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Cost Risk Framework

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Abstract

This document describes a framework that is designed to standardize the identification, analysis, and reporting of a project's cost risk within the Department of National Defence (DND) and Canadian Armed Forces (CAF). While there are extensive academic and industrial standards on risk identification, analysis, and reporting, the distinguishing characteristics of this framework are its particular emphasis on DND/CAF operating environment, the constraints of existing public service policies, and stakeholder's unique requirements. These important public sector considerations include: the Data Readiness Level metric to measure the availability of data for risk assessment; a checklist to link the Chief Financial Officer's attestation process to the selection of appropriate visualization and reporting techniques; and the contextualization of cost risk in DND as a subset of the Government of Canada's own challenge of funding its policies and programs within available fiscal room.

Significance for Defence and Security

The Department of National Defence is one of the largest departments in terms of the management of large scale projects and is already extensively involved with the management of projects/procurement cost risks. However, it has been identified that, in the absence of a singular guidance instrument, cost risk management activities may be relatively diffused and inconsistently applied. This can lead to suboptimal approaches. This framework brings a degree of objectivity to the discussion of cost risk factors, their estimation, and reporting. It also enables cost analysts to apply standard cost risk assessment criteria that are consistent with both the academic and industry standards.

Résumé

Dans ce document, nous pésentons un cadre visant à normaliser l'identification, l'analyse et le signalement des risques liés au coût d'un projet du ministère de la Défense nationale (MDN) et des Forces armées canadiennes (FAC). Bien que les milieux industriel et universitaire regorgent de normes concernant l'identification, l'analyse et le signalement des risques, notre cadre se distingue par le fait qu'il s'applique tout particulièrement à l'environnement opérationnel du MDN et des FAC, et qu'il tient compte des contraintes découlant des politiques en vigueur dans la fonction publique et des besoins uniques des parties intéressées. Les aspects les plus importants liés au secteur public sont : la mesure de la disponibilité des données pour l'évaluation des risques; une liste de vérification pour faire le pont entre le processus d'attestation par l'agent principal des finances et la sélection des techniques appropriées de visualisation et de production de rapports; et la contextualisation des risques associés aux coûts au sein du MDN afin de refléter à plus petite échelle les difficultés qu'éprouve le gouvernement du Canada pour financer ses politiques et ses programmes à l'intérieur de la marge de manuvre financière dont il dispose.

Importance pour la défense et la sécurité

Le ministère de la Défense nationale est l'un de ceux qui gèrent le plus de projets de grande envergure; il déploie déjà des efforts intenses dans la gestion des risques liés aux coûts des projets et des achats. Cependant, nous avons déterminé que sans outil d'orientation unique, les activités de gestion des risques liés aux coûts peuvent être relativement diffuses et menées de façon incohérente. Cela peut mener à l'adoption de méthodes peu efficaces. Le cadre que nous proposons permettra de jeter un regard objectif sur les facteurs de risques lis aux coûts ainsi que sur les questions relatives aux estimations et à l'établissement de rapports sur les coûts. De plus, les analystes des coûts s'appuieront désormais sur des critères d'évaluation des risques conformes aux normes des milieux industriel et universitaire.

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1 Background

In 2012, the Deputy Minister (DM) of National Defence articulated the modernization of defence governance. Specifically, the DM introduced the Chief Financial Officer (CFO) and emphasized that the Assistant Deputy Minister (Finance & Corporate Services) organization be solely responsible for financial management and oversight within the Department. This governance modernization ensures that activities are managed by the proper organization, provides clearer lines of accountability, and streamlines DNDs financial management and business planning processes. Since this implies the centralization of all departmental financial management and oversight, the standardization of financial analysis, procedures and reporting within Department of National Defence (DND) and the Canadian Armed Forces (CAF) is a necessary step.

Consequently, preliminary meetings between CFO and Assistant Deputy Minister Science and Technology (ADM S&T) were held in March 2014 to discuss potential research and analytical support toward the development of a DND framework on cost risk assessment and reporting. Specifically the meetings focused on:

1. The rationale for focusing on risk assessment,
2. Types of risks (financial, scheduling, etc.),
3. The phases of the life cycle that need to be examined, and
4. Adherence to existing guidelines and framework such as those of the Treasury Board Secretariat (TBS) and other central agencies.

