consolidate and distribute all critical captured information before the risk workshop, including a pre-populated risk register, background information, key constraints, major internal and external interfaces, and specific data. For example, rain data for assessing the risk of severe weather for a civil engineering project
f) Proactively identify and plan for appropriate list of internal and external stakeholders (who could be affected by the project risks or treatment actions) and potential attendees. Examples are regulators, the general public and alliance partners. They could be either groups or individuals.
g) Be aware of and plan for the risk of group thinking, for example: "I'll follow the others, they know more than me"
h) Identify any assumptions the team makes during risk identification. This can help to better understand the risks
i) Identify the project constraints, e.g. political, regulatory, environmental, social, economic, technical and logistics. Also identify the internal and external boundaries that the risk assessment will be undertaken within, for example, geographical, operational, interfaces, and project phase
j) Arrange for an appropriate room for the workshop with enough light (natural if possible), the right temperature, right size, availability of presentation capabilities, and appropriate seating arrangements
k) Arrange for proper furniture layout to support group discussion, e.g. round tables
l) Identify and nominate the best group of attendees, usually less than 7-10 people in each workshop
m) Plan to have a support person during the workshop to take notes, change slides, and help with other tasks.

RES Tips & Tricks: It's better not to walk into a risk workshop with a blank risk register!

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9.2 Phase 2 – During Risk Workshop

For running an efficient and productive risk workshop and brainstorming session, RES recommends the notes below for consideration:

a) Have the right mix of stakeholders to extract good quality risk information
b) Conduct the workshop as a group activity in a controlled and structured manner, otherwise issues as ‘group think’ or ‘cognitive biases’ may occur
c) Invite people to sit around the room rather than letting them sit at the back or form sub-groups
d) Give a short introduction, including: objectives, time schedule for the workshop including breaks, key facilities, and safety items
e) Deliver a short (15-30 minute) presentation for project scope, current status, risk management process, project specific requirements, objectives of the workshop, and agenda. Also plan for short breaks periodically to refresh the group
f) Focus on top risks first, then low risks – also consider very low probability risks with high consequences
g) Do not spend too much time on any one risk. Plan off-line discussions (and allocate a responsible person) if further details are required
h) Facilitate group discussions rather than reading and filling the risk register word by word
i) Plan your approach to identify the risks and opportunities and be consistent during the workshop, e.g. Project Management Institute (PMI) Risk Work Breakdown Structure
j) Use available time during workshop for risk identification and high level analysis. RES suggests detailed risk analysis, evaluation and treatment discussions should be done with individuals or smaller teams out of workshop
k) Differentiate between ‘issues’ and ‘risks’. Capture the issues but document them in a separate Issues Register and move on. Ask: “is this an issue?” and explain that: “an issue is a certainty and a problem for us today but a risk is an uncertainty and a potential problem for us tomorrow”
l) Ensure that there is a verb included in the risk definition
m) Ensure that an owner is assigned to every risk for future follow up before ending the risk workshop. Also document the due date of follow-up action
n) Consider both internal and external risks. For external risks, focus on the consequences; for internal risks, focus on the causes
o) When summarising the discussions, use the participants’ words if possible. Remember you are doing this for them, so they need to read and understand the note later
p) Use positive body language: look at participants when they are talking, use hand gestures to liven presentation, and smile
q) Use benchmarking and structured elicitation processes
    - do not initially share these with the team to avoid unintended anchoring
    - as the process progresses, this will provide further context to the discussion
    - do not use it to blame the team, but to positively challenge or support estimates
r) Be aware of cultural factors and differences e.g. the impact of seniority of participants
s) Be aware of potential conflict between participants which may lead to hidden agendas
t) Keep the group at a manageable size, generally less than 10 people
u) Try to focus on the few key risks, rather than the many trivial risks
v) Be aware of and manage higher-up participants and people with dominant personalities
w) Set clear objectives for the workshop and avoid starting out with desired outcomes
x) Do not only rely on the smartest or most dominant people in the workshop.

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RES Tips & Tricks: Remember that 'facilitation' is different to 'teaching'. As a facilitator, you are there to manage the flow of information from participants to meet the workshop objectives!

Be aware that different people have different learning and engagement styles, e.g. hear only; see only; hear and see; hear and talk; and see; hear and see and talk and do. Have your engagement toolbox with you. Keep the workshop lively and fun. Dull and boring sessions disengage the participants and don't make good use of their time.

9.3 Phase 3 – After Risk Workshop

RES recommendations for post workshop actions are:

a) Schedule follow-up sessions with individuals after the workshop as early as possible
b) Discuss, evaluate and further develop the risk register, then share it with the whole team
c) Circulate the updated risk register to everyone for review and comment no later than a week after the workshop
d) If a quantitative risk analysis is undertaken, a short group meeting is also recommended to share the draft results and assumptions (including key risk drivers) before you finalise the assessment.

A good balance of time allocation between the three phases (before, during and after the risk workshop) will considerably increase the likelihood of success in achieving the team's risk workshop objectives.

9.4 Good Risk Workshop Facilitator

While RES acknowledges that there is no one approach for being a successful risk workshop facilitator, some of the practical and helpful characteristics of successful facilitators are:

a) relevant and appropriate domain knowledge
b) strong emotional intelligence as well as strong communication, listening and presentation skills
c) proper body language and appropriate appearance
d) a wide range of facilitation tools and techniques
e) management skills for cognitive biases
f) ability to appropriately use a range of behaviour types, e.g. directive, collaborative and supportive
g) leadership skills supported by process and people management capabilities
h) conflict management skills
i) time management skills.

9.5 Quantitative Risk Register

A quantitative risk register is the output of risk workshop facilitation for the purpose of contingency management. This register is a record of all key risks with potential time and/or cost impacts. These will include mainly contingent risks, but the quantitative risk register can also have some references to inherent risks identified and quantified by the project team. Inherent risks may have either a positive or negative impact on the cost estimate and/or the project schedule.

The quantitative risk register includes information such as:

a) a description of the risk or consequence as well as a description of the cause(s)

b) the risk owner, who is responsible for the quality of its qualitative and quantitative information
c) key risk treatment strategies and associated costs (if applicable)
d) the probability that the residual risk, or consequence, will occur
e) the range of schedule impacts of the event if it should it occur. It is important to note that the impact of the event could be an unfavorable result (negative), or a favorable result (positive)
f) the validation and determination supporting each element of the schedule impacts, i.e. best cost impact, most likely cost impact and worst-case cost impact
g) the range of cost impacts of the event if it should it occur. It is important to note that the impact of the event could be an unfavorable result, i.e. negative, or a favorable result, i.e. positive
h) the validation and determination supporting each element of cost impacts, i.e. best cost impact, most likely cost impact and worst-case cost impact
i) other key notes, e.g. possible correlation of risks or consequences.

The information above is generally laid out in columns as presented in Table 16. It should be noted that risk registers generally have other columns as well, which are used for risk management purposes: for example, triggers, controls, risk owner and treatment action.

#	Description of risk or consequence	Cause	Risk Owner	Probability of residual risk or consequence	Schedule Impact				Cost Impact				Notes
					BC (d)	ML (d)	WC (d)	validation	BC ($)	ML ($)	WC ($)	validation	
1													
2													

Table 16: Key columns of quantified risk register

The project risk manager needs to prepare the quantitative risk register and determine which contingent risks not captured by the cost model are significant enough to add to the model. However, the sources of discrete risk items to be modeled are not limited to the risk register. Opportunities to reduce cost should also be captured and discussed.

Each item in the quantitative risk register needs to be carefully assessed to properly augment the cost and schedule uncertainty model. Additional effort may be required to properly interpret the cost and schedule consequences – as the team may only provide impacts to the program's current or pending contract. The register should be archived and attached to the final contingency report for future reference.

RES Tips & Tricks: when identifying the risks with schedule/cost impacts, it is useful to consider:

a) both risks and opportunities, i.e. negative impacts as well as positive impacts
b) only key risks and opportunities. According to the Pareto Principle (80-20 rule), about 80% of outcomes result from 20% of the causes. You should focus on 'rocks' not 'sand'!
c) the schedule and cost impacts together to increase the accuracy of assessment
d) the inherent and contingent risks together for the optimum contingency
e) the potential relationship and interfaces not only between risks and uncertainties but also between key internal and external stakeholders, i.e. correlation
f) human and organisational aspects, behaviour and organisational culture.

10. Appendix C – Schedule Risk Analysis (SRA)

10.1 Purpose

The purpose of this appendix is to provide further information on the Schedule Risk Analysis (SRA) approach used to develop, assess and allocate a reasonable schedule contingency for the desired confidence level. Within the context of contingency, quantitative risk analysis is a broad terminology referring to different techniques that provide a numerical estimate of the overall effect of risk on project objectives. These risks result from the combined effect of all residual risks and their potential interactions with each other.

SRA is a form of quantitative risk assessment that applies a probabilistic process (most often a Monte Carlo simulation technique) to assess the reliability associated with the Base Schedule. The rationale behind a SRA is that as a result of potential risks the projected final duration of a project is better depicted by a range of values with associated probability, rather than as a single schedule (or deterministic schedule). Schedule contingency is then measured in terms of percentile (or 'P') values that indicate the percentage confidence that works will be completed on or before a given date. Correlation between activities is measured in the schedule model and the project durations of interest are used to identify the main drivers of schedule risk, expressed as the 'schedule sensitivity analysis'.

10.2 SRA overall process

The key elements of a realistic and reliable SRA in determination and allocation of a reasonable schedule contingency for different confidence levels are below, as illustrated in Figure 35.

a) schedule health check and rectification
b) risk allocation to Base Schedule
c) probabilistic links and branching
d) Monte Carlo Simulation
e) output review and validation.

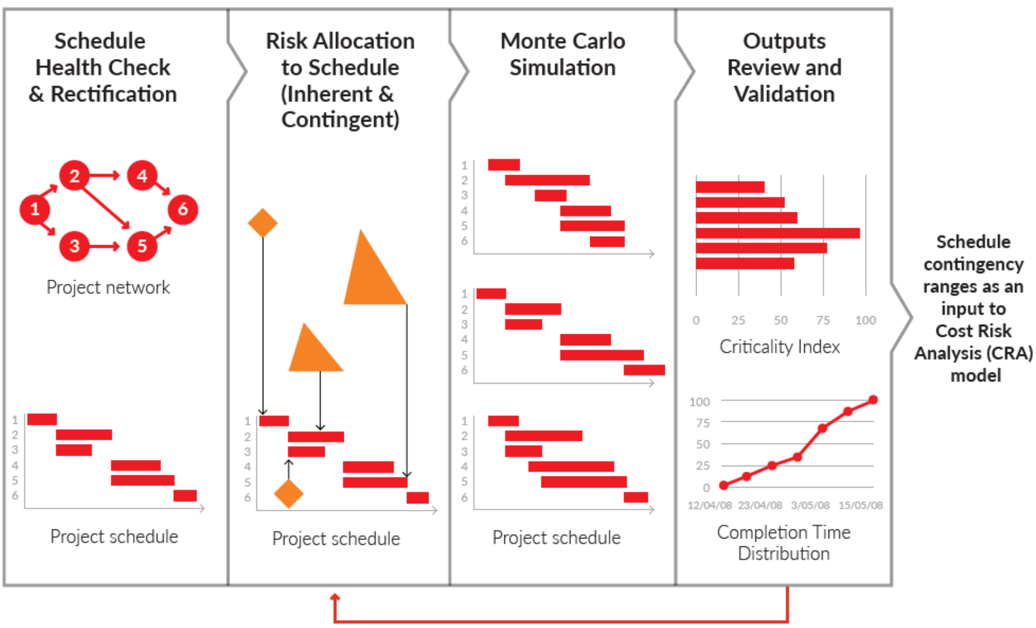


Figure 35: A typical process map for probabilistic Schedule Risk Analysis

10.3 Schedule Health Check and Rectification

The Base Schedule is the expected duration and delivery strategy of a project which can reasonably be expected if the project materialises as planned. This schedule is produced before the inherent and contingent risks are taken into account. The Base Schedule may include some embedded allowances to represent the most reasonable scenario, but it should not include any contingency.

A comprehensive health check of the Base Schedule for use in SRA is of the utmost importance as it forms the foundation of the analysis and all its outputs. There are many considerations when preparing a schedule for use in SRA, typically based on good planning principals including factors such as contractual obligations, schedule structure and schedule integrity. These concepts are discussed briefly in the following sections.

10.3.1 Contractual Obligations

The key considerations for contractual obligations when conducting an SRA health check include:

a) The Base Schedule must meet all contractual obligations including, but not limited to, level of details, delivery strategy, separable portions, durations, key contractual milestone dates and interim milestones
b) The Base Schedule must represent all known scope – both included or missing from the drawings
c) The Base Schedule must be representative of the latest approved project execution strategy or plan
d) The Base Schedule must include the key activities of all stakeholders that may influence contractual milestone dates
e) The Base Schedule should clearly include the internal and external dependencies that involve a relationship between project activities and non-project activities

10.3.2 Schedule Structure

Depending on the project requirements, there are a number of different approaches to developing the project scheduling plan, including but not limited to: Critical Path Method (CPM), critical chain method and Line of Balance (LoB).

CPM is the most common method of project scheduling – where a schedule network represents the project time management strategy. Activities are tasks where the work is accomplished are logically linked by physical relationships (e.g. finish-start, start-start, finish-finish, or start-finish) or resource relationships (e.g. limit of resource availability) showing how the work is planned.

By using a logical-driven or resource-driven approach, the CPM is used to derive the critical activities – that is, activities that cannot be delayed without delaying the end date of the schedule. The amount of time an activity can slip before the schedule's end date is affected is known as the "Total Float". Critical activities have the least amount of float. Therefore, any delay in critical activities generally causes the same amount of delay in the schedule's end date. Activities with little Total Float are called "near-critical" activities, because they can quickly become critical if their small amount of Total Float is used up in a delay. Management must closely monitor critical and near-critical activities by using sound schedule practices.

Unless the Base Schedule represents the entire scope of effort and the effort is correctly sequenced through network logic, the scheduling software will report an incorrect or invalid critical path. That is, the critical path will not represent the activities affecting the schedule finish date. With no accurate critical path, SRA cannot identify the activities that will be detrimental to the project's key milestones and finish date if they slip.

There are two types of schedules developed using the CPM technique:

1. Logic driven schedules – CPM calculates the shortest project completion duration and/or project completion date from the longest path through the network of activities linked by physical relationships
2. Resource driven schedules – CPM calculates the shortest project completion duration and/or project completion date from the longest path through the network of activities set not only by their physical relationships but also the availability of required resources and priority of activities.

It is critical to use the most appropriate schedule structure to ensure the SRA is reliable and robust and its results are reasonable. Regardless of the type of schedule (logic or resource driven), the CPM schedule is only accurate and reliable if every activity is started 'as soon as possible' and takes just as long as its duration estimate indicates. Obviously, this is only one possible scenario, hence there is a need for a detailed SRA to assess the confidence level of this scenario.

10.3.3 Schedule Integrity

The key considerations for schedule integrity include:

a) Base Schedule must reflect 100% scope as defined in the project's WBS. This is the work necessary to accomplish the project's objectives, including key activities of both the owner and contractors
b) Base Schedule logic should be determined. By establishing the network logic, the schedule can predict the effect on the project's planned finish date of – among other things – misallocated resources, delayed activities, external events, scope changes, and unrealistic deadlines
c) As a general rule, every activity within the Base Schedule should have at least one predecessor and at least one successor. The two natural exceptions to this rule are the project start milestone, which will have no predecessor, and the project finish milestone, which will have no successor
d) Date hard constraints (e.g. must start on, must finish on) and lags should be minimised and justified to help ensure that the interdependence of activities that collectively
e) Lead time to the completion of events or milestones can be established and used to guide work and measure progress
f) Summary activities should not have logic relationships because their start and finish dates are derived from lower-level activities. Therefore, there is no need for logic relationships on a summary activity in a properly networked schedule
g) Path convergence should be taken into account
h) Several parallel activities joining with a single successor activity is known as path convergence. Path convergence can represent an unrealistic plan because it implies the need to accomplish a large number of activities on time before a major event can occur as planned. This may cause problems in managing the schedule. These points should be a key schedule management concern because risk at the merge point is multiplicative. In complex projects convergent paths are unavoidable leading to MBE (Section 2.6.3). SRA enables MBE to be recognised and managed
i) The path divergence should be taken into account. A single activity joining with several parallel successor activities is known as path divergence. Similar to path convergence, this can represent a schedule risk
j) The Base Schedule must reflect the resources (labor, materials, overhead) needed to undertake the work, whether they will be available when needed, and any funding or time constraints. Depending on the type of schedule (logic or resource driven), this can be a critical aspect of the base schedule prior to any SRA assessment

k) The Base Schedule must realistically reflect how long each activity will take (both internally and externally). Durations should be reasonably short and meaningful and allow for discrete progress measurement
l) Depending on the type of schedule (logic or resource driven), the Base Schedule must identify the schedule critical path that is the path of longest duration through the sequence of activities. Establishing a valid critical path is necessary for SRA in examining the effects of any activity slipping along this path. As part of this assessment, it is recommended to also review activities with large total floats
m) In general, assessing the quality of the Base Schedule and its critical path by counting the number of critical activities against the total activities is not useful. The number of critical activities will depend on the visibility required to manage the schedule and the risk profile of project. However, if the ratio of critical path activities to the total activity count (i.e. the schedule criticality index) is more than 50%, then the schedule may be overly serial and resource limited. Further review and development of the base schedule is recommended before undertaking SRA
n) Long duration non-level of effort activities should be re-evaluated to determine if they can be broken down into more manageable pieces, particularly if they appear on the critical path
o) For most projects with a multi-phase lifecycle calendar changes are generally unavoidable. For the purposes of SRA, it should be noted that the changes in working periods per day and/or per week may result in criticality gaps when trying to determine the driving critical paths through a schedule risk model. These gaps occur when the calendars attached to a predecessor and a successor activity are different.

10.4 Level of SRA

Depending on the requirements and objectives, SRA can be undertaken at different levels of the schedule including detailed master schedule, rolled up schedule or even a separate summary schedule. By engaging the right people in the assessment, the most reasonable Base Schedule with an appropriate structure should be used for SRA.

Mapping contingent and inherent risks to the schedule is a challenging step of the SRA process, as it requires a detailed understanding of the nature of the risks and schedule tasks involved in the process. The integrity of any schedule risk model is dependent on the validity of the risk allocation, such that the impact of risks is neither overstated nor understated. For a reliable SRA, it is fundamental to identify and map all key contingent risks as well as the schedule uncertainties.

10.4.1 Common Sources of Schedule Uncertainty

There are many factors that contribute to schedule uncertainty (inherent risks) in a project. The key contributors to schedule uncertainty are:

a) 100% scope uncertainty – uncertainty that 100% of scope will be covered in the Base Schedule
b) delivery strategy uncertainty
c) activity duration uncertainty – due to uncertainty about quantity, productivity rate or efficiency of resources.
d) contingent risks – events that may or may not occur – but if they do, will impact the schedule positively or negatively
e) schedule logic uncertainty – including the dependencies that may or may not exist between activities or the alternative situations or pathways for completing an objective
f) calendar related uncertainty – these uncertainties usually determine the times in which certain work can be performed (e.g. inclement weather).

10.4.2 *Workshops and Review Meetings*

A number of workshops and meetings should be conducted with the relevant stakeholders in order to review the scope, the Base Estimate and the Base Schedule to identify and quantify all sources of schedule uncertainty as explained in the previous section. Depending on the size of the project and its scope and complexity, it may also be necessary to seek expert input to these meetings from outside the project team.

The relevant people to attend workshops and review meetings include:

a) the estimators and cost planning team
b) the schedulers and programming team
c) the engineers, designers, planners and other advisors or service providers who prepared the material which the estimators used
d) work stream leads and delivery strategy personnel who understand how the work will be procured and delivered on the ground
e) leads from functional groups and other external experts, when required.

10.4.3 *Schedule Risk Model Development*

Following the completion of risk workshops, a schedule risk model should be developed. Key steps include:

a) collect and further assess the identified inherent and contingent risks (e.g. from the latest risk register)
b) review and assess the latest assumptions with the basis of estimate and basis of schedule for areas of concern and potential variances
c) assess the most appropriate method of schedule risk assessment, e.g. Risk Factor, SRA or a hybrid method, i.e. Risk Factor method for inherent risks and SRA for contingent risks
d) determine the overall range of activity durations for areas of concern or uncertainty – duration uncertainty typically refers to a three-point estimate of how long a task may take:
    - best case or optimistic duration – if everything goes as well as could be expected
    - most likely duration – under most likely conditions
    - worst case or pessimistic duration – if everything goes towards worst case scenario.
e) select and allocate the most appropriate probability distribution type to activity durations (further details about distribution types can be found at Appendix D)
    - The most commonly used types of distributions include: Triangular; Trigen – similar to the Triangular distribution, but with the corners cut off; uniform – a simple constant probability distribution for which every value in the range between the minimum and maximum limit is equally likely to occur; Alt-Pert – best described as a Normal distribution that allows for positive or negative 'skewness'
    - Depending on availability of historical data and actual performance benchmarks (e.g. within the road and rail sectors), this guideline recommends that the Alt-Pert (10, 90) distribution be used for modelling uncertainty. In the absence of actual data, an application of a more conservative distribution, e.g. Trigen (10, 90) is recommended
f) include and model the likelihood of occurrence and range of schedule impacts for key risks
g) model inclement weather:
    - most construction activities will be subject to some kind of weather conditions that may dictate working and non-working periods for all or part of the workforce. In deterministic plans, this is usually accounted for by making an allowance for downtime in the relevant plan calendars. However, in reality, weather is often more complex and may require special probabilistic techniques to be able to model its potential effects appropriately

h) assess and model the potential correlations between risks (if required) – further details about correlation have been provided at Appendix E
i) assess and model probabilistic links and branching (if required)
j) review and finalise the schedule risk model for the first iteration of simulation with consideration to optimism bias.

10.5 Probabilistic Links and Branching

As highlighted earlier, the Base Schedule should represent the most likely assumptions including required activities, productivity rates, resources, logic, relationships, etc. However, the occurrence of some specific contingent risks may require a new sub-schedule to be introduced within the schedule. This is called 'probabilistic branching' and represents a branch, or branches, that happen only with some probability.

RES Example: below are a couple of examples of events which may need probabilistic branching within Schedule Risk Analysis model:

a) the source of fill material may need to be changed from one query to another due to the final geotechnical results and unsuitability of the assumed query
b) failure in the final test of an integrated software may require additional activities for cause analysis, further consultation, recovery actions and re-test.

In some SRA tools, another advanced technique known as 'conditional branching' is also available. For example, if a commissioning activity takes two weeks more than planned, then a recovery plan should be developed and implemented.

10.6 Monte Carlo Simulation

The Monte Carlo Simulation (MCS) is a mathematical technique that uses repeated random sampling within specified distributions to calculate the probability of defined outcomes. As applied to SRA, MCS involves the random sampling of uncertainties within a project schedule. Against each item in the model, uncertainties are randomly sampled for duration and/or probability.

Normal forward and backward pass critical path method calculations are then made, and the resulting early and late start and finish dates for each of the tasks and milestones in the schedule are recorded, as are the activity durations. Following multiple iterations, the results are collected – ready for interpretation.

10.7 Output Review and Validation

SRA results are derived from date and duration information collected across multiple iterations of a schedule risk model. When interpreting this data, it is important that it can be conveyed in a simple and meaningful form. The commonly accepted means of presenting MCS results uses a histogram overlaid with a cumulative curve to display percentile data. Some of the reports of SRA results are described in the following sections.

10.7.1 Histogram and Cumulative Curve

The histogram shows the results for all iterations ('hits') of the simulation for any activity or milestone within the schedule risk model. The cumulative curve adds up the number of hits in each bar progressively to represent the number of iterations up to a particular date.

An intercept of the curve to the horizontal axis represents the percentage of iterations up to that date, or the probability of the selected activity or milestone finishing on or before that date. This result is usually referred to as a 'P value'. The most common P values are summarised below:

a) P10 – this is the best case figure, and is often referred to as the stretch target
b) P50 – this is the median schedule, and is often used as the target schedule. However, targets may be set at other percentile values due to various reasons including commercial considerations
c) P90 – this is a conservative position, and is often used for government announcements to the public.

10.7.2 Tornado Graph

A tornado graph is another typical output of sensitivity analysis. It provides a ranking of the inputs with the greatest regression sensitivity (in simple terms, it shows which risks have the greatest effect on the variability in the output). It will not necessarily include the items of the greatest value, particularly where they have low risk ranges applied. The tornado graph should be combined with a sanity check, to verify that what the model is calculating as the greatest risks meets with reasonable expectations. It is recommended that the tornado graph be used to prepare a qualitative description of greatest risks to be listed in the probabilistic assessment report.

10.8 Updating and Documenting SRA

The SRA should be performed periodically as the schedule is updated to reflect actual progress on activity durations and sequences. As the project progresses, risks will retire or change in potential severity and new risks may appear. The length of time between SRA updates will vary according to project length, complexity, risk, and availability of management resources. This guideline recommends that SRA should be undertaken on a quarterly basis as well as at the key decision points for major projects.

The SRA and its updates should be documented to include the risk data, sources of risks and techniques used to validate the risk data. Key outputs should also be documented, including: the risk list; the likelihood of the project meeting its completion date; and the activities that most often ended up on the critical path.

11. Appendix D – Other Methods of Cost Contingency Determination

11.1 Probabilistic Methods – Non-Simulation

These non-simulation methods produce probabilistic outputs without using simulation (e.g., without Monte Carlo Simulation). Most are empirically-based at some level (e.g., regression) such that the statistical analysis provides distribution information (e.g., standard error) with varying levels of statistical rigour. An advantage of the empirical basis is that the base risk model is real to some extent rather than theoretical. The distributions for simulation models (to be covered later) are records of data generated by software from risk models that are – to varying levels – theoretical representations of how projects behave. In either case, empirical validity is desired. Combining methods can offer a way to get the best of empirical and theoretical modeling.

11.1.1 Enhanced Scenario Based Method (eSBM)

The Scenario-Based Method (SBM), initially introduced in 2008, offered a simpler analytical deterministic method – as an alternative to advanced statistical methods or simulation – for generating measures of cost risk. Since 2008, enhancements to SBM have included integrating historical cost performance data into its cost risk analysis algorithms. These improvements define the enhanced scenario-based method (eSBM), which was published in 2012.

The objective of an eSBM is to assess the impact of various scenarios against a project baseline. Consequently, the baseline scenario is often based on the Cost Analysis Requirements Description (CARD) parameters. Rather than building up risk and uncertainty element by element as in a Monte Carlo simulation, eSBM instead shifts attention to the identification and quantification of what can go right and what can go wrong with the project from a high-level management point of view. Hence – like other deterministic methods – eSBM is more of a top-down approach.

The key benefits of the eSBM are its visibility, defensibility, and the cost impacts of specifically identified risks. The SBM specifies a well-defined set of conditions or scenarios (i.e. Protect Scenario or PS) that would create a condition that management would like to protect against. The eSBM assumes specified scenarios that – if they occurred – would result in costs higher than planned or budgeted levels. These scenarios do not have to represent worst cases. Rather, they should reflect a set of conditions a project manager or decision maker would want to budget for, should any or all of those conditions occur.

These are the eight steps associated with an SBM:

a) Step 1: Generate/Obtain Base Estimate, i.e. most likely estimate
   - Assess Base Estimate Probability, i.e. α, the probability that Base Estimate will not be exceeded. This probability is mainly calculated from the analysis of project cost growth histories in the past.
   - Select the Coefficient of Variation (CV), i.e. the ratio of a probability distribution's standard deviation to its mean. The CV is a way to examine the variability of any distribution at plus or minus one standard deviation around its mean. An appropriate realistic, historically based, CV for use in generating a probability distribution should be selected
b) Step 2: Drive the project's cumulative cost probability distribution
c) Step 3: Define the Protect Scenario (PS)
   - A PS captures the cost impacts of major known risks to the project – those events the

project must monitor and guard against occurring. The PS is not arbitrary, nor should it reflect extreme or worst case events. It should be a possible project cost that – in the judgment of the risk modeler – has an acceptable chance of not being exceeded. In practice, it is envisioned that a few iterations of the process may be needed for defining the final PS

d) Step 4: Cost the PS
   - Once the PS is defined, its cost should then be estimated.

e) Step 5: Derive Cumulative Density Function (CDF), i.e. eSBM S-Curve
   - with values assessed for α and CV, the project's cumulative cost probability distribution, i.e. CDF or eSBM S-Curve, can then be created. This distribution is used to view the probability level associated with the PS cost, as well as probability levels associated with any other cost outcome along this distribution.

f) Step 6: Determine Confidence Levels, i.e. Probability Levels

g) Step 7: Perform Sensitivity Analysis
   - to identify critical drivers associated with the protect scenario and the project's Base Estimate cost. It is recommended that the sensitivity of the amount of Contingency Reserve be assessed with respect to variations in the parameters associated with these drivers
   - on key assumptions or conditions expressed in the protect scenario(s), as well as uncertainties in values chosen for α and CV. This allows a broad assessment of probability level variability, which includes determining a range of possible program cost outcomes for any specified probability level.

h) Step 8: Finalise assessment and select required contingency allowance for desired confidence level.

The non-statistical eSBM described above has limitations. As mentioned earlier, cost risk – by definition – is a measure of the chance that the planned or budgeted cost of a program will be exceeded due to unfavorable events. A non-statistical eSBM does not produce confidence measures. Also, the chance that the cost of the PS – or the cost of any defined scenario – will not be exceeded is not explicitly determined.

The lack of reasonable historical data for similar projects may also create challenges in selection of α and CV, impacting the accuracy of the assessment. Considering the minimum practical application of this method in the construction and infrastructure sectors, this guideline refers its readers to other references (e.g. 'A Scenario-Based Method for Cost Risk Analysis' by Paul R Garvey or USA's Joint Agency Cost Schedule Risk and Uncertainty Handbook, 2014) for further guidance on this method.

11.1.2 Method of Moments (Delta Method)

Method of moments also goes by a variety of other names such as the Delta method or the mean-value first-order second-moment method. It is a deterministic cost-risk analysis approach that allows the risk analyst to statistically sum WBS element costs, which are represented by probability distributions. The method is a technique for finding approximations to the moments (particularly the variance) of functions of random variables when these moments cannot be directly evaluated (Oehlert, 1992).

From this, it is possible to obtain a probability distribution of total cost. Summation of WBS element costs is done not by Monte Carlo sampling, but by fitting a lognormal probability distribution to the mean and variance of total cost. Specific percentiles of the lognormal distribution of total cost can be displayed (e.g., 10^{th}, ... , 90^{th}, 95^{th}).

This method tries to estimate a total-level mean and variance from the sum of the subordinate elements. The mean and variance are the first and second moment of a random variable, hence the name method of moments. With knowledge of the mean and standard deviation for each element and how they are correlated, the mean and standard deviation at the parent levels can be calculated without simulation.

It must be noted that – due to its reliance on normal and lognormal distributions – this method may underestimate risk in certain situations. Method of moments is a convenient approach when the model is a simple sum of uncertain elements, particularly if there are a large number of them. However, there are several complications, including:

a) challenges to develop a custom method of moments for every estimate
b) mean and variance of subordinate elements should be supported by reliable historical data
c) the variance sum must be adjusted for correlation
d) distributions at the parent levels are assumed rather than derived
e) efforts to combine uncertainties can lead to complex calculations.

This Guideline does not recommend the method of moments for general use, especially for the building, construction and infrastructure projects.

11.1.3 Reference Class Forecasting (RCF)

The reference class forecasting (RCF) method was introduced, by Kahneman and Tversky (1979) and later Lovallo and Kahneman (2003), Bent Flybjerg and Cowi (2004), in order to overcome human bias and the resulting inaccurate forecasts. RCF – also known as Optimism Bias Uplifts or Comparison Class Forecasting – is a method of predicting the performance of future projects by referring to the performance of similar past projects. A concern with this method is that by setting budgets based on past performance, which is mediocre at best, one forecloses on the opportunity for improvement (repeat history by design). That is contrary to risk management principles which seek to support continuous improvement.

RCF is generally adopted to mitigate two main factors which cause persistent cost overruns in infrastructure projects – optimism bias and strategic misrepresentation as described in Chapter 2 earlier. This can be more properly considered a validation or benchmarking practice for quality management and governance, not a contingency determination method.

By using data from previous projects, this method aims to divide projects into a number of distinct groups. For example, groups for transport projects may include: road, rail, tunnel, bridge, buildings and Information and Communication Technology (ICT) projects. For each category, the probability distribution for cost overrun – as the share of projects with a given maximum cost overrun – should be then created.

RES Recommendation: organisations should establish and regularly capture as much accurate real life project data as possible. Organisations should make a point of capturing, validating and recording their projects' progress and performance data in a structured and systematic approach. This data then can not only be used for cost/schedule contingency forecasting, but also to improve their risk management practices.

By establishing an empirical cumulative probability distribution, uplifts will be then set up as a function of the confidence level (i.e. risk appetite) that the organisation is willing to accept. Uplift (i.e. contingency reserve) represents the required additional amount on top of the Base Estimate required to achieve the desired confidence level. The process for the most common approach of this method is represented in Figure 36 below.

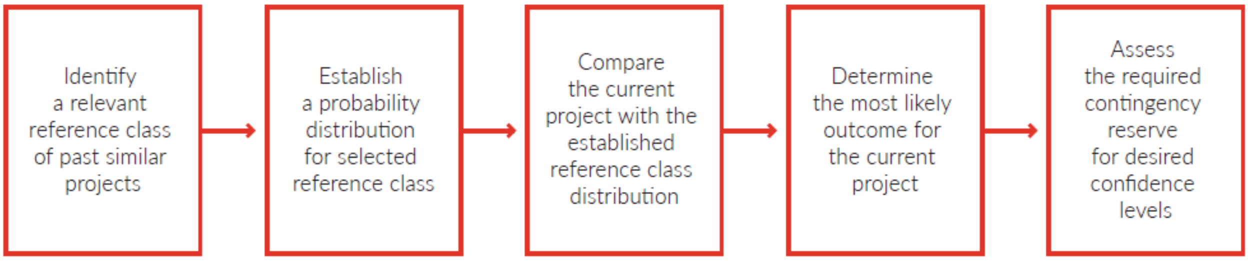


Figure 36: The process of reference class forecasting (RCF) methodology

The key challenges associated with this method are:

a) The method assumes that future projects will perform similarly to past projects. Considering the influences of internal and external factors on project performance, there are a number of uncertainties associated with this assumption
b) By assuming that future performance will be similar to past performance, the method is discouraging good practice of project risk and contingency management, as well as opportunities for improvement
c) Most organisations do not have good data from a large number of their past projects. This may cause a significant error in the determination of contingency reserve (uplifts)
d) While the selected projects should be broad enough to be meaningful, they should be as similar as possible to the current project – so comparison can provide reliable results
e) The RCF does not involve any serious attempt to identify, mitigate and quantify any specific major contingent risks (events) that may affect the considered project. In other words, while using historical data is a great initiative, the key objective is not to repeat the past, but to improve on it by reduced residual risks
f) Although the project cost estimate and duration forecast are perhaps the two most important objectives of the RCF method, this method ignores other key risks such as safety, quality, environment and reputation which have time and/or cost impacts which should be identified, quantified and assessed
g) From a number of studies, it has become apparent that the RCF method needs a reference class consisting of projects that are highly similar to the project at hand, as forecasting accuracy considerably diminishes with decreasing similarity level.

11.1.4 Parametric Based

The parametric method determines and applies the correlation of systemic risk drivers and cost growth and schedule slips outcomes. The inherent regression diagnostics (i.e., error of prediction) provides the basis for probabilistic model outcomes. Regression and MCS are the only two practical inferential statistical methods available. One is based on distribution of an actual dataset, the other on distribution of a theoretical dataset generated by sampling. The method aims to develop a relationship between a cost overrun or schedule slip (normalised to percentages) and systemic risk drivers by using historical data. This method uses parameters which are risk factors such as project definition, size of the project, complexity, team development, bias, existing historical data, etc. This method uses linear relationships between dependent (cost increase or schedule slip) and independent variables (the systemic risk factors).