The meetings between CFO and ADM S&T staff highlighted the importance of the CFO attestation process and its narrower focus on financial risk as opposed to the wider risk environment that includes scheduling, technological, and related risks. The meeting also highlighted the importance of developing a framework that is sufficiently generic to include all life cycle phases. Within this scope, it was agreed to focus on three components of cost risk:

1. Cost Risk Identification,
2. Cost Risk Analysis, and
3. Cost Risk Reporting.

While there are extensive academic and industrial standards on risk identification, analysis and reporting, these will be adopted within the constraints of existing public service policies, DND/CAF operating environment, and stakeholder requirements.

2 Outline

As discussed earlier the subsequent chapters in this document follow the three components of cost risk: identification, analysis and reporting. These three components are closely linked to each other and the level of detail both in the quantity of risks identified and the quality and quantity of data collected impact the robustness and effectiveness of the cost risk assessment for decision support. We begin with a brief introductory chapter that outlines the DND cost risk framework aim and scope. Chapter two, authored by Mr. Ghergari from the CFO organization, provides the key principles and tools and techniques for risk identification. In addition, the chapter includes various annexes on cost risk categories and taxonomy. Specifically the chapter provides guidelines for cost risk analysts in the selection of personnel to be involved in the identification of risks, in the identification of data requirements, the selection of tools and techniques for structuring interviews and engaging Subject Matter Experts (SMEs) and the documentation of the identified risks for assessment.

Risk assessment, the focus of Chapter three, deals with the quantification of the likelihood and consequence of the identified cost risks. Authored by Drs. Ghanmi and Sokri from the ADM S&T organization, the chapter outlines the type of cost risk analyses to be undertaken for identified risks. In addition it addresses if and how contingency should be calculated and assigned based on quantified risks. While this chapter considers leading standards and recent academic developments in estimation methods and techniques, these are discussed within the constraints of existing public service policies, the operating environment and stakeholder requirements. The chapter also develops guidelines for applying appropriate statistical and operational research techniques applicable throughout the program lifecycle, and improve existing risk assessment methods. The choice of the analytical techniques can be either qualitative (risk analysis where the likelihood and impact of a risk outcome are presented using an interval scale and a non-numerical label such as high, medium, low) or quantitative (risk analysis that assigns fixed numerical values to both the likelihood and impact of an outcome).This choice of analytical technique is crucially dependent on data availability both at the risk identification stage and the project under consideration.

Consequently, one of the key contributions of this chapter is the concept of the Data Readiness Level (DRL) metric to measure the availability of data for risk assessment. This metric will be indispensable for cost risk analysts as they navigate through the chapters exhaustive lists of qualitative and quantitative approaches.

It is recognized that risk information has little or no value in-and-of-itself but only gains value through its use, to promote and support sound decision-making. In the real world, we cannot manage a risk which we do not understand ourselves. Further to this, since most risks are managed in a group setting, risks cannot be managed which we cannot explain or communicate effectively to others.

The last chapter in this framework document deals with the matter of risk communication, including the "human engineering" aspects thereof that is matters of how salient risk information can be formatted and presented to decision-makers in a manner which is efficient, effective and meaningful. Authored by Mr. Rempel from the ADM S&T organization, the chapter on cost risk visualization and communication also tap into the existing literature on both the psychology of risk, which deals with how people understand information, and visualization, which relates the facilitation of the communication of risk information.

While the literature review contained in this chapter provides the basis for assessing and selecting appropriate visualization and reporting techniques, the CFO attestation framework outlined by TBS is the main driver. Specifically, the chapter outlines seven items that ought to be included in a cost risk report in response to key assertions from the CFO attestation framework.

As stated earlier, this guide (DND cost risk framework), which is complementary to existing departmental and central agencies' guidelines seeks to facilitate a systematic costs risk identification, assessment and communication to support risk-informed decision-making. It is intended to be a tool for the benefit of hands-on DND/CAF personnel, engaged in cost risk identification assessment/analysis and communicators or, more generally, DND/CAFs "Cost Risk Managers". The framework is expected to be updated regularly to reflect changes in policy, strategic directions and new methodologies. It is also hoped that the user group (i.e., cost risk management practitioners) will provide feedback and suggestions for improvement.