Parametric models can be classified as simple or complex. For this Guideline, simple models are cost or schedule estimating relationships consisting of one risk driver. Complex models, on the other hand, are models consisting of multiple relationship, or algorithms, to derive cost overrun and schedule slip estimates. The following present the typical forms of simple parametric estimating formulas used in risk quantification:

$$\text{Outcome} = \text{Base} * (1 + \text{Parameter A Factor} + \text{Parameter B Factor} + \dots)$$

$$\$\ \%\ \text{cost overrun or schedule slip} = a + b*V1 + c*V2 + \dots\ \text{(Linear Relationship)}$$

$$\%\ \text{cost overrun or schedule slip}\$ = a + b*V1^x + c*V2^y + \dots\ \text{(Non-Linear Relationship)}$$

Parametric based methods, as the name suggests, are based on parameters that define the inherent (including systemic) drivers of uncertainty including complexity, risk, schedule, cost and risk of a program, project, service, process or activity. Some of the most common parameters are:

a) maturity of design
b) maturity of estimate and schedule
c) type of technology
d) process system complexity
e) site conditions
f) team experience and competency
g) cognitive biases.

The process for the most common approach to this method is represented in Figure 37.

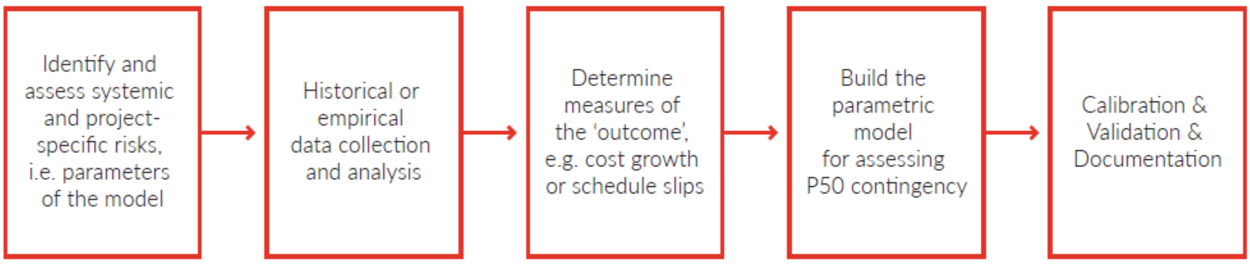


Figure 37: Common process of Parametric based methodology

The development of parametric cost models generally occurs through the steps below:

a) database development
b) model requirements
c) resolution of model architecture and data availability
d) model development
e) model calibration and validation
f) model documentation
g) model updating.

Usually, a series of regression analysis cases (linear and non-linear) will be run against the data to determine the best algorithms to eventually comprise the parametric model. The data application stage of the development process involves establishing the user interface and presentation form for the parametric cost model. Using the mathematical and statistical algorithms developed in the data analysis stage, the various inputs to the cost model are identified. An interface is then developed to provide the estimator with an easy and straightforward way in which to enter this information.

The process above generally generates the mean or P50 contingency. To generate a probabilistic range of outcomes, e.g. from P10 to P90 range, it is quite common to assume that the contingency is normally distributed when expressed in the form of estimate/actual and is equal to the standard deviation of the distribution of that ratio. With these assumptions, the normal cumulative distribution can be generated using the NORMINV function within Microsoft Excel. The probabilistic distribution can be refined as one obtains better data for validation.

RES Example: utility owner DAXA, is planning to expand one of its commercial buildings. As part of the required preliminary business case, a Class 5 estimate and schedule has been developed. A parametric based method as shown below has been used to assess the required cost contingency.

a) Base Estimate excluding contingency (1,000 square meters × $10,000/m2) = $10m
b) Parameters: A=1.15, B=1.1, C=1.05, D=1.0
c) Luxury Factor (Parameter A) = 1.15
d) Complexity Factor (Parameter C) = 1.05
e) Site Conditions Factor (Parameter C) = 1.05
f) Maturity of Design Factor (Parameter D) = 1.0
g) Total Cost Estimate (TCE) including contingency = $10m × (1+0.15+0.05+0.05+0.0) = $12.5m
h) P50 Contingency = $2.5m
i) NORMINV (probability, mean, std. dev)
   - TCE P10 = NORMINV (0.1, $12.5m, $2.5m) = $9.3m
   - TCE P50 = NORMINV (0.5, $12.5m, $2.5m) = $12.5m, i.e. $2.5m or 25% contingency
   - TCE P70 = NORMINV (0.7, $12.5m, $2.5m) = $13.81m, i.e. $3.81m or 38% contingency
   - TCE P90 = NORMINV (0.9, $12.5m, $2.5m) = $15.7m, i.e. $5.7m or 57% contingency

The strengths of parametric based methods are:

a) reasonable at early stages of project development (e.g. preliminary business case)
b) probabilistic results
c) data-based (all this happened before and all of it will happen again)
d) simple and quick assessment
e) repeatable.

The weaknesses of parametric based methods are:

a) may not be reasonable and accurate at final stages of project development, e.g. FBC
b) access to sound historical and empirical data
c) quality of project data including Base Estimate and Base Schedule
d) complex to create
e) do not address project specific risks
f) generally do not address the importance of good practice risk management to identify and mitigate risks.

Parametric based methods can be a reasonable method in preparing early conceptual estimates, e.g. at the stage of Preliminary Business Case development. They are often used during both the concept screening and feasibility stages of a project. Parametric estimating models can be developed using basic skills in estimating, mathematics, statistics, and spreadsheet software.

RES Tips & Tricks: Make sure your project data is collected, validated, cleansed and maintained in order to provide a complete audit trail with expenditure dates so that costs can be adjusted for escalation. You should identify and capture non-recurring and recurring costs separately, preferably through project Work Breakdown Structure (WBS).

It is important to understand that the quality of results can be no better than the quality of the input data, and great attention should be taken during the data collection and analysis stage to gather appropriate and accurate project scope and cost data.

Based on a number of studies, the relationship between parameters and cost growth and schedule slip as percentages (output) have proven reliably consistent for projects of all types and sizes involving construction from simple pipelines to nuclear projects. In other words, the models from industry research can be used with some confidence by anyone, though one should validate the outcomes over time with one's own data.

RES Recommendation: Parametric based methods are generally reasonable and adequate at very early stages of project development (e.g. Preliminary Business Case with Class 5 estimates) – given the dominance of systemic risk impacts and wide range of inherent risks associated with assumptions as well as lack of knowledge of project specifics including possible contingent risks.

For key decision points at the later stages of project development (e.g. Final Business Case with Class 4 estimates or better) or during project delivery – RES recommends other methods of Contingency Determination (such as First Principles Risk Analysis (FPRA) as described in Appendix E) are used in combination with the parametric based methods.

11.1.5 Regression Based

Regression based analysis is a probabilistic (non-simulation) method used to find relationships between variables for the purpose of predicting future values. In project cost estimating, this method is used to develop CERs between a dependent variable (project cost) and one or more independent variables (e.g. cost drivers such as weight, power or volume) from historical completed project data.

By a statistical relationship, it is meant that the observed variation of the dependent variable (project cost) across similar projects can be explained or predicted by one or more independent variables (e.g. technical, performance, or programmatic). The objective is to find the functional relationship that most accurately estimates the cost of a particular element in a project WBS. There are several different approaches to this method including the list below:

a) Ordinary Least Squares (OLS)
b) Minimum Unbiased Percentage Error (MUPE)
c) ZPB/MPE Method (or ZMPE Method)
d) Iterative Regression Techniques.

Considering the limited application of this method in industry, especially construction and infrastructure projects, this Guideline refers its readers to other references (e.g. AFCAA Cost Risk Analysis Handbook or JA CSRUH Handbook) for further guidance on this method.

11.1.6 Range Based

A single-point cost estimate can be improved by using a range: the optimistic (best case); the most likely; and the pessimistic (worst case) estimate for each cost element – instead of one forecast. These three point estimates will be determined for both inherent and contingent risks by SMEs; validated by actual historical data from previous projects; and will be then combined into one number by using an appropriate average formula (e.g. the triangular or beta distribution formulas, as shown in Figure 38 below).

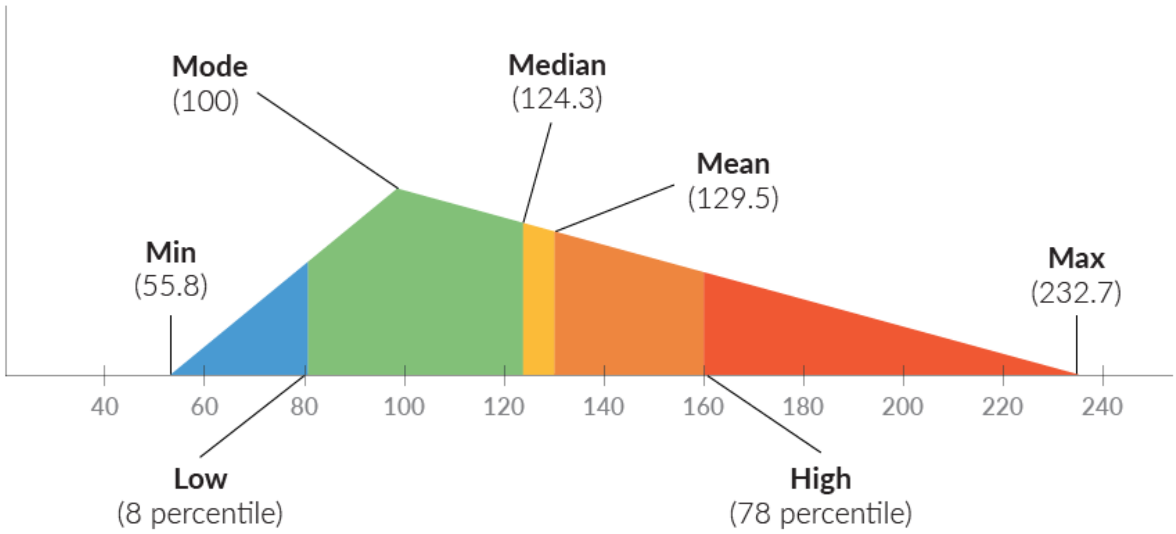


Figure 38: Distribution parameters of a Notional Triangle (NASA Joint Cost Schedule Risk and Uncertainty Handbook)

The range based approach to quantifying contingencies aims to improve on other non-simulation probabilistic approaches by using a validated range of possibilities for each item across the project scope for the inherent and contingent risks. Similar to the item-based method, the structure of items might be based on the WBS, contract packaging, commodity types or other groupings. The process for the most common approach to this method is represented in Figure 39.

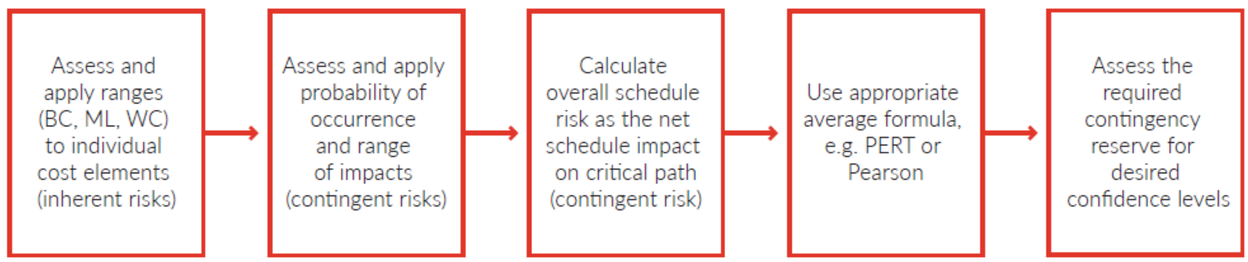


Figure 39: the process for probabilistic range based methodology (US Air Force Cost Risk and Uncertainty Analysis Handbook)

In assessing the best case, most likely and worst case ranges, a number of factors including estimating judgment, previous experience, historical data, risk appetite and the organisation's previous performance should be considered. The example below illustrates the required steps further:

a) For inherent risks: apply a range (best case, most likely and worst case) to individual cost elements (recommended at project WBS level 4), then use any weighted average formula to turn the range into a number. Examples include:
    - PERT formula: (BC + 4 X ML + WC)/6
    - Johnson modification of the Pearson-Tukey formula for assessing a 50% confidence level: (3 X BC + 10 X ML + 3 X WC)/16
b) For contingent risks: apply the probability of risk occurring and range of time and cost consequences for residual risks
c) Calculate total schedule contingency as the net schedule impact of inherent and contingent risks on the completion date
d) Calculate total cost contingency as:
    - for a 50% confidence level:

  - P50 contingency = P50 contingency for inherent risks + P50 contingency for contingent risks
- for a 90% confidence level (noting that the P90's of each item are not additive so overall will be conservative. Only the means are):
  - P90 contingency = P90 contingency for inherent risks + P90 contingency for contingent risks
  - A reasonable multiplier to P50 contingency may be used for determination of P90 contingency for each item, e.g. P90 = P50 + 2 x Standard Deviation.

Table 17 presents the range based method using the weighted average Pearson-Tukey formula.

	Range of potential impact			**Weighted average formula (e.g. Pearson)**			
P(x) (%)	Best case	Most likely	Worst case	Standard Deviation	W.Av=(3*BC+10*ML+3*WC)/16 P50=P(x)*W.Av		P90=P50+(2SD x P(x))
35	$100,000	$500,000	$2,500,000	$524,934	$800,000	$280,000	$647,453
50	$2,500,000	$3,000,000	$6,000,000	$772,802	$3,468,750	$1,734,375	$2,507,176
75	$100,000	$110,000	$300,000	$46,007	$143,750	$107,813	$176,823
5	$200,000	$220,000	$500,000	$68,475	$268,750	$13,438	$20,285
35	$125,000	$150,000	$500,000	$85,594	$210,938	$73,828	$133,744
80	$2,500,000	$3,000,000	$6,000,000	$772,802	$3,468,750	$2,775,000	$4,011,482
12	$100,000	$110,000	$500,000	$93,125	$181,250	$21,750	$44,099
10	$200,000	$220,000	$600,000	$92,014	$287,500	$28,750	$47,152.90
80	$125,000	$150,000	$300,000	$38,640	$173,438	$138,750	$200,574
90	$2,500,000	$3,000,000	$6,000,000	$772,802	$3,468,750	$3,121,875	$4,512,917
10	$100,000	$110,000	$500,000	$93,125	$181,250	$18,125	$36,749
75	$200,000	$220,000	$600,000	$92,014	$287,500	$215,625	$353,646
60	$125,000	$150,000	$500,000	$85,594	$210,938	$126,563	$229,275
40	$2,500,000	$3,000,000	$6,000,000	$772,802	$3,468,750	$1,387,500	$2,005,741
100	$100,000	$110,000	$500,000	$93,125	$181,250	$181,250	$367,499
						$10.2m	**$15.3m**
						P50	**P90**

Table 17: An example of the range based method by using the Pearson-Tukey formula

11.2 Probabilistic Methods – Simulation

11.2.1 Outputs Based Uncertainty

The outputs based method applies uncertainty directly to the cost model results rather than to the model's inputs. The approach relies on historical data to estimate the overall uncertainty at output levels of indenture within the estimate. The assumption is that the aggregate uncertainty of both the methodology and the inputs is addressed through the use of uncertainty distributions on the outputs.

RES Recommendation: upon completion of the Base Estimate, the risk analyst will examine the WBS and determine the level at which to apply uncertainty. Application at every WBS child element is recommended though circumstances may lead to application at WBS parent levels instead. For example, in a model where a WBS parent element is the sum of a large number of low-cost WBS child elements, it may be appropriate to simply treat uncertainty at the level of that parent.

The simulation model is set up such that the distributions are defined with a most likely value of “1” (or in the case of Lognormal, the median) to be multiplied by each element’s Base Estimate. Each simulation pass will draw a sample of the distribution and multiply the drawn value times the Base Estimate value – the simulation need not execute the entire cost model upon each draw. Since the objective is to model combined effects in one distribution, the shape and bounds of the distribution will often by necessity be subjective unless the bounds were derived from a data set or from a more detailed series of simulations.

The subjective selection of uncertainty can often be enhanced by the use of risk score mapping – this is often used in outputs-based simulations. Risk score mapping is a technique consisting of a risk scoring matrix and a map of uncertainty distribution bounds against risk scores. Figure 40 (after the US Air Force Cost Risk and Uncertainty Analysis Handbook) depicts this method conceptually. The risk scoring matrix at the top of the figure consists of uncertainty-causing categories by row. By column, the attributes of those categories are listed that are deemed low risk, high risk, etc. Separate matrices may be developed for different types of cost elements.

The matrices are used to elicit judgments from technical personnel as to the technical and schedule risk associated with a particular cost element. The columns are quantified with assigned scores of increasing value from low to high risk. The average score from the matrix across the categories is the overall risk score for that cost element. The categories may be weighted if desired. The risk scores are converted to distribution bounds as shown in the bottom of the Figure 40. Although this method has merit in formalising the assignment of subjective risk and providing a mechanism for eliciting participation from the technical personnel in judging risk, this Guideline does not recommend application of this method at key project investment decision-making points, (e.g. Final Business Case).

	Risk Scores		
Risk Categories	**Low**	**Medium**	**High**
Category 1	Reference text describing attributes of low risk of each category	Reference text describing attributes of medium risk of each category	Reference text describing attributes of high risk of each category
Category 2			
Category 3			
Category 4			
Category 5			

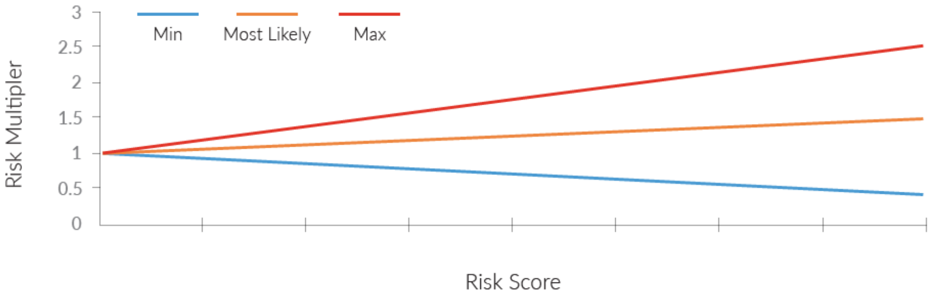


Figure 40: Risk score mapping concept

11.3 Further Reading

- AACEi, RP 41R-08 Risk Analysis and Contingency Determination Using Range Estimating
- AACEi, RP 42R-08 Risk Analysis and Contingency Determination Using Parametric Estimating
- Garvey, Paul R. , Book, Stephen A., and Covert, Raymond P., *Probability Methods for Cost Uncertainty Analysis*, 2nd Edition
- Hollmann, John K., *Project Risk Quantification*, 2016, Probabilistic Publishing
- Johnson, D., "Triangular Approximations for Continuous Random Variables in Risk Analysis", *Journal of the Operational Research Society*, vol. 53, no. 4, pp. 457-467, 2002
- NASA, *Joint Cost Schedule Risk and Uncertainty Handbook*
- US Air Force, *Cost Risk and Uncertainty Analysis Handbook*

12. Appendix E – First Principles Risk Analysis (FPRA)

12.1 Purpose

The purpose of this appendix is to provide information on First Principles Risk Analysis (FPRA) – as a method of Cost Risk Analysis (CRA) – to develop, assess and allocate a reasonable risk based contingency allowance (time and cost) for the desired confidence level.