The chapter authors acknowledge the support of the Cost Risk Assessment and Reporting Working Group members for providing the background research, review and discussions that led to the finalization of the framework chapters. In particular, the cost risk identification chapter was supported by Mr. Dana Beaumont, Major Jill Archibald, Ms. Lindsay Janota, and Mr. Jason Heyes. Support to the cost risk assessment chapter was provided by Dr. Bohdan Kaluzny, Mr. Kamal Jayarathna, Mr. Derrick Pockiak and Lieutenant Commander Kim Poirrier. The chapter on cost risk reporting and visualization was supported by Ms. Shannon Adams, Mr. Peter Iburg, and Mr. Rodney Anderson. Additional research support was also provided by Mr. Keith Murchison (Contract Community Inc.).

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Scope and Assumptions

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1 Strategic Context

Risk is defined in Canada and internationally as "the effect of uncertainty on objectives"[1]. While other relevant definitions from Committee of Sponsoring Organizations of the Treadway Commission (COSO), TBS and DND/CAF differ in the inclusion/exclusion of positive impacts (consequences) they all agree on the association or effect of risk on objectives. It is therefore relevant to discuss the objectives of an organization along with risks (Rempel, 2014). The objective of DND and CAF in relation to its major asset acquisition activities (or acquisition projects) is to be equipped and "mission ready" in a timely, efficient, and cost-effective manner. As a public institution it is also expected that DND/CAF addresses stakeholder expectations consistent with the direction of the Minister of National Defence (MND).

With regards to the latter, it is recognized that DND/CAF spends significant public funds on its important projects and acquisitions, and is accountable – through the Minister of National Defence – to a diverse array of stakeholders/members of the public, etc. It is necessary that its use and management of public funds stands-up to public scrutiny and is aligned with international best practices, Government of Canada policies, directives, etc. - including but not limited to those set-out in TBS guidance instruments, etc[2].

While the scope for the cost risk framework is limited to DND/CAFs project level, it should be noted that the overall strategic context for conducting cost analysis assumes that DND is just a subset of the Government of Canada's own challenge of funding its policies and programs within available fiscal room. At a strategic level, the Federal Government policies are often communicated, in broad terms, through the Speech from the Throne. Allocating specific funds through the Federal Budget (often announced a few months after the Speech) operationalizes the specific priorities outlined in the Speech. While the Speech gives the general short-term direction of the Federal Government, policy statements and White Papers provide more precise expectations and directions of the central government to specific departments or policy areas. The 2005 Defence Policy Statement (DPS) and the 2008 Canada First Defence Strategy (CFDS) are key documents that provide the context for defence.

Using these policy documents, the Department employs a strategic management tool to link government policies to departmental activities. Specifi-

[1] From ISO 31000.

[2] For example, as found at http://www.tbs-sct.gc.ca/tbs-sct/rm-gr/guides/girm-ggirtb-eng.asp.

cally, Capability Based Planning (CBP) provides the tools through which the Defence Services Program can be linked to government policy and expectations. CBP is employed through a process that creates scenario specific force-wide capability goals or future force options. This begins with a forecast of the Future Security Environment (FSE) and consideration of a Strategic Operating Concept (SOC). CBP then examines each scenario under the lens of the FSE and determines which capabilities and capacities will be required in the future. Through this process CBP encourages innovation by moving away from equipment solutions early in the process and linking strategic goals to capability decisions. Indeed, by focusing on forecasted future capabilities and the effects that must be created, the tendency to simply upgrade existing systems and/or to replace platforms with newer versions can be avoided.

When DND conducts cost risk analysis on a given project x, the assumption is that x satisfies a capability deficiency identified through CBP, it is a means by which certain military effects are delivered and alternative projects have been compared before choosing x.

The cost risk analysis discussed in this framework, therefore, assumes that a cost-benefit analysis has been conducted beforehand to compare the capabilities (effectiveness) and total cost of each alternative. It should be noted that during the capability gap analysis one still needs to compare the cost risk of different alternatives. Using the cost distribution for each alternative, one can asses which alternative project/capability is superior regardless of the funding (budget) level.

The assets which may be required to be used by DND/CAF to support the present and future assignments involve complex procurements which embody new or unique technologies, diverse and complex sourcing arrangements, etc. Even routine systems upgrades, new procurement of a relatively-common nature, etc. can involve uncertainties – while special projects and procurements generally involve even greater uncertainties with commensurate adverse or unexpected outcomes.