12.2 FPRA Overall Process

The key elements of a realistic and reliable FPRA in determination and allocation of a reasonable cost contingency for different desired confidence levels are:

a) quality validation of the Base Estimate representing the most likely scenario
b) quality validation of the Base Schedule representing the most likely scenario
c) identification and quantification of inherent risks at the most appropriate level of first principles cost estimate against labour, material, and subcontractor
d) identification and quantification of key contingent risks
e) allocating the inherent and contingent risks into the cost risk model
f) assessing and modelling key correlations for both inherent and contingent risks
g) running a Monte Carlo Simulation
h) reviewing, validating and finalising the results

The process for the most common approach to this method is represented in Figure 41.

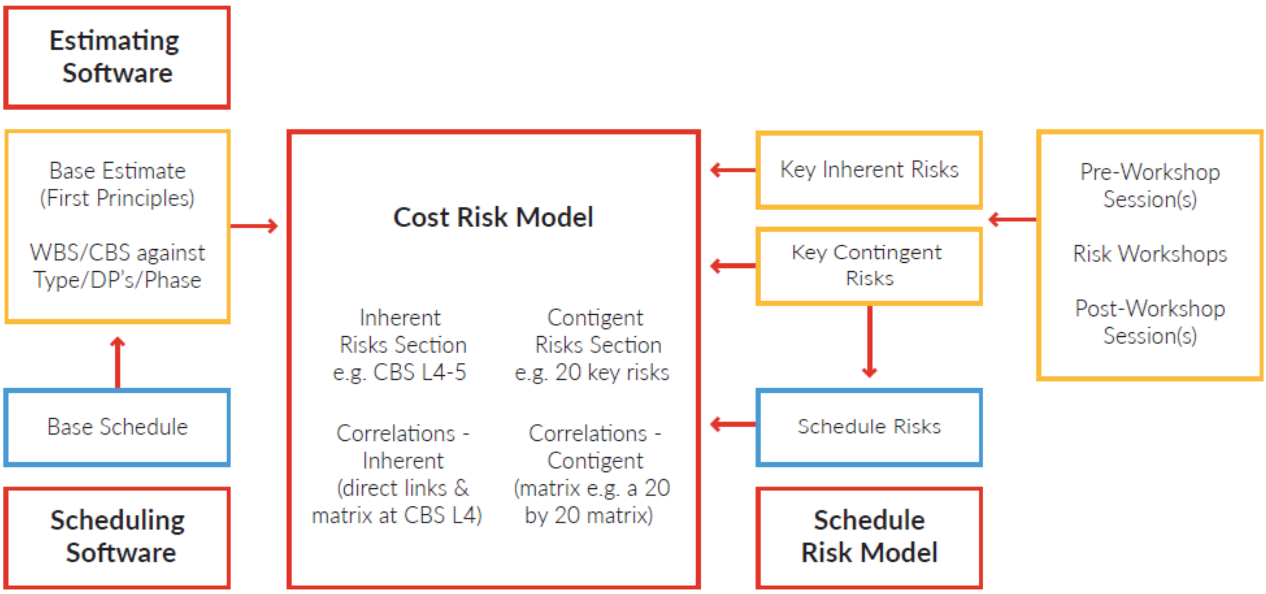


Figure 41: A typical process map for the FPRA method

These key elements are further explained in the sections below or other chapters of this Guideline.

12.3 Base Estimate

To prepare an effective probabilistic risk assessment, it is important that the following items can be identified from the Base Estimate:

a) the relationships between different cost line items, rates and quantities
b) the relative uncertainty in the estimate of different line items, rates and quantities
c) the key assumptions that underpin the base estimate
d) the best structure of the first principles Base Estimate, e.g. material, equipment and labour.

These aspects will determine the design of the risk model, and the approach taken to quantify risks. The approach taken should be consistent with inherent and contingent risk models – that is, where an allowance is made in the Base Estimate, it should not 'double up' with further ranges or risks in the risk models.

12.4 Base Schedule and Schedule Risks

Key notes for consideration include:

a) ensuring appropriate integration of schedule risk (by using a range of schedule impacts) within the cost model
b) ensuring the residual risk exposures are not double counted or missed between the cost and schedule risk assumptions and overall model
c) ensuring that the Base Schedule on which the SRA is to be performed is fit for purpose – with the appropriate level of detail and logic contained within it
d) ensuring there has been reasonable assessment of inherent risk within the Base Schedule as well as the possibility of discrete risk events (contingent risks).

In addition to the above, application of a fully integrated schedule cost risk model may be considered depending on the availability of early design and Base Estimate data (as detailed in Appendix E).

12.5 Risk Workshops and Review Meetings

A number of risk workshops and meetings should be conducted with the relevant stakeholders in order to both review the estimate and schedule and populate the risk model. Considering the size of project and its scope, it may also be necessary to elicit expert input through other means. The relevant people to attend workshops and/or review meetings include:

a) the estimators and cost planning team
b) the schedulers and programming team
c) the engineers, designers, planners and other advisors or service providers who prepared the material which the estimators used
d) work stream leads and delivery strategy personnel who understand how the work will be procured and delivered on the ground
e) leads from functional groups and other external experts, when required.

> **RES Tips & Tricks:** While workshops and reviews can help to record many risks in the risk register, it is important to note there may be other discrete risk sources that need to be assessed and modelled.

For further details about risk workshop facilitation, please refer to Appendix B.

RISK ENGINEERING SOCIETY

12.6 Optimism Bias

It is important to note that people have a tendency to be consistently optimistic and overconfident in their assessment of uncertain outcomes such as probabilities and ranges. One possible impact of optimism bias is to set unrealistically low contingencies. To mitigate this impact the control approaches below recommended:

a) benchmarking against other cost estimating procedures which describe the contingency range expected at each phase of the project, based on the estimator's experience and considering experience from the wider industry
b) cross checking assumptions with different people at several separate meetings
c) conducting multiple short risk reviews with a significant number of people rather than long risk workshops with limited number of people
d) using wide ranges that are generally biased on the upside.

For further details about optimism bias and other possible cognitive biases influencing risk and contingency assessment, refer to Section 2.6.3, Chapter 2.

12.7 Correlation

A critical part of the simulation model is to define the correlation between each of the distributions defined in the model. Correlation is the term used to describe the degree to which variables 'move together'. For instance, if a random sample from one distribution is taken from the high end of the distribution, is there any reason to expect others would be drawn in a similar way? The level of correlation in a model has a profound influence on the results and is addressed in the following sections.

Correlation is the term used to describe the degree to which variables are related or associated. Correlation between any two random variables does not prove or disapprove a cause-and-effect relationship between them. An important consideration in risk analysis is to adequately account for the relationships between the cost elements during a risk simulation. This interrelationship between the WBS elements is commonly known as dependency or correlation. For example, if something causes the cost of WBS element A to increase, it may be that the cost of WBS element B also increases (positive correlation), and perhaps the cost of WBS element F decreases (negative correlation). For inputs-based analyses, correlation between random input variables should be included where significant.

For the purpose of FPRA modelling, two different types of correlation – functional and applied – should be considered, assessed and then modelled.

RES Tips & Tricks: The FPRA analysis is not complete until both functional and applied correlation is addressed. If correlation is ignored, the variance at the total levels in the estimate may be understated – in many cases considerably.

12.7.1 Functional Correlation (Implicit)

Correlation is a statistical measure that indicates the extent to which two or more variables rise and fall together. A positive correlation (e.g. +1) indicates the extent to which those variables increase or decrease in parallel; a negative correlation (e.g. -1) indicates the extent to which one variable increases as the other decreases. It should be noted that correlation does not necessarily imply causation. Research and guidelines show that correlations must be included in Monte Carlo simulations, otherwise the analysis leads to an incorrect assessment of the overall risk profile. Studies also suggest that the effect of excluding correlations from the model is more profound than the effect of the choice between different probability distributions.

The term functional correlation has been around since at least 1994 and yet it is largely misunderstood. Essentially, it is referring to the correlation that is developed in the simulation due to the mathematical (functional) relationships within the elements of the risk model. Uncertainty that is defined on a variable or assigned to a cost element will be inherited by any relationship that uses them in its equation. Functional correlation can exist between:

a) cost element inputs if these inputs are in fact a function of each other
b) cost elements if these elements share one or more common input variables. With this variable's uncertainty modeled only once, these elements will be inadvertently correlated in the model
c) two or more cost elements if one element is related to other elements (for instance through a factor relationship).

RES Recommendation: if the relationship between uncertain elements in the Base Estimate is known, then capturing that in the functional relationships within the risk model should be attempted. For instance, if the cost of design is known to be a function of the direct construction cost, then this relationship should be explicitly implemented in the FPRA model rather than allowing the elements to behave independently in the model. This simplifies what-if analysis and improves the chances of the simulation behaving properly.

If there are no known functional relationships to employ, every simulation tool will allow correlation to be applied. Applied correlation is when the risk analyst specifies a correlation between two or more uncertainty distributions. It is also possible to apply additional correlation across functionally correlated items. Applied correlation does not replace functional correlation. The net effect in the simulation is the combination of the applied and functional correlation, and it is not a simple sum. It is necessary to measure correlation in the simulation result before and after applied correlation to determine the applied correlation impact. Most simulation models contain a mix of both functional and applied correlation. Functional correlation is a result of model functional relationships, while applied correlation is specified by the risk analyst.

There are two main ways to define and model the required Functional Correlation/s within the cost risk model:

1 By using links and formulas between variables to model functional correlation – this is probably the easiest and most effective way to reflect a direct relationship between variables
2 By grouping the smaller elements together and assessing their risk together. This is useful when there are a large number of smaller variables that are similar in nature but are difficult to relate directly to each other.

12.7.2 Applied Correlation (Explicit)

Applied correlations are those specified by the user and implemented within a model. Before specifying any additional correlations among the WBS elements, RES recommends that the user measure the correlations already present in the cost risk model. Correlations (or dependencies) between the uncertainties of estimates for the WBS elements are determined by the structure of the project. These correlations should not be estimated by the cost-vs-cost correlations in the historical database from which the CERs are derived.

In other words, strong correlations between cost elements in a database should not be mistaken for evidence that residuals or percentage errors of the CERs derived from the same database are correlated.

A correlation matrix is an efficient way to define key correlations amongst a group of uncertainty distributions built into the FPRA model. The diagonal of the correlation matrix should be populated with '1's to define the correlation between each distribution in the group and itself. Only half the matrix need be modeled, as the other half (on the other side of the diagonal) is a mirror image. An example of correlation matrix presented in Table 18.

	A	B	X	Y
A	1			
B	0.5	1		
X	0.3	0.5	1	
Y	0.8	0.3	0.8	1

Table 18: An example of a correlation matrix for 4 variables

In developing the correlation matrix, there are several key items that should be considered:

a) Correlation Coefficients
   - correlation coefficients range in value between -1 and +1
   - a value of 0 indicates there is no correlation between the two variables – this is called 'independence
   - a value of +1 is a perfect positive correlation between the two variables – when the value sampled for one variable input is 'high, the value sampled for the second variable will also be high
   - a value of -1 is a complete inverse correlation between the two variables – when the value sampled for one input is high, the value sampled for the second will be 'low'. This called 'perfect correlation'
   - coefficient values between -1 and +1 are known as 'partial correlation'. For example, a coefficient of +0.5 specifies that when the value sampled for one input is high, the value sampled for the second value will have a tendency to, but not always, be high. A 0.5 correlation can also be read as 50%. In other words, the second variable will be high in only 50% of iterations

b) Consistent Matrix: correlations between multiple variables should be consistent. For example, if X:Y and Y:Z are highly correlated in a positive direction, then assigning a strong negative to X:Z would cause an inconsistency in the FPRA model

c) Inconsistent Matrix: most current risk modelling software, e.g. Palisade @RISK, detects and highlights a correlation matrix that is inconsistent enough to prevent the simulation from running. The software will then offer the option to adjust correlations enough to allow the simulation to proceed

d) Empty Cells: be aware that different software treat empty cells within the correlation matrix differently, e.g. Palisade @Risk requires all cells to be populated

e) Note that correlation is a measure of the linear relationship between random variables. It does not prove a cause-and-effect relationship

f) Often the correlation coefficients will be calculated from actual historical data on which the risk analyst is basing the distribution functions in the cost risk model. In this case, data needs to be collected on correlated items and used to compute the correlation coefficient.

In the absence of objective data, risk analyst is encouraged to make subjective correlation assessment and matrix following the process below:

1. Apply functional correlations within the risk model whenever possible. Most Base Estimates contain many cost elements that are functionally related through linear and non-linear methods. This often causes uncertainty distributions to be multiplied, divided or exponentiated
2. Measure the correlation present in the model due to functional correlations and identify those elements with a low level of correlations, e.g. less than or equal to 0.3
3. Determine if specific elements that are currently uncorrelated should move together, that is, be correlated either negatively or positively
4. Assign additional correlation using a correlation value between -1 and +1 at an appropriate level of the Cost Breakdown Structure or WBS. Table 19 provides guidance on default correlation values
5. Measure and review the correlations again to ensure elements are properly correlated.

Level of Correlation	Positive	Negative
Full	1.0	-1.0
Strong	0.8	-0.8
Medium	0.5	-0.5
Weak	0.3	-0.3
Nil	0.0	0.0

Table 19: RES recommended correlation factors in the absence of objective data

RES Recommendation: several references suggest a default correlation of 0.25 to 0.3 when there is no other information available. However, others provide evidence that 0.45 or 0.63 may be more appropriate. As a compromise between all the published recommendations, RES recommends 0.3 as the default correlation value – and discourages perfect correlation of +/-1.0.

12.8 Probability

Probability is the relative frequency of an outcome of a repeatable, observable experiment. Probability is measured on a scale between 0 and 1. Probability is assigned to each outcome of an experiment based on its relative frequency – where 1 represents always and 0 represents never.

Probability Distribution

A probability distribution is a mathematical formula that describes how the relative frequency of occurrence is assigned to the real numbers in the range of a random variable. The distribution may be described by either a density function p(x) or a cumulative probability function F(x). These functions are two different representations of the same data. In Figure 42, the dark, curved line represents the statistical distribution underlying the sample data shown in the table at the left. This type of curve is also called a Probability Density Function (PDF).

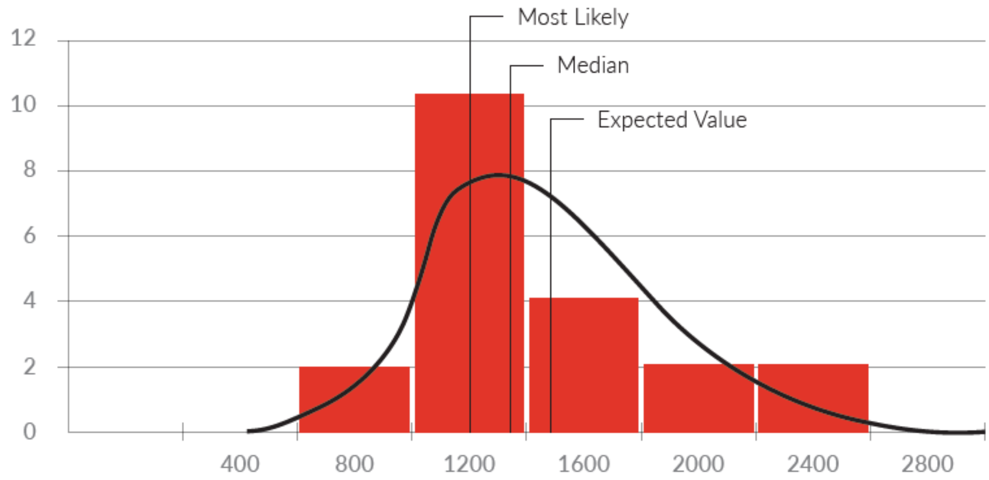


Figure 42: Distribution example

Probability Density Function (PDF)

A continuous PDF is the 'smoothed out' version of a histogram. The area under any PDF is equal to 1. A PDF identifies the probabilities associated with specific values or intervals of values of the random variable (see Probability Distribution). If there is a finite probability associated with a specific value x, then the PDF will have a 'spike' at that value of x.

Cumulative Distribution Function (CDF)

The CDF is a mathematical curve that for any given possible value of an item, identifies the probability that the actual value will be less than or equal to the given value. When shown graphically, the CDF is an S-shaped curve. The term S-curve is used synonymously with CDF. The value of a cumulative distribution function is bounded between 0 and 1, with 0.5 indicating the median of the population (see Figure 43).

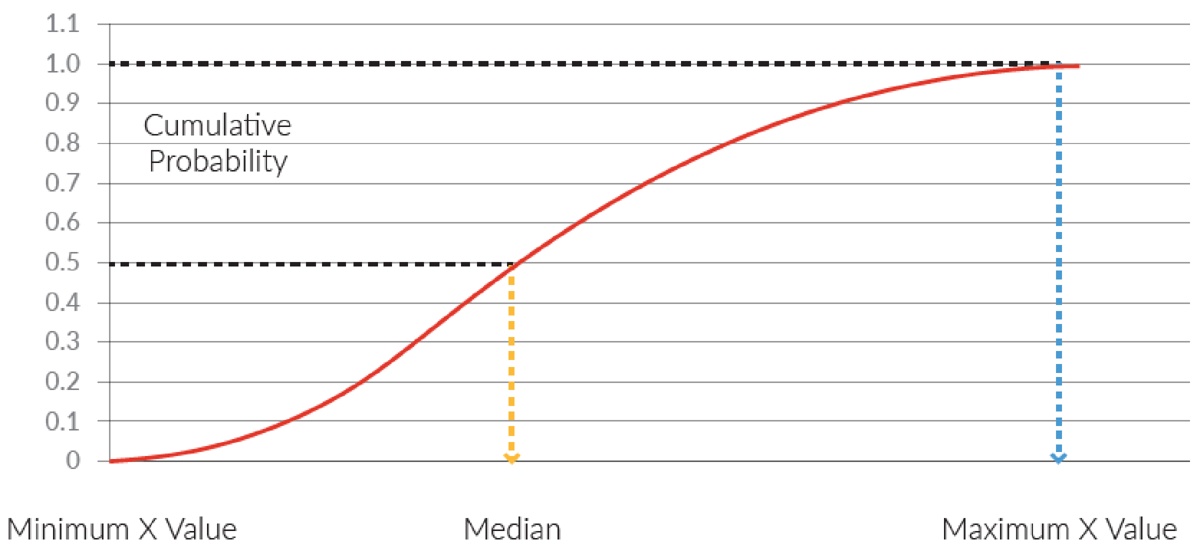


Figure 43: Cumulative Probability Distribution (CPD)

Probability and FPRA

FPRA differentiates two probabilities when assessing and setting the assumptions within the model:

1. Probability of risk occurrence
2. Probability of range of consequences due to risk occurrence

While many risk analysts insist to align the qualitative risk assessment and probabilities within the risk matrix with the probability assumptions within the cost risk analysis. The example below represents this approach:

a) Risk: fire may happen at site during construction
b) Probability of occurrence based on risk matrix: likely or 50%
c) Range of consequences: $1m (Best Case), $3m (Most Likely) and $6m (Worst Case).