2 Links to Other DND Guides

Traditionally both in the private and public sector, cost estimates for projects used to be provided as a point estimate based on the most likely value (Mak et al., 1998). Uncertainties about the cost estimates, when acknowledged, tended to be a percentage estimate on the most likely value. These percentage additions or contingencies tend to be arbitrary and thus difficult to replicate or justify (Hartman, 2000).

DNDs Costing Handbook (of National Defence, 2006) and Project Approval Directive (PAD) (of National Defence, 2012) do provide general guidelines on how to assess data quality around cost estimates and apply contingencies depending on the level of government approval required for the project. However, it is not clear how data quality, cost estimates, project approval stages and contingencies are related or distinguished in these guides. Specifically, the DND Costing Handbook suggests confidence levels around cost estimates based on the quality of the data used to generate the base or most likely estimate. The PAD suggests a contingency amount (as a percentage of the total estimate) in accordance to TBS project approval stages and data quality. As an example, a project that is sufficiently mature (substantive) and ready for Effective Project Approval (EPA) is expected to have quality data to generate cost estimates that are about 80-85% accurate. Thus a project at EPA stage requires a contingency amount equal to the implied inaccuracy, in this example about 15-20%.

The purpose of this cost risk framework is to provide clearer definitions on cost risks and the processes for identification, analysis, and reporting of these financial risks. This framework brings a degree of objectivity to the discussion of cost risk factors, their estimation, and reporting. Finally the framework enables DND analysts to apply standard cost risk assessment criteria that are consistent with both the academic and industry standards. This is also in line with an internal review on capital project cost estimation that recommended clearer standards for contingency funding and cost estimation accuracy (Review Services, 2013).

3 Cost Risks

In this framework, and particularly as discussed in the risk analysis chapter (see Chapter 3), cost risk is defined using the Kaplan and Garrick (1981) quantitative definition. Specifically:

1. What is the cost risk (what could go wrong with the cost estimate),
2. What are the associated likelihoods (looking at cost overrun), and
3. What are the consequences (if the risk is realized or the consequences of a cost overrun).

How we identify, analyze, visualize or communicate the answer to these questions is the primary objective and scope of the framework. From the decision maker perspective, the answer to the first question (for example that the project exceeds the funds allocated) has several implications[3].

For the decision maker a cost overrun implies the need to request and justify additional funding to be held in reserve. This requires a portfolio rebalance within DND or worse a government-wide optimization exercise within a fiscal framework. Even a cost underrun (the actual cost of the project is less than the budget), which is not considered a risk, implies that a certain project within the DND portfolio is likely under budgeted.

This framework will not suggest or recommend a level of risk tolerance implied by the second question. The answer to the second question (likelihood of cost overrun) is essentially about how much the project manager or DND has in the budget. The relevant question is how much should the project manager or DND put in the budget? Assuming costs are approximately normal, the budget can be set at the mean. In this case the project manager is assumed to be comfortable with a 50% chance of exceeding the budget!

A cost overrun can be avoided by setting aside an amount greater than the mean. How much more than the mean? This is entirely dependent on the risk tolerance of the project manager, risk stakeholders of DND or even the Government. The higher the amount budgeted or the lower the risk tolerance, the clearer the signal that individual program cost overruns are unlikely. Having a large contingency may reduce the risk of overrun but from a DND wide perspective this implies fewer programs can be funded in the portfolio. In addition it implies that there are fewer incentives for program managers to control costs.[4]

The third question on the consequences of higher costs than projected, leads to consequences far beyond the project managers' domain. In defence the consequences often result in a reduction in the number of units purchased (essentially a reduction in capability) or a re-phasing through the purchase of less units over a given period. Since defence goods are produced for limited buyers (often a government department) by limited firms, cutting the

[3] According to the TBS Guide Risk Taxonomies, it is common for organizations to confuse drivers and risks. In particular, organizations sometimes refer to certain external circumstances (e.g., social, economic, etc.) as "external risks", when in fact they are drivers. To distinguish the two concepts, it is helpful for an organization to consider why the external circumstance challenges the organization, or why it presents an opportunity for the organization. Risk Drivers are conditions that exist in the environment (internal or external) that introduce risks. ("Given that"). http://www.tbs-sct.gc.ca/tbs-sct/rm-gr/guides/grt-gtr02-eng.asp#tocA.