RES Recommendation: While this approach may be reasonable for low risk and less complex projects, it may not appropriately address the likelihood of possible consequences. From a FPRA perspective, RES recommends that the probabilities in the model should be also aligned with the likelihood of consequence as well as the likelihood of risk occurrence.

All the percentages and impacts above should be modelled within the FPRA risk model. In other words, both the likelihood of risk occurrence and probability of consequences are important to ensure that an accurate and reasonable contingency allowance is calculated.

Another issue is how to maintain consistency in probability and consequence assumptions between a qualitative risk assessment (risk matrix) and FPRA. In practice, this Guideline highlights that qualitative risk assessment using a risk matrix should only be used as a starting point to select the key risk items that need further assessment –including quantitative analysis. There are many references highlighting the issues associated with the sole use of a risk matrix and its assumptions (probabilities and range of consequences) to drive cost risk analysis. RES does not recommend this course of action.

RES Example: Modelling schedule risk is a good example. Assuming that we have the Base Schedule right and representing the most likely circumstances, the probability that the schedule will be delayed is 100%. To assess the best-case scenario, we are 90% sure that we will finish the project within a one month delay. With 50% probability, we will finish the project within a two-month delay – but there is only a 10% probability that we will need more than five months' delay. This is summarised below:

- Risk: schedule delay compared to the Base Schedule – likelihood of 100%
- Best Case: 90% sure the delay will be less than one month
- Most Likely: 50% sure the delay will be less than two months
- Worst Case: 10% chance that we will need more than five months' delay.

RES Tips & Tricks: in the absence of an internal probability table for FPRA purposes, RES recommends the table below. To minimise optimism bias, RES recommends the project team uses the "Qualitative Descriptive" column during risk workshops and the "Probability Ranges" column for risk quantification and modelling purposes.

Qualitative Descriptive	Probability of Occurrence	Probability Ranges
Almost Certain	The event is almost certain to occur within the planning period	90% < P(x)
Likely	The event is likely to occur within the planning period.	70% < P(x) < 90%
Possible	The event may occur within the planning period.	40% < P(x) < 70%
Unlikely	The event is not likely to occur in the planning period.	10% < P(x) < 40%
Rare	The event will only occur in exceptional circumstances.	P(x) < 10%

12.9 Statistical Measures

Expected Value, Average or Mean

The expected value is the arithmetic average or mean of the distribution of possible values for a variable. For a given set of n values (y1, y2, …, yn), the mean (y) is defined to be the arithmetic average of these n values. In mathematical notations, it is given by the equation:

$$\bar{y} = \frac{\sum_i y_i}{n}$$

RES Tips & Tricks: Expected values have an important mathematical property: the sum of the expected values of a set of variables is equal to the expected value of the sum of the set of variables. In other words, when summing the expected values of a number of WBS items, the result will be the expected value of the sum of the WBS items. This is not true for percentiles or most likely values.

Median

The median is the point in a distribution where half the observed values will be lower and half will be higher (the 50th percentile). In other words, this is the point where the actual cost is just as likely to be higher as it is to be lower. For a finite number of observations – if the sample size is odd – the median is the middle value. If the sample size is even, the median is the average of the middle two values. The sum of the medians of a number of WBS items is not equal to the median of the sum of the values, except in the unusual cases in which the distributions of all the WBS items are symmetrical.

Most Likely Value (Mode)

The mode is the most probable single value for a variable (the peak of the distribution). The output of the primary estimating methodology (i.e. the point estimate) for a WBS item is typically interpreted as the most likely value. The sum of the most likely values of a number of WBS items is not equal to the most likely value of the sum of the values, except in the unusual case in which the distributions of all the WBS items are symmetric.

Skewness

A distribution is skewed if one of its two tails is longer than the other. For example, if there is a long tail to the right of the distribution, then it is positively skewed (or skewed right). This means that the distribution has a long tail in the positive direction. Similarly, if there is a long tail to the left, then the distribution is negatively skewed (or skewed left). If the distribution is symmetrical, then the distribution has no skew. For example, the normal distribution has a skewness value of zero as it is a symmetric distribution.

Variance

To calculate the variance, first calculate the arithmetic mean and then for each data point, then find the difference between the point and the mean. Next, square all these differences and sum them. Divide this sum by the number of items in the data set (if the data is from a sample, the sum is divided by the number of items minus one). The variance is a measure of the average squared distance of each value from the mean, but it is not expressed in the units of measure of the mean or the original data. The measure of variance is greatly affected by extreme values.

Standard Deviation (SD)

The standard deviation is one of the most widely used statistics for measuring the spread, or dispersion, of values in a population of data. For a given set of n values (y1, y2, …, yn), the standard deviation (Stdev or S) is defined by the equation:

$$S = \begin{cases} \sqrt{\dfrac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1}} & \text{if data is from a sample} \quad - \text{Std. Dev. (Sample)} \\ \sqrt{\dfrac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n}} & \text{if data is from a population} \quad - \text{RMS (Population)} \end{cases}$$

Coefficient of Variation

The coefficient of variation (CV) of a distribution is defined as the ratio of the standard deviation to its mean (i.e., SD/Mean). It is a relative measure of dispersion because it expresses the standard deviation as a percentage of the mean. CV is fast becoming one of the more recognised metrics to characterise the spread in a CDF (S-Curve).

12.10 Distributions and Ranges

There are two different types of distributions that may be applied to each input: continuous and discrete distributions. Common continuous distributions include the Triangular, Pert, and Uniform distributions, as presented in Table 20 and Figures 45 and 46. The decision to use a particular distribution depends upon the nature of the risk being considered and other supporting data. For specific risk modelling (e.g. rain) with available statistical data, other empirical fit distributions should be considered, if required.

RES generally recommends that an Alt form of the distribution (e.g. AltPert distribution rather than Pert distribution) should be used where possible, especially for modelling inherent risks and estimate ranging. This is because the assessment of minimum and maximum outcomes is generally approximated based on the participants' experience. This assessment is unlikely to consider the absolute worst or best situations that could occur.

RES Tips & Tricks: It is worthwhile suggesting that practitioners at a workshop should not attempt to estimate the Most Likely value of an event risk prior to other values. Everyone will have a different image of the consequences. It is best for the workshop to come to grips with the maximum possible cost, then consider the smallest possible costs.

Distribution	Application	# of Parameters	Parameters
Lognormal	Not enough info available	2	Median, High
Triangular	SME, labour productivity rate, quantum	3	Low, Mode, High
BetaPert	Similar to Triangular with more weighting to mode	3	Low, Mode, High
Beta	Similar to Triangular, but min/max boundaries known better than mode	4	Min, Low, High, Max
Normal	Equal likelihood for Low and High	2	Mean/Median/Mode and High
Uniform	Equal likelihood over uncertainty range	2	Low, High

Table 20: Recommended uncertainty distributions

RES Recommendation: in the absence of better information, RES recommends the Lognormal distribution shape. When the distribution is known to be left-skewed, RES recommends BetaPert.

Some agencies include failure analysis mathematics in their operations and support cost models to estimate the number of spares and/or maintenance actions. A few of these distributions are introduced here. Distributions include:

a) Poisson distribution: which can be used to define the number of failures in a specified time when the average number of failures is small. It is also a useful distribution to estimate testing, inventory levels, and computing reliability. The Poisson distribution is a discrete distribution that requires only a single parameter – the mean – to define the distribution. A common use of the Poisson distribution is to simulate the number of failures per year using the inverse of the mean time between failures as the parameter
b) Exponential distribution: which is a continuous distribution that can be used to estimate the time between failures. The parameter in this case is the mean time between failures
c) Weibull distribution: which is a continuous distribution often used to estimate time between failures. A common approach is to assume a high failure rate at the beginning of the lifecycle due to manufacturing errors (infant mortality), reducing to a constant (the design failure rate), and then increasing at the end of life (wear out). Infant mortality and wear out phases are often modelled with the Weibull distribution.

Figure 44, sourced from the US Air Force Cost Risk and Uncertainty Analysis Metrics Manual (CRUAMM), illustrates the frequency of each distribution found across 1,400 fits of various cost data and other factors.

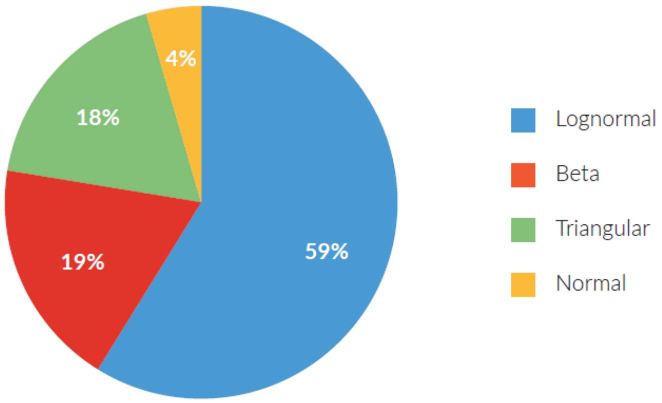


Figure 44: Relative frequencies of distribution shapes (US Air Force CRUAMM)

Some examples of common continuous distributions are represented in Figure 45.

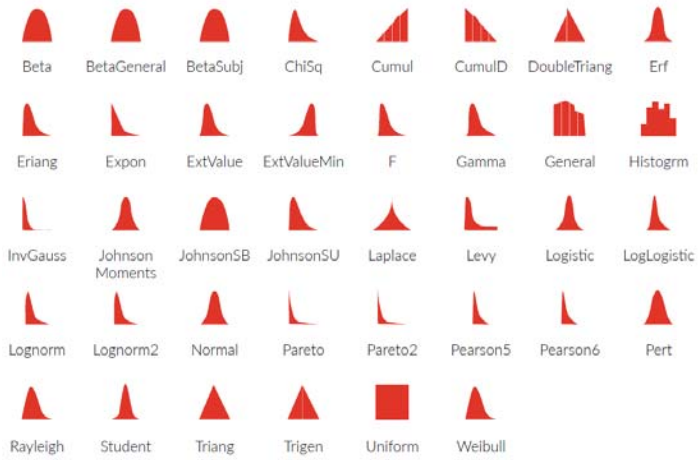


Figure 45: Common continuous distributions (Palisade @Risk)

The most commonly used discrete distribution is the binomial distribution – which returns either a single value or zero, depending on a percentage input to the formula. This can be used to model the likelihood of a contingent risk occurring. Some examples of discrete distributions are represented in Figure 46.

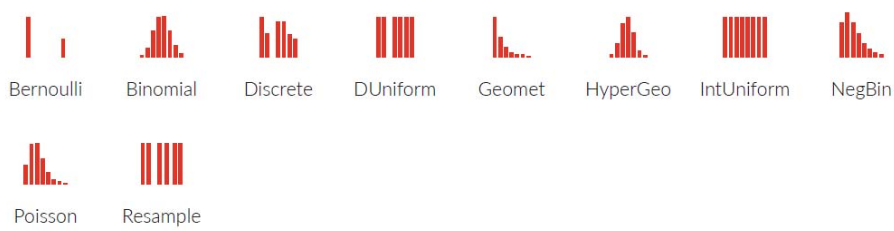


Figure 46: Common discrete distributions (Palisade @Risk)

12.11 Truncated Distributions

In cost risk modelling, it is not unusual to obtain objective or subjective bounds that cause the distribution shape to get into the negative region (i.e. below zero) despite never observing a value in that region. In the circumstances that the distribution will result in having non-logical outputs, the risk analyst may choose to force a lower bound when performing the distribution fit for modelling.

Alternatively, an unconstrained fit that stretches into the negative region can be truncated when used in the simulation tool. All risk analysis tools provide the ability to truncate distributions at either a low point, high point or both. Establishing the lower limit of the distribution to be zero will avoid irrational situations of negative values in cost or schedule.

There are two significant impacts to be considered when truncating at low point, e.g. zero:

a) First, the distribution variance will be reduced
b) Second, the mean will shift to the right, i.e. higher value.

Care should be taken to determine the impact of these setting and if it is acceptable and make sense. However, in situations when negative tails would represent irrational results, the risk analyst is encouraged to either truncate or select another distribution, e.g. lognormal, that does not require truncation to simplify the explanation of the risk model. Alternatively, another solution is to not use these Alt forms of distributions for risks, and use SMEs or historical data to determine what the minimum value should be.

12.12 Number of Inputs: Ranges and Distributions

The FPRA approach uses two different numbers of inputs for setting cost ranges and simulation modelling:

a) number of cost ranges: to ensure uncertainties are identified and accurately quantified, the ranges on cost items should be quantified and assessed at the lowest level of first principles estimate, e.g. against quantum, productivity rates, or equipment
b) number of distributions: the information from previous cost ranges should then be aggregated to a higher level of the WBS. The distribution will be then applied against those items.

The rule of thumb when preparing a FPRA risk model is that the number of simulation inputs should be reasonably limited, and commensurate with the level of detail applied in the Base Estimate. In other words: the level at which inherent risks can be reasonably quantified and also well understood in terms of possible correlations. The model can have as many variables and inputs as needed so long as the way they interact is well understood and any correlations that exist are included within the model.

This Guideline recommends the assessment of uncertainties and ranges (for productivity rates and quantities) at the lowest level of estimate based on a first principles estimate. The overall impact of these ranges should then be aggregated to a higher level of the project WBS (e.g. WBS Level 4) before appropriate distributions and correlations are introduced, and a Monte Carlo modelling simulation is undertaken. Figure 47 (below) illustrates the process.

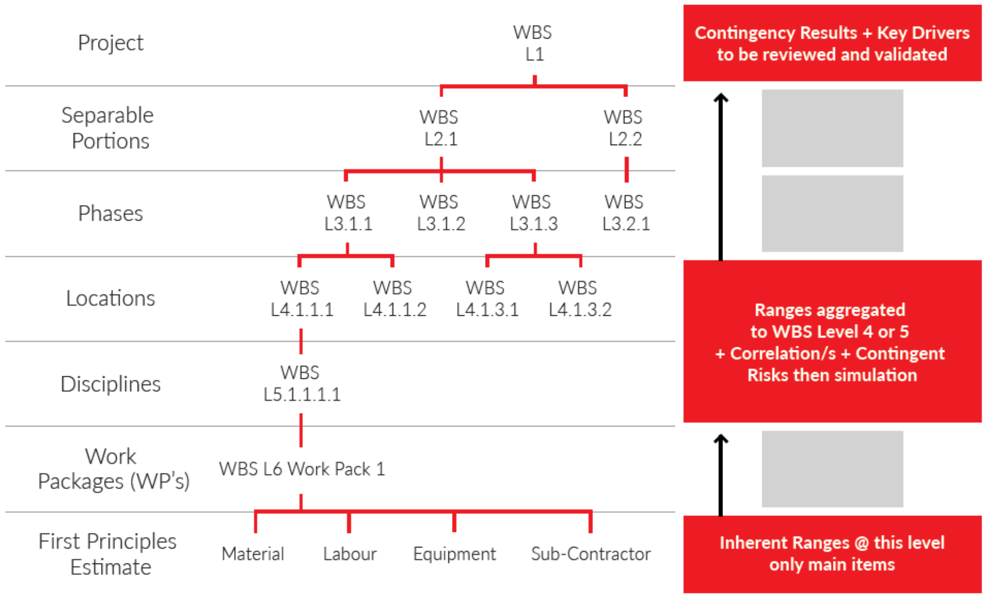


Figure 47: Brief illustration of FPRA flow of information

12.13 Sunk Costs

Sunk costs are the costs that have been incurred and cannot be recovered. For many acquisition decisions, funds that have been allocated and obligated in prior years are often deemed sunk though they have not been totally expended.

Sunk costs are often part of a lifecycle cost model because current and prior years are part of a project's total cost. Prior years' costs (and often current year's costs) should not have uncertainty distributions associated with them. In any event, it is essential to report both sunk and remaining Cost to Complete (CTC) when reporting cost in order to facilitate comparisons to project Cost at Completion (CAC) and previous estimates.

When sunk costs are in play, cost risk modelling can be complicated. There are many ways to approach the modelling task. The uncertainty for the initial estimate is generally based on an analysis of the Base Estimate resulting in Total Outturn Cost (TOC), not on costs-to-go from some point in the project. Subtracting the sunk costs from the total cost estimate to arrive at CTC may make sense. But defining how much of the uncertainty remains in the CTC portion is more difficult to assess.

This guideline recommends the process below when addressing sunk costs assigned to a specific element in the risk and uncertainty model:

a) Every effort should be made to estimate the CTC based upon the best assessment of performance so far and current and most likely circumstances ahead:
   - noting that the CTC should be the Base Estimate of remaining work at the time of assessment. Other methods of forecasting (e.g. trend analysis) may be also used to ensure CTC is representing the most likely circumstances similar to the Base Estimate at the beginning of the work
   - noting that the total point estimate changes (sunk plus cost-to-go) may not equal the original total point estimate cost. This should not discourage risk analysts from using this approach.

b) Divide the original uncertainty parameters by the point estimate cost to convert parameters to a percent of the original total point estimate

c) For cost items or activities with objective uncertainty:
   - use the results from the previous step to calculate the uncertainty parameters for the uncertainty on the CTC. Use a distribution of the same shape, but scaled to the CTC

d) For cost items or activities with subjective uncertainty:
   - consult with SMEs to assess uncertainty parameters
   - compare these ranges with the results from the previous step
   - select the most reasonable uncertainty parameters – RES recommends using conservative ranges.

e) If possible, obtain evidence to determine if the sunk costs are consistent with progress to date. Ideally, this assessment should be data-driven – for instance through analysis of earned value data. If the evidence is convincing, consider multiplying the scaled uncertainty by a positive or negative adjustment factor

f) Review the latest updated risk register and determine if any contingent risks associated with the element have been retired or changed – or whether they need to be included in the assessment of the CTC risk model

g) Complete the risk model with other key elements, e.g. correlations

h) Run the risk model

i) Review the results, revise the model (if required), and then finalise.

12.14 Simulation

Before finalising the risk model for simulation, there are other influences on simulation results that need to be reviewed and addressed properly.

12.14.1 Random Seed and Number Generator

The random seed is a number that sets the selection of numbers from a random number generator. Given the same seed, a random number generator will generate the same series of random numbers each time a simulation is run. For example, Palisade @RISK software – by default – picks a different random seed each time the simulation runs.

To avoid this, an initial random seed may be set by the user. However, if the location of various assumptions is changed on the worksheet, answers will still vary. Additionally, if other workbooks are open that contain separate risk models, this can influence the random seed assignments. Changing the random seed (either manually or by allowing the tool to do so) will cause the percentile results to vary on the order of 0.5%.

Furthermore, it is not possible to get precise matches across tools since each uses a different random number generator and different methods for assigning random seeds.

RES Recommendation: where possible, let the simulation software select a random seed initially and then fix this seed in the FPRA model. It is important to document the random seed selected and if choices are available, the random number generator selected. To promote consistency, RES recommends organisations define a set random seed and random number generator.

12.14.2 *Sampling Method*

Some tools allow the user to choose either Monte Carlo or Latin Hypercube sampling. Latin Hypercube draws random numbers more evenly and it will generally require fewer trials to obtain the same level of accuracy. RES recommends that the number of partitions equals the number of trials when using Latin Hypercube sampling. Doing so helps to ensure that the entire distribution is sampled with fewer trials.

RES Tips & Tricks: Palisade @RISK and ACE do not have a user setting for the number of partitions; both fix the number of partitions to the number of trials.

12.14.3 *Number of Iterations*

The number of iterations required to achieve reasonable accuracy is a function of many factors including:

a) the complexity of the functional relationships
b) the number of distributions being defined in the model
c) the degree of uncertainty applied
d) the number of defined functional and applied correlations.

A number of references suggest that 10,000 iterations are sufficient for most cost risk models and this number is a common practice in the cost and risk communities. However, most simulation tools have a feature to stop the simulation when selected convergence criteria are met. For instance, both Crystal Ball and @RISK will test the mean, standard deviation or a selected percentile to determine when the statistic is estimated to be within a user defined percentage of its actual value for a specified probability level.

Risk modelling software like Crystal Ball and Palisade @RISK provide a feature to run the simulation until predefined criteria are met on one or more of the model forecasts. The concept is to have the tool measure the chosen statistics and stop the simulation when the difference is less than a specified interval at a defined confidence level.

RES Recommendation: RES recommends that the 10,000 iterations be considered. While there is no reference for defining standard deviation convergence, 1.5% seems like a reasonable target as it generally takes at least a 1.5% change in standard deviation to impact percentile results by 0.5%.

RES Example: the criteria recommended by an organisation was: 95% confidence that the mean, standard deviation and 90 percentile are stable within 3% of their value. If this type of feature is to be used, this Guideline recommends that organisations should specify the required settings for their risk modeling across the enterprise.

RES Tips & Tricks: simulation settings such as sampling type (Monte Carlo vs. Latin Hypercube), random seed, correlation on/off and similar settings will have an impact on the simulation results. These and similar settings may not be saved with the model file. Organisations are encouraged to publish recommended settings for each tool that is used. Perform a convergence analysis to verify the number of iterations required to develop a stable result.

12.15 Escalation

An escalation allowance is necessary to provide adequate capital funding to compensate the project for likely cost increases, mainly within the construction sector, during the life of the project. The estimate of escalation is generally determined by applying an assumed rate of escalation for each financial year from the base date of the estimate through to practical completion. However, it should always be recognised that the overall escalation – if expressed as a percentage of the base estimate plus contingency – is in fact a function of the specific cost profile of the project and the rate of escalation in each year.

The escalation is based on the cash flow of the project estimate for both P50 and P90 values. Good industry practice recognises that escalation is calculated on cash flow by financial year using forecast percentage increases annually, compounded year-on-year. If a project includes a contingency that is based on risks, and those risks have associated costs, this may imply use of the same base-year dollars. And generally, performance periods can be associated with those risks within components, so, escalation may be applied to contingency.

However, if contingency is not easily discernable by WBS element (or cost elements) or cannot be associated with a time period, it may not be appropriate to escalate contingency. The accuracy of an escalation forecast can also be considered a risk, with appropriate cost impacts that are then included in contingency.

The Base Estimate comprises the sum of construction costs and principal’s costs, but excludes contingency and escalation. Escalation is the anticipated increase in project costs over time as a result of various factors such as inflation or market conditions. Most major projects take (on average) between three and six years to complete. Therefore, escalation plays an important role in the planning process because the value of the dollar changes, even though the project's estimate remains the same, which causes the project's price estimate to be low according to the new time frame.

However, most organisations require estimates to be expressed in out-turn dollars based on the project or program development and delivery schedule of development and delivery. While the determination of escalation is not part of the scope of this Guideline, the relationship between contingency and escalation determination is explained below.

When developing a project budget, estimate assumptions must be made on the future price of goods and services. These prices change over time because of inflation, market conditions, peaks and troughs in demand and legislative impacts. Future price changes must be applied to the project cash flow. Escalation is highly sensitive to predictions of market conditions, systemic changes, and the supply and demand of specific project inputs. Key historical indices or measures of cost movements used for future estimation of rates are available in industry publications and are produced by the Australian Bureau of Statistics.

These indices are based on observed historical data that is available for a range of specific components of the project, for example: concrete, cement and sand; petroleum and coal products; and steel. An estimator must use judgment to determine appropriate escalation factors for project-specific components and the overall escalation. In circumstances of volatility, escalation needs to be brought to the fore in the presentation of the project budget so that management can better understand the assumptions underlying the budget. Hence, the determination of escalation is based on the cash flow of the project.

As the project progresses, project cash flow will affect the cost base. Project teams need to consider the impact of lead times as escalation compounds each year. This discussion is generally more important for the major infrastructure projects in the early stages of development (e.g. preliminary and final business cases) for government and owners’ budgeting purposes.

While the subject of escalation determination is not part of this Guideline, the example below is provided for some clarity regarding the relations between the contingency and escalation allowances.

RES Example: there are different approaches to address determination and management of escalation allowance. RES recommends the practical approach below to address determination, allocation and control of escalation (this depends on factors including: the project specific requirements; project risk exposure to commodity price changes; and stage of the project (i.e. development or delivery):

Determination:

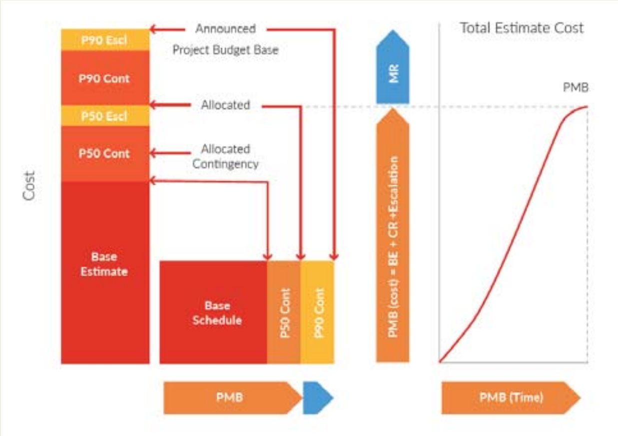
a) for small projects: the most likely escalation rates can be used reasonably

b) for major projects at the preliminary business case: most reasonable escalation rates can be used to produce the P50 escalation, and the pessimistic escalation rates as well as a full probabilistic escalation method can be used. For further details please refer to AACEi's RP 58R-10 "Escalation Estimating Principles and Methods Using Indices" and RP 68R-11 "Escalation Estimating Using Indices and Monte Carlo Simulation".

Allocation:

a) for small projects: escalation and contingency allowances can be added together to create the overall project contingency. This allowance can be split in two buckets (e.g. 60% and 40%) The first bucket should be added to the Base Estimate to generate the PMB for progress measurement and reporting. The second bucket should be kept and controlled outside the PMB.

b) for major projects:
   - Depending on the delegation of authority and access to project funding, appropriate allowances (e.g. P50 escalation and P50 contingency) should be added to the Base Estimate, then cash flowed against the P50 Schedule to generate PMB. Project progress will be then measured and reported against this PMB
   - This has been shown in the diagram below.



Controls:

a) for small projects: the second bucket (as explained above) will be kept and controlled outside PMB.

b) for major projects: after establishing the PMB, both P50 Escalation and P50 Contingency allowances will be taken out and will be controlled by using two distinct buckets. The remaining P90 Escalation and P90 Contingency will be managed as a MR by higher levels of delegation.

12.16 Exclusions

An attempt to include all possible outcomes of a project is likely to be futile. This is because a risk model is unlikely to account for all possible extreme events. The assessment should quantify the contingency required in order to achieve the project's objectives in most situations without trying to provide contingency for every eventuality. It may therefore be appropriate to exclude some risks from the probabilistic model, for example: additional scope that would change the nature and objectives of the project; 'acts of God'; delays to project funding; or changes to the nominated delivery strategy.

12.17 Other specific areas of concern

There are a number of other items that need to be assessed separately and in detail, then included within the FPRA risk model if required. These may include (but are not limited to):

a) risks related to property acquisitions
b) risk of foreign exchange variations
c) risks of financing costs and interest rate variations
d) organisational risks.

12.18 FPRA Report

The key elements of the FPRA report are:

a) key assumptions, model parameters and settings
b) exclusions
c) high consequence, very low likelihood risks – noting that in most projects, if these cannot be mitigated by insurance, should be clearly documented and presented to the Client as risks which have not been modelled, but which the Client must consider separately, not by setting money aside, but by deciding whether or not to take on the commercial risk
d) the process undertaken and workshops and review meetings held
e) probabilistic S-curve (e.g. P10, P50, and P90)
f) tornado graph (sensitivity analysis on both schedule and cost)
g) overall contingency and its allocation across work packages
h) supporting evidence – including risk model inputs and outputs, data sheets, correlations and interface matrix (if applicable), details of workshops and meetings held and attendees.

The final FPRA report should also present the overall contingency distribution (for both P50 and P90) between contract package breakdown (based on the delivery strategy) and interface risks between packages.

The required tasks for undertaking a CRA process should be discussed, agreed and included within the master development program. The program should include timing and responsibilities as well as inputs and outputs of the process. Key activities should include:

a) timing of key inputs (e.g. base estimate, base schedule, workshops)
b) cost risk modelling process and validation and sanity checks for iterative inputs
c) schedule risk modelling process and validation and sanity checks for iterative inputs
d) interface risk assessment between work packages (contract packages)
e) reviews (internal and external)
f) reports.

12.18.1 Output review and validation

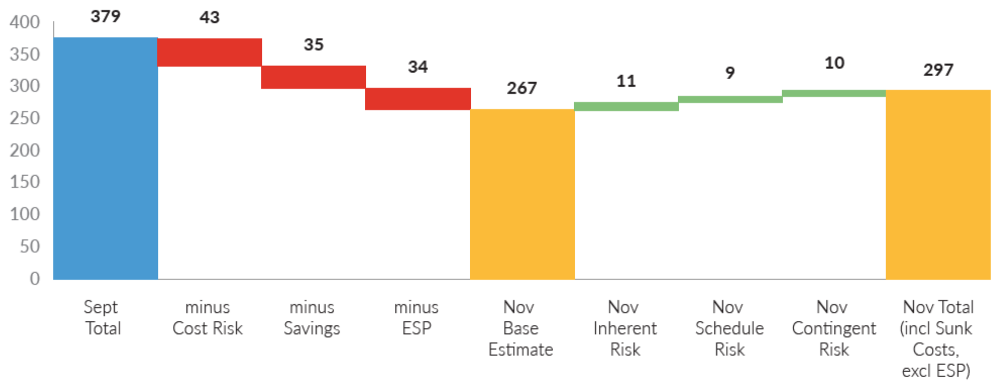
Key outputs and their interpretations should be validated through the iterative nature of the CRA process (as explained in the section above), so assumptions and inputs can be reviewed and revised if required.

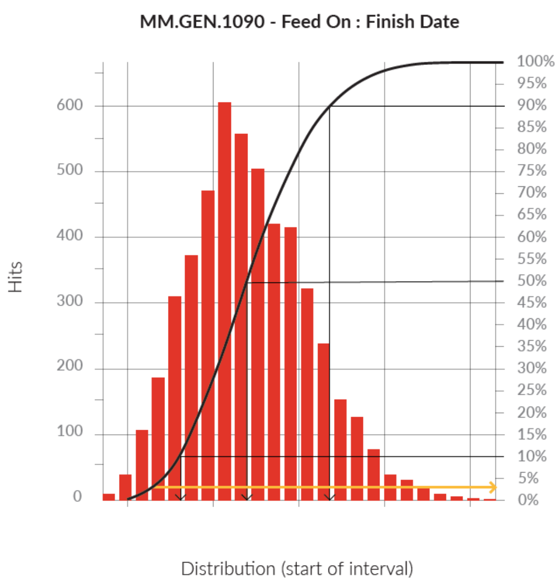
Following the final iteration of the probabilistic model and subject to the review and acceptance of key stakeholders, a report should be prepared to document the probabilistic assessment undertaken. The key probabilistic assessment outputs and their interpretations are:

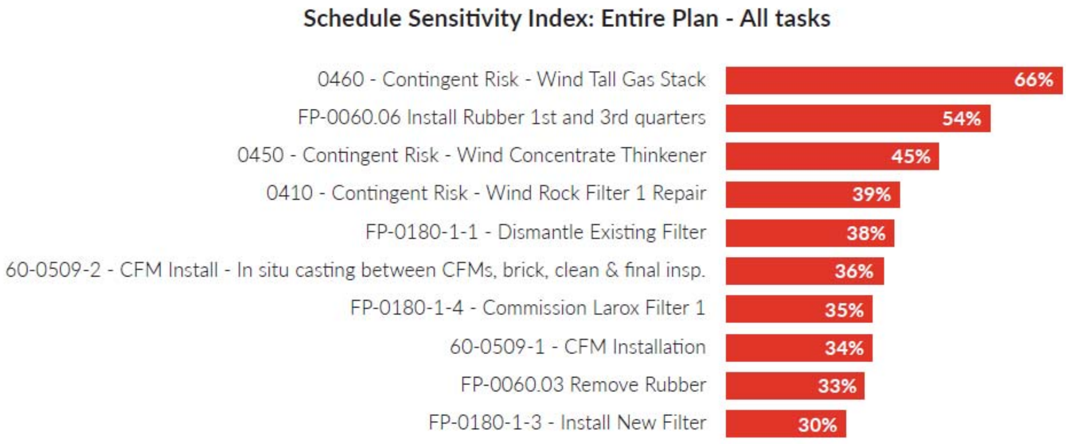
a) probabilistic S-curves
b) tornado graphs.

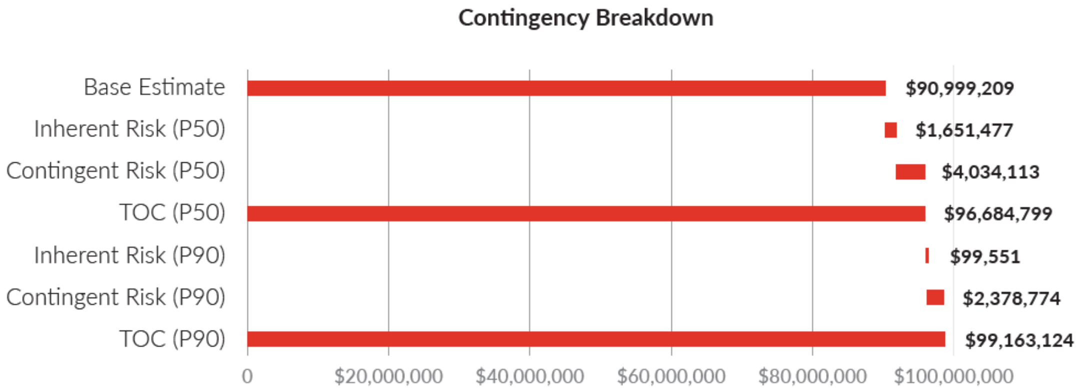
The most common probabilistic assessment output is a cumulative probability distribution graph (also known as an S-curve) or a histogram. This S-curve presents the final cost against probability of occurrence, while the histogram graphs the final cost against the number of 'hits' returned during the simulation. A very flat S-curve may suggest a project with a lot of risks. Conversely, a project with only a small amount of risks has a very steep S-curve. A tornado graph can also be used to report CRA outputs.

Different reports may be used to communicate the results of FPRA not only for management decision making but also to ensure the information being effectively communicated and understood by the project team. Figure 48 illustrates a few examples of reports.