[4] For a full discussions on such issues consult Defence Acquisition: New Insights from Transaction Cost Economics, Defense & Security Analysis Volume 24, Issue 2, 2008

quantity of units produced increases the unit cost, resulting in less capability, as fewer units can be purchased for a given budget. This is one of the reasons why cost risk identification often includes the assessment of learning and production quantity effects.

Ultimately costing and the associated cost risk assessment enhance decision making. Costing information provide relevant information for making budgetary decisions, milestone reviews, investment decisions and external reporting of expenditures. If the costing exercise indicates a funding shortfall, this may lead to a reduction in scope or capabilities and sometimes even the cancellation of the program. Another implication is that one program will be cut to fund another (higher priority) program as DND tries to maintain its portfolio of capabilities.

4 Aim

The aim of the framework is to develop a DND cost risk assessment and reporting guide with the three main components of cost risk: identification, analysis and reporting. It is also intended to improve the quality of cost risk management work and to support and promote effective project/procurement decision-making. Effective procurement objectives include among others, the prudent expenditures of public funds.

The management of cost risks is not an isolated activity undertaken at one discrete point in the project life by designated specialists. It is in fact a shared responsibility borne by all associated with the advancement of all significant projects/procurements, on a continuous basis – throughout the entire project life cycle. The framework will consider all life cycle cost phases but within the constraints of financial risks. While other cost risk factors can be identified during the risk identification phase, these need to be classified within the departmental governance and functional authority and their relationship to cost. This implies, for example, risks associated with scheduling should be tagged to the materiel or project office for scenario analysis, and CFO staff would only participate in determining the cost impact.

The framework is seen as complementary and not a substitute to the existing DND and TBS guidelines on risk. TBS has produced a wealth of guidance information both with respect to project management and risk management[5];

[5]Risk management involves a systematic approach to setting the best course of action under uncertainty by identifying, assessing, understanding, making decisions on, and communicating risk issues, is an integral component of good management. It does not

with an important array of very readable resources made available on its website. Note that TBS guidance on risk management is closely aligned with well-established international best practices in risk management codified under the ISO 31000 standard (Organization for Standardization, 2009). The fact that TBS endorses and encourages Canadian agencies and departments to flexibly adopt the ISO 31000 should facilitate a closer link with DNDs supply chain and allies in the development of risk management activities.

DND/CAF are already extensively involved with the management of project and procurement cost risks[6]. However, it has been identified that, in the absence of a singular guidance instrument, cost risk management activities may be relatively diffused and inconsistently-applied. This can lead to suboptimal approaches such as:

- The over-management of familiar risks, with commensurately less attention applied to less familiar sources of risk.
- The potential failure to account for lifecycle considerations in relation to Cost Risk management.
- The application of a "one-size-fits-all" approach, where large and small projects may be cost risk managed in a similar manner – not fully taking into account the necessity of adapting the cost risk process to address the special requirements of more complex, or unique projects.
- The potential for cost risk management to not be embedded into normal business practices, and connected to other planning and reporting processes.
- The potential failure to align cost risk management activities with best practices, applicable TBS guidance[7], etc.
- The failure to take into account the special significance of asymmetric costs risks, these being those cost risks which may have a perceived very low likelihood of occurrence, but a very high impact – if a risk event of this type were to occur.

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necessarily mean risk avoidance in the case of potential threats. Rather, risk management equips organizations to make decisions that are informed by an understanding of their risks, and ultimately to respond proactively to change by mitigating the threats, and capitalizing on the opportunities, that uncertainty presents to an organization's objectives - http://www.tbs-sct.gc.ca/tbs-sct/rm-gr/guides/girm-ggirtb-eng.asp.

[6] See DND and other government guidebooks, procedure documents and links detailed in Annex A of this chapter.

[7] Such as Treasury Board Secretariats (TBS) Framework for the Management of Risk.

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Cost Risk Identification

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1 Introduction

The purpose of cost risk identification is to recognize what can happen or what situations exist that may affect the achievement of the expected cost estimate. Cost risk identification is the process of finding, recognizing and recording risks that have the potential to impact the cost estimate.

Cost risk identification activities are a subset of the risk management process. As such, organizations should consider the same set of principles, but with an emphasis on elements that affect the cost estimate. More specifically, the generic criteria of:

1. What is being affected and what tools and techniques are required?
2. What type of information needs to be collected?
3. Who should be involved in the identification of risks? and
4. How identified risks should be documented for assessment purposes continue to apply, but with the cost estimate