PSC Contingency Summary				
Confidence Level	P_{10}	P_{50}	P_{90}	
Capex Retained Uncertainty	$3,064,438	$3,287,956	$3,492,693	37%
Capex Transferred Uncertainty	$ -	$ -	$ -	0%
Capex Retained Contingent	$1,707,211	$3,406,863	$5,850,736	63%
Capex Transferred Contingent	$ -	$ -	$ -	0%
Total Capex Contingency*	$4,771,649	$6,694,819	$9,343,429	100%
	5%	8%	11%	

*Note all costs are in DD/MM/YY

TOTAL CAPEX			
Base Estimate (Total Capex Excl. Contingency & Escalation) $86,865,335			
	P_{10}	P_{50}	P_{90}
Total Capex Incl. Contingency	$91,636,984	$93,560,154	$96,208,764
Escalation*			
Total Capex Incl. Contingency & Escalation	$91,636,984	$93,560,154	$96,208,764

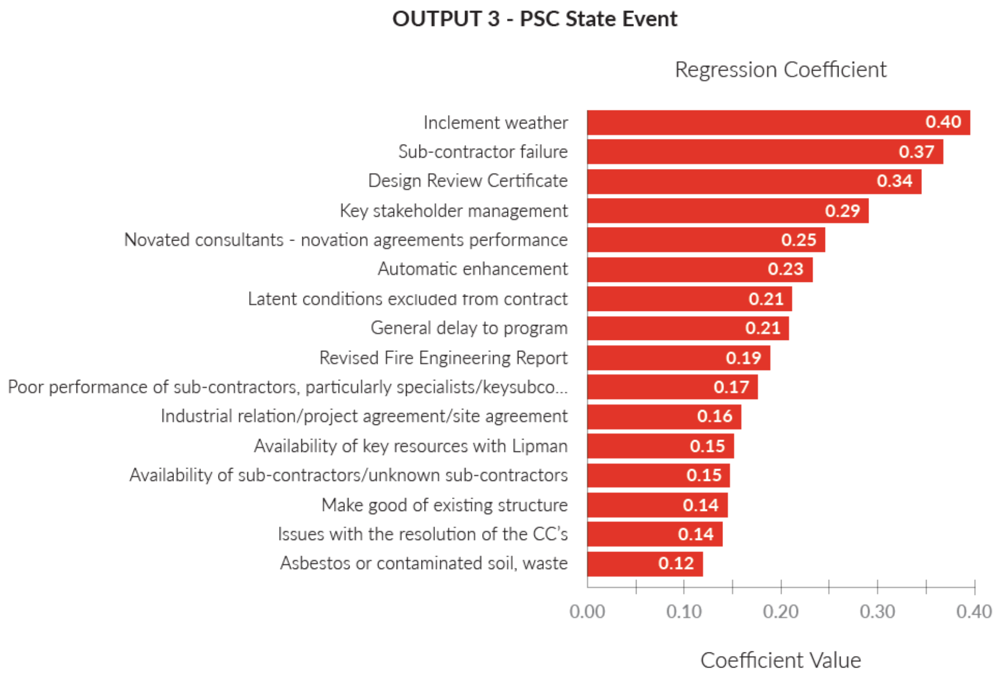


Figure 48: A number of different contingency reports of FPRA outcomes

12.19 Updating and documenting FPRA

A FPRA should be performed periodically as both the cost and schedule are updated to reflect actual progress on activity durations, sequences and costs. As the project progresses, risks may retire or change in potential severity and new risks may appear. The length of time between FPRA updates will vary according to project length, complexity, risk, and availability of management resources. This Guideline recommends that FPRA should be undertaken on a quarterly basis as well as at key decision points for major projects.

The FPRA and its updates should be fully documented to include the risk data, sources of risk data, and techniques used to validate the risk data. In addition, the methodologies used to perform the simulation should be detailed – and outputs such as a prioritised risk list; the likelihood of the project completion date; the activities that most often ended up on the critical path; and the derivation of contingency sufficient for risk mitigation should be documented.

RES Recommendation: RES recommends that a regular, no longer than quarterly, FPRA be undertaken for major projects during delivery phase, as well as key decision points during development, i.e. Preliminary and Final Business Case.

As well as providing an effective early warning indicator, as highlighted in Section 2.5.2, another benefit is identifying the confidence level trend as evidence for future claims and disputes.

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13. Appendix F – Integrated Schedule Cost Risk Analysis (iSCRA)

1.1 Purpose

In Integrated Schedule Cost Risk Analysis (iSCRA), the risk analysis of the cost estimate is conducted using the resource loaded project CPM schedule, where the project cost estimates (excluding contingency) are assigned to the schedule activities or summary groups. Then, the schedule and its cost expenditure are modelled using the MCS.

In the iSCRA model, time dependent costs (e.g. design costs) will increase if their activities take longer because of risks to the schedule. These include labour resources assigned to the activities, and supporting resources – including the project management team, who continue working until the schedule is complete. The typical process is illustrated in Figure 49.

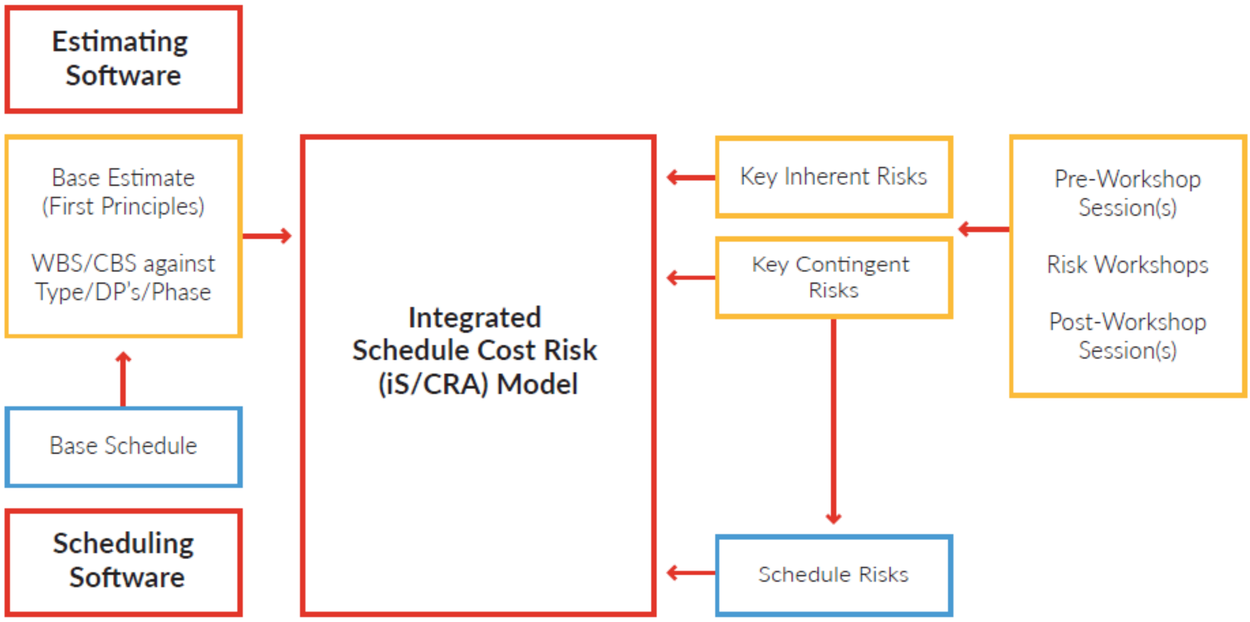

Figure 49: A typical process map for the Integrated Schedule Cost Risk Analysis (iSCRA) model

13.1 Overall process

The key elements of a realistic and reliable iSCRA in determination of a reasonable schedule and cost contingency for desired confidence level are:

a) schedule health check and rectification
b) Base Estimate
c) risk mapping to Base Schedule
d) cost mapping to Base Schedule
e) correlation and relationships between model inputs
f) building the iSCRA model
g) integrated analysis
h) output review and validation.

An example is illustrated in Figure 50 which assumes a construction project with weather risk exposure.

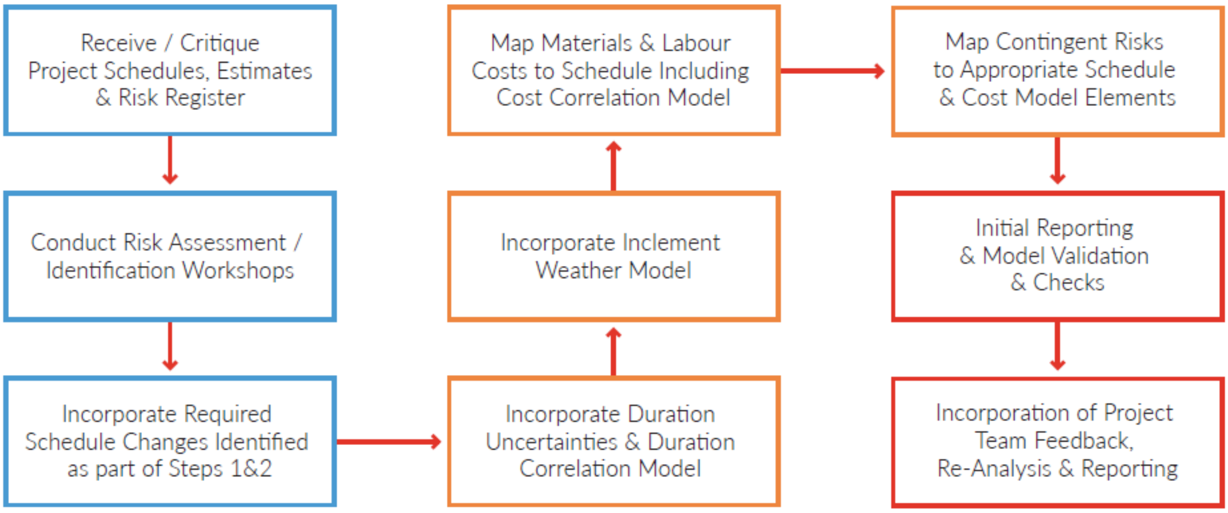

Figure 50: An example of iSCRA process for a construction project with wet weather risk exposure

The benefits of iSCRA include:

a) enabling the simultaneous analysis of probabilistic schedule and cost distributions incorporating all known and possible sources of time and cost uncertainty
b) enabling the probabilistic method of the cost consequences of schedule changes based on where and when they occur in each iteration
c) enabling the quantification and ranking of all driving sources of uncertainty.

13.2 Schedule health check and rectification

Refer to Appendix C.

13.3 Base Estimate

Refer to Appendix C.

13.4 Risk mapping to Base Schedule

Refer to Appendix C.

Depending the capabilities of software, different approaches may be used for mapping risks into the schedule, including:

a) put ranges against activity durations for representing inherent risks
b) create quantified risk register within the software then mapping the risks to relevant activities
c) create additional activities logically linked within the schedule
d) define risk factors, then mapping them to relevant activities
e) use a combination of risk factors, range of activity durations and contingent risks.

13.5 Cost/Resource loading to Base Schedule

The project estimate can be overlaid on the project schedule in a series of hammock activities (tasks that change in duration according to the durations of the tasks to which they are linked without taking part in critical path calculations).

The line item costs are a mixture of variable (time dependent) and fixed (time independent) costs, all of which are uncertain at the start of the project. The proportions (or splits) of fixed and variable costs must be accurately known or estimated for each line item. This is necessary so that the summarised variable costs – when spread over the applicable groups of tasks in the schedule – can vary realistically due to duration changes. Variable costs can vary due to task duration changes and also due to uncertainty in their rates. For example, labour and equipment hire rates may be uncertain at the start of the project. Costs and/or resources can be loaded into different schedules or levels depending on available data and project specific requirements. These requirements could include:

1. allocating costs and/or resources into activities within the detailed schedule
2. allocating costs and/or resources into hammock/summary activities within the detailed schedule
3. allocating costs and/or resources into a high level schedule built from the detailed schedule.

13.6 Correlation

Correlation models are developed to ensure that groups of activities and resources that behave in related ways are represented realistically in the iSCRA model. This extends to risk factors that vary in related ways, such as productivity risk factors for different disciplines. Correlation inputs are essential instructions to the modelling tool to correct the inherent assumption of the complete independence of all inputs, and to enable the model to forecast realistic probabilistic spreads of schedule and cost. A more detailed discussion of correlation is provided in Appendix E.

13.7 Building the iSCRA Model

The iSCRA model is built from the following:

a) a carefully reviewed and technically corrected schedule, or a model network constructed for the purposes of the risk analysis
b) an overlaid summarised estimate
c) schedule and cost ranges inputs
d) schedule and cost correlation models
e) mappings of the treated cost and schedule impact risk events and risk factors
f) probabilistic calendars e.g. wet weather (usually derived from historical data) assigned to appropriate tasks where the project involves risk-exposed activities.

13.8 Integrated Analysis

The analysis is usually performed at least twice and sometimes three or more times. The number of analyses depends on the complexity of the model and how much the client wants to optimise the risk profile of the iSCRA model and thus the project. The key point is that changes in inputs to the model depend on the wishes of the project team in reviewing the results and what the sensitivity rankings reveal about the schedule drivers and the underlying logic.

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13.9 Output review and validation

The iSCRA report should include the following sections:

a) executive summary
b) description of methodology
c) assumptions and exclusions
d) deterministic and probabilistic results for key milestones and summary costs
    - drivers of key results
    - discussion of results
    - conclusions and recommendations
    - appendices of inputs and outputs of the analysis.

13.10 Software requirements

Software for iSCRA must offer fast simulations, be able to handle resource-loaded schedules of several thousand tasks, and run simulations of required iterations efficiently.

Good planning capabilities are also essential – as complex models take significant time to build. The software should be able to perform changes to schedule logic for the treated risk-mapped and cost-loaded schedule model, and not require complete rebuilding of the model from an external planning tool. The software should have a comprehensive range of modelling capabilities, including:

a) percentage probability of task existence, which can be correlated with the existence of other tasks
b) probabilistic branching and probabilistic links
c) percentage lags (where the lag in a dependency becomes a percentage of the duration of the predecessor or successor, or both)
d) resource and duration uncertainty with a wide range of distribution types
e) ability to create chains of multiple threats and opportunities with link to a parent task.

The software must also have sophisticated and statistically reliable correlation models which can be applied to the iSCRA model – both duration and cost and preferably multi-level. The assignment of correlation should be performed using coding and not be restricted to individual assignment at the task level.

The software should be capable of building time and cost impact risk factors, with families of risk factors able to be correlated to each other – for example, the productivity of different disciplines within a project.

It should be possible to assign probabilistic weather calendars to weather-exposed tasks. Preferably, the weather distributions should be able to be built as discrete distributions based on historical weather data.

Finally, it is preferable that the software selected for the iSCRA includes an application programming interface (API) that enables the user to add analysis and reporting functionality to the software, and to incorporate decision making within iterations, without slowing the iterations unacceptably.

14. Appendix G – Australian Government and Contingency

This appendix contains information quoted from government websites and documents accessed on the date of publication of this Guideline. It is recommended that the sources be regularly checked for any updates.

14.1 Federal Government

14.1.1 The Treasury

Information in this section is quoted from <www.treasury.gov.au>. It should be noted the information below might not be relevant to contingency for individual projects or portfolios of projects as it relates more to aggregate budget estimates.

Contingency Reserve (CR)

The Contingency Reserve (CR) is an allowance, included in aggregate expenses, principally to reflect anticipated events that cannot be assigned to individual programs in the preparation of the budget estimates. The CR is designed to ensure that aggregate budget estimates are based on the best information available, and are as close as possible to expected outcomes at the time of the release of an economic and fiscal outlook. The CR is not a general policy reserve.

Allowances included in the CR are not appropriated and can only be drawn upon once the relevant appropriation legislation has been passed by Parliament. These allowances are removed from the CR and allocated to specific agencies for appropriation closer to the time when the anticipated events eventuate.

In addition to allowances for anticipated events, the CR may also include measures that reflect Government decisions that were either made too late in the estimates process for inclusion against individual agency estimates, or are commercial-in-confidence or national-security-in- confidence and therefore cannot be disclosed explicitly in portfolio estimates.

In general, the Contingency Reserve can include:

a) commercial-in-confidence and national security-in-confidence items that cannot be disclosed separately, and programs that are yet to be negotiated with State and Territory governments, for instance, Commonwealth provisioning for unfunded superannuation liabilities for New South Wales universities;
b) the effect on the budget and forward estimates of economic parameter revisions received late in the process which were unable to be allocated to individual agencies or functions, in particular the impacts of the September quarter national accounts;
c) decisions taken but not yet announced by the Government, and decisions made too late for inclusion against individual agency estimates; and
d) provision for other specific events and pressures that are reasonably expected to affect the budget estimates, for instance, provisioning for unfunded public service redundancies and critical funding shortfalls for the operations and capital requirements of some agencies.

Conservative Bias Allowance (CBA)

One of the largest components of the CR is the conservative bias allowance (CBA). This is an allowance for the tendency for estimates of expenses for existing Government policy to be revised upwards over time. This is of particular importance for demand driven programs where precise cost estimates are difficult.

The allowance is set as a percentage of total general government sector expenses (excluding GST payments to the States). The rates applied across the Budget and forward estimates are reviewed periodically by Treasury and Finance. The CBA is reduced for earlier forward estimate years as program estimates are progressively updated, thereby decreasing the bias.

Drawdowns (which are reflected as reductions) of the conservative bias allowance are treated as parameter variations and are consistent with long standing practice. Such adjustments do not realise any actual budgetary savings, nor offset Government spending measures, as the CBA is always reduced to zero prior to the commencement of the budget year. That is, the CBA does not affect the accrual level of government spending — it is only a device to improve the accuracy of the forward estimates.

Other allowances that may be included in the CR

Allowances may also be made for other anticipated events including:

a) a provision for underspends in the current financial year reflecting the tendency of budgeted expenses for some bodies or functions not to be met; and
b) provisions for events and pressures that are reasonably expected to affect the budget estimates.

14.1.2 *Department of Infrastructure, Regional Development & Cities*

Information in this section is quoted from two sources:

a) The Notes on Administration for Land Transport Infrastructure Projects
http://investment.infrastructure.gov.au/files/investment_road_and_rail_programme/NoA_Jan_2016.pdf
b) The Cost Estimation Guidance
http://investment.infrastructure.gov.au/about/funding_and_finance/cost_estimation_guidance.aspx

For land transport infrastructure projects for which Australian Government funding is being sought, the Department of Infrastructure and Regional Development (the Department) requires that a probabilistic cost estimation process be used in preparing cost estimates for projects with a total anticipated Outturn P90 cost (including contingency) exceeding $25 million.

For projects with a total anticipated Outturn P90 cost (including contingency) under $25 million, a deterministic methodology may be used; however, the Department recommends using a probabilistic cost estimation method where possible.

The Department will review and assess the project cost estimate (including the cash flows by financial year and project phase) provided in the associated Project Proposal Report (PPR), before making a recommendation to the Minister.

Guidance on the preparation of the PPR and associated cost estimation requirements are outlined in the Notes on Administration for Land Transport Infrastructure Projects 2014-15 to 2018-19 (the NOA) which provides administrative guidance for managing projects to be funded under The National Partnership Agreement on Land Transport Infrastructure Projects (the NPA). The NPA requires project proponents to provide access to underpinning data, and to cooperate with any review undertaken. As such, proponents must maintain an electronic library of all documentation consulted in determining the Project Estimate.

As specified in the NOA, cost estimates accompanying a PPR must be prepared in accordance with the principles outlined in the Department's Cost Estimation Guidance and presented using the Department's Road and Rail Project Cost Breakdown (PCB) templates.

The Department's cost estimation Guidance Notes which, in aggregate, will constitute the Cost Estimation Guidance referred to in Appendix B to the NOA, are progressively being developed and, following public consultation, will be published on the Department's website.

14.2 States & Territories

14.2.1 New South Wales (NSW)

NSW Treasury and Infrastructure NSW (INSW)

Information in this section is quoted from two sources:

a) NSW Treasury <https://www.treasury.nsw.gov.au/sites/default/files/pdf/TC14-29_Management_of_Contingency_Provisions_for_Major_Projects.pdf >
b) INSW http://www.infrastructure.nsw.gov.au/media/1266/insw_contingency_management_guidebook_-_february_2014.pdf

Agencies seeking approval for new major infrastructure projects (with an estimated total cost over $100 million) are required to identify the amount of contingency provision, controls and delegations proposed to manage those funds and monitoring and reporting arrangements.

In addition to organisation's internal assurance processes, it is a mandatory requirement of the NSW Treasury that all General Government agencies and Public Trading Enterprises (PTEs), except State Owned Corporations (SOCs), are required to identify the amount of contingency provision and the controls/delegations proposed to manage the release of the provision for new major infrastructure projects when seeking project approval through the Cabinet Standing Committee on Expenditure Review (ERC).

The Treasurer (as the Chair of ERC) will explicitly approve:

a) the amount of contingency provision allocated with regard to the project risk profile
b) the controls and delegations proposed to manage the release of the provision.

A major project that is considered high risk might warrant the Treasurer controlling/holding a proportion of the contingency funds or delegating this responsibility to the Portfolio Minister. Other projects with a lower risk profile could be managed with delegations for the use of contingency funds set at lower levels (including Head of Agency and or Project Director/ Manager).

Infrastructure NSW (INSW) provides advice to the Treasurer as to the adequacy of the contingency funds allocated and the controls proposed. INSW also reports on the use of contingency for major projects to the Cabinet Standing Committee on Infrastructure (CIC) every two months.

To enable Treasury and where requested by the Treasurer, INSW, to assess the proposed amount of contingency and the controls and delegations, project business cases or project identification submissions should:

a) provide details of how the contingency has been determined with reference to the determination method (e.g. deterministic or probabilistic), risk profile of the project, the investment lifecycle stage, the delivery method, the risk allocation and other key aspects of the business case
b) propose and provide a rationale for the delegations and controls, consistent with the risk profile, the business case and the governance arrangements for the relevant project, delivery entity and owner
c) provide details of arrangements for regular monitoring and reporting contingency requirements and performance throughout the investment lifecycle.

Transport for NSW (TfNSW)

Information in this section is quoted from Transport for NSW's Risk-based Cost Contingency (3TP- PR-157/1.0). The reference document is intended to supplement the methodology for assessing contingency described in the Project Cost Estimating Standard (4TP-ST-173). This document applies to all project staff that are responsible for the determination of their project Total Outturn Cost (TOC) and/or Forecast Final Cost. To determine a risk-based contingency, the document requires the development of an itemised cost estimate. The risk based model then captures essential parts of the project cost estimate for risk modelling with contingency proportionate with risk.

The risk based contingency model captures an allowance for main two aspects:

a) Inherent Risk – uncertainty within individual cost items of the cost estimate
b) Contingent Risk – additional risks not considered in the cost estimate

Roads and Maritime Services (RMS)

The Roads and Maritime Services' Project Estimating Manual is designed to assist Roads and Maritime staff and industry partners engaged to estimate Roads and Maritime major infrastructure construction projects.

http://www.rms.nsw.gov.au/business-industry/partners-suppliers/document-types/guides-manuals/project-estimating-manual.html

In summary, for Strategic Estimate, e.g. Preliminary Business Case, RMS requires appropriate contingency to be added to each component of the project estimate. RMS highlights that at the strategic estimate stage for major infrastructure projects and for projects classified as KIPs, contingencies in the range of 35% to 70% are appropriate. Contingencies outside this range must be justified.

To determine an appropriate contingency for a strategic estimate a review of risk elements is recommended by RMS. Each of these elements must be reviewed and due consideration must be given to the reliability and confidence of the information used to calculate the estimate. The elements of risk and the range of contingency are shown below.

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Risk element	Percentage points
Project scope	9% - 15%
Risks	9% - 15%
Constructability	6% - 8%
Key dates	3% - 5%
Information	9% - 15%
Length of project	4% - 10%

At concept estimate stage, e.g. Final Business Case, for major infrastructure projects and for projects classified as KIPs, contingencies in the range of 25% to 40% are appropriate. Contingencies outside this range must be justified. At the detailed estimate stage, for major infrastructure projects and for projects classified as KIPs, contingencies in the range of 15% to 25% are appropriate. Contingencies outside this range must be justified.

When a probabilistic estimate is requested, RMS requires two estimates to be prepared, i.e. Aggregate P90 and Fragmented P90. The Aggregate P90 cost estimate is the value that is produced when the appropriate probability distributions have been allowed for each element of the estimate in the simulation. The simulation generates a cost distribution spread for the total cost of the project, from which the P90 value must be selected as the appropriate total project estimated cost.

The Fragmented P90 cost estimate is the value that is produced when the appropriate probability distributions have been allowed for each element of the estimate in the simulation. From the simulation, a distribution spread must be generated for each subtotal.

14.2.2 Victoria (VIC)

Information in this section is quoted from the Department of Treasury and Finance's Investment Lifecycle and High Value/High Risk Guidelines – Preparing Project Budgets for Business Cases Technical Guide and it applies in all cases where the Victorian Government requires a business case to be prepared.

<https://www.dtf.vic.gov.au/investment-lifecycle-and-high-value-high-risk-guidelines/technical-guides>

Currently (as of 2018), business cases are required for all projects costing $10 million or more in total estimated investment (TEI), including High Value/High Risk (HVHR projects have a TEI of $100 million or more, or have an identified high risk) projects. This applies to all projects and asset-related proposals seeking funding through the budget process, and for government business entities, for those proposals that require the Treasurer's approval. This guide applies to all projects regardless of any preferred procurement option such as Partnerships Victoria, alliance contracting or any other procurement arrangement.

In presenting recommendations for the base risk allocation and contingency amounts in the project budget, the agency will need to employ judgment and a test that involves the notion of likelihood. Agencies are required to provide sufficient justification in the business case for both recommended amounts.

A selection of different risk estimation techniques has been recommended.

Technique	When to use
Simple scenario analysis (or expected value technique)	Small projects, often repeatable, that are well understood and relatively simple to implement. The risks can be readily identified/analysed using limited time and resources. (Simple scenario analysis (or the expected value technique) involves considering different possible scenarios, estimating the likely effect they will have on the project and the probability they have of occurring. The level of exposure on a particular risk is given by the effect the scenario has on the project, multiplied by the probability of its occurrence.)
MERA (multiple estimating using risk analysis)	Small to medium-sized projects where risk is a feature but relatively well understood and not very material to the project budget. (MERA analysis is the extension of the simple scenario analysis technique to consider multiple different possible scenarios, estimating the likely effect these will have on the project and the probability that they have of occurring. The level of exposure on a particular risk is given by the sum of the combined effect each scenario has on the project, multiplied by the probability of its occurrence.)
Sensitivity and scenario analysis	Typically used to test underlying assumptions and in particular where simple and MERA analysis is used. The test involves changing the underlying assumptions and analysing the sensitivity of total risk estimates to that change. Sensitivity and scenario analysis can also be combined with stochastic simulation, although less often because simulation automatically builds in sensitivity and multiple scenario considerations.
Stochastic simulation techniques like Monte Carlo or Latin Hypercube	Medium to large-sized projects for which the risk analysis is important. Suitably qualified expertise and reviewers must be used to conduct and verify the use of such techniques.

The justification must include a rationale for the contingency that provides an appropriate upper limit for the total project budget 'beyond the most likely value for all risks' (i.e. the base risk allocation). This upper limit must provide a realistic estimate that the project cost is unlikely to exceed (and not an easy target).

A purely statistical representation of risk (using stochastic tools) is insufficient evidence to justify either the contingency or the base risk allocation. While such tools may provide supporting analysis for setting the estimates they must also be supported by a rigorous and in-depth rationale, including the capability of the project delivery team, the 'sense check' and sign off by management.

14.2.3 Queensland (QLD)

QLD Treasury

Information in this section is quoted from the Queensland Government Treasury.
https://www.treasury.qld.gov.au/growing-queensland/project-assessment-framework/

The Government's decision makers, primarily Cabinet, the Cabinet Budget Review Committee (CBRC) and the Ministers and Chief Executive Officers of Departments, require consistent, transparent and accurate information to:

a) align agencies' policies, projects, programs and activities to the Government's stated priorities
b) prioritise individual projects within programs
c) ensure that their project procurement and resource allocation decisions achieve maximum value for money
d) benefit for the State.

Rigorous and robust project evaluation will materially help in delivering on these requirements. In this context, the purpose of the Cost-benefit analysis guidelines is to assist analysts, across the whole of the Queensland Government by providing:

a) a standard methodology and approach for cost-benefit analysis
b) a guide to undertaking the analysis

Department of Transport and Main Roads (DTMR)

Information in this section is quoted from the Department of Transport and Main Roads estimating policy. https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Project-cost-estimating-manual.aspx

The Infrastructure Cost Estimating Policy (estimating policy) requires all cost estimates for Department of Transport and Main Roads infrastructure projects to be completed in the format prescribed by the Project Cost Estimating Manual (PCEM). This includes all state and federally funded projects including road and rail, black spot and bridge renewal programs. The purpose of this policy is to maintain the consistency, accuracy and high level of confidence required in transport infrastructure project cost estimates.

TMR estimating policy has been founded on five key principles in order to achieve these objectives:

a) Estimates are created in accordance with the requirements of the department's Program Management Framework (PMF), OnQ project management methodology, Work Breakdown Structure (WBS) and Main Roads Specifications (MRS).
b) All estimates are prepared on an "unlikely to be exceeded but not excessively conservative" basis for various stages of the project lifecycle to provide confidence in project priority, affordability and strategic fit.
c) Estimates are to be presented using the prescribed estimate document format which highlights the elements of the estimate structure and relevant project cost attributes.
d) Estimates are subject to a review and approval process to ensure accountability, responsibility, costing standards and controls are applied to any budget that is to be released.
e) Estimate performance will be ascertained at all funding approval points.

14.2.4 Western Australia (WA)

Department of Treasury

Information in this section is quoted from the Department of Strategy Strategic Asset Management Framework – Business Case.
www.treasury.wa.gov.au/uploadedFiles/Treasury/Strategic_Asset_Management/14_SAMF_Business_Case.pdf

The Department requires that the contingency estimate must be robust, based on careful consideration of the risks that are specific to a particular option and its elements.

The contingency is based on sound logic, benchmarks and reasons as to the amount that should be set aside specifically for each cost item and its associated risks. For example, the contingency to address an unexpected increase in the salary of an ICT specialist would be based on: current salary + future labour supply and salary projections (in competition with the private sector). The information to support this work is publicly available.

Department of Finance, Building Management and Works (BMW)

Information in this section is quoted from the Department of Finance, Building Management and Works (BMW).
www.finance.wa.gov.au/cms/uploadedFiles/Building_Management_and_Works/Policy/project_cost_planning_guidelines_for_consultants.pdf

Department's Project Cost Planning Guideline is part of the BMW Cost Management Services 2011 Panel arrangement 210757/11. The Guideline contains information specifically written to assist cost consultants in preparing and reporting on project costs for non-residential building and infrastructure projects. The cost plan provide a consistent reporting format and shall be used when presenting cost plans and estimates for review, analysis, evaluation and key performance measurement. The Department acknowledges that it is important to recognise that in the project cost, specific contingencies are identified at key points in the project's development as follows:

- Client/Planning Contingency

Allow up to 10% of Total Construction Cost, depending on uncertainty (ie, the level of definition of client requirements). For example, the Department of Education has well documented scope requirements including defined functional area briefs for its new primary school and high school developments. In discussion with the Department of Education, the contingency provisions should be reduced for such projects. This is particularly relevant with new primary schools (and additions) due to the detailed specifications available to consultants through the Primary School Brief.

This contingency is:

a) applied until certainty of accommodation schedule is achieved, which depends on when final users are included in the decision-making process (may be as late as Schematic Design). It is not for scope changes.
b) for additional floor area over and above the business case/PDP accommodation schedule, and is not to be used for any other purpose unless there is a floor area component.

By completion of the Project Definition Plan (or Schematic Design if final user input is delayed to that point), the planning contingency must be reduced to $0 (applied in full or part).

The Client/Planning contingency does not appear in the PDP Cost Plan, with any carry over amounts for Schematic Design added to the Design Contingency.

- Design Contingency

Allow up to 20% of Total Construction Cost, to reflect the preliminary nature of scope and design definition at this phase. This contingency is:

- progressively reduced until construction documentation is completed and all "unknowns" have been discovered.
- for design issues that were unforeseen during the planning process. Uncertainty is greater in refurbishments than in new builds.

By tender, the design contingency must be reduced to $0 (applied in full or part).

- Construction Contingency

Allow 3% to 10% of Total Construction Cost for managing construction uncertainty. This is not an errors and omissions contingency. Construction uncertainty will be higher in older building refurbishments, additions or new buildings in existing facilities which may necessitate the upgrading of some aspects of the existing infrastructure and contingency may need to be increased to reflect this.

14.2.5 South Australia (SA)

Department of Treasury and Finance

Information in this section is quoted from the Department's Guideline for the evaluation of public sector initiatives – Part A: Overview.
https://www.treasury.sa.gov.au/__data/assets/pdf_file/0018/36315/ti17-guidelines-part-a.pdf

Full compliance with these guidelines is required where a proposal has an estimated cost equal to or more than $11 million unless otherwise exempt from Treasurer's Instruction 17 approval requirement (Treasurer's Instruction 17 provides exemption to these approval requirements, typically for commercial sector project(s) undertaken by a public corporation provided that the project is included in the corporation's capital plan and that the plan is endorsed as part of the annual performance statement required by section 13 of the Public Corporations Act.)

Department's 'Guideline for the evaluation of public sector initiatives – Part B: Investment Evaluation Process, https://www.treasury.sa.gov.au/__data/assets/pdf_file/0019/36316/ti17-guidelines-part-b.pdf)' requires that for each risk, the probability of the risk occurring and its potential cost impacts should be assessed and quantified. Note the project budget (step 4 in the investment evaluation process) requires the determination of a monetary amount to be held as a contingency to cover the potential costs incurred should an identified risk eventuate.

Determining risk estimates is best based on a combination of professional judgment and previous project data where available. A number of different risk estimate techniques are well documented ranging from simple scenario analysis to Monte Carlo simulation technique. The extent to which risk analysis is undertaken and the potential contingency amounts required depend on the complexity of the proposed solution. Generally:

a) for most routine public sector projects such as school buildings and simple road developments, reference can be made to corporate history and the contingency amount for project risks would typically be between 5 to 10% of the total project budget estimates
b) for more complex or larger projects that are not regularly undertaken by agencies, expert advice may be required for assessing the project risks which would typically be between 15 to 20% of the total project budget estimates
c) for other one-off and high risk projects, the project risks may be greater than 20% of the total project budget estimates.

Agencies should ensure that they do not over-identify and over-estimate the risks associated with delivering the preferred solution. An informed and experienced view should be taken of the construction and design industry's capability and expertise in delivering such projects and advice within the time and cost estimates should be sought accordingly.

Consideration of which party, that is, the investor (government), client (lead agency) or supplier, is best able to manage the risk may also be required for developing strategies designed to reduce and manage each risk and determining the potential budget impacts should the identified risk eventuate.

Department of Planning, Transport and Infrastructure

Information in this section is quoted from the Department of Planning, Transport and Infrastructure.
https://www.dpti.sa.gov.au/__data/assets/pdf_file/0003/173532/Estimating_Manual.pdf

The Department's Estimating Manual sets out the approach, processes and standards for the preparation, review and acceptance of cost estimates. The manual introduces standard processes, forms and a work breakdown structure to guide estimators, project managers and planners in the consistent production and review of estimates.

The manual is applicable to all road and rail projects over $150,000, and applies to estimates owned by and prepared for:

a) Planning Division (PD)
b) Transport Services Division (TSD)
c) Public Transport Service Division (PTSD).

When assessing inherent and contingent risks probabilistically, P50 and P90 values are calculated using risk analysis software. P50 and P90 values are to be calculated for the following estimates when prepared by members of the estimating panel:

a) Level 3 – Preliminary Concept Estimate
b) Level 4 – Concept Estimate
c) Level 5 – Preliminary Design Estimate
d) Level 6 – Detailed Estimate.

Where estimates at these levels are prepared by DPTI staff inherent and contingent risks are assessed deterministically and therefore will produce only equivalent P50 and P90 values.

14.2.6 Tasmania (TAS)

Department of Treasury and Finance

Information in this section is quoted from the Department of Treasury and Finance.
http://www.treasury.tas.gov.au/budget-and-financial-management/guidelines-instructions-and-legislation/budget-guidelines/structured-infrastructure-investment-review-process-(siirp)

The Department's 'Structured Infrastructure Investment Review Process (SIIRP)' is a review and assessment process for General Government Sector infrastructure investment proposals. Infrastructure investment proposals will be subject to a series of decision points prior to being considered for funding and will be required to meet reporting requirements during the development, and following the completion of, the project.

At each of the points an assessment is made as to whether the project should: proceed to the next stage; require further details to be provided for further assessment, or not proceed if the project is not supported at the present time. The SIIRP consists of four decision/reporting points:

a) Investment Concept and Options Analysis
b) Business Case
c) Budget Committee Consideration
d) Project Review – Closure and Benefits Realisation.

Agencies should confirm the processes to be used for estimating, monitoring and controlling project expenditure as well as any provisions for contingencies factored into the Budget.

All capital and recurrent cost estimates must be detailed in the business case as the business case is the basis for the Treasurer's and Budget Committee's decision making. The processes to be used for estimating, monitoring and controlling project expenditure should be confirmed as well as any provisions for contingencies factored into the Budget.

14.2.7 Northern Territory (NT)

No specific reference to contingency management within Northern Territory (NT) was identified at the time of this publication.

14.2.8 Australian Capital Territory (ACT)

No specific reference to contingency management within Australian Capital Territory (ACT) was identified at the time of this publication.

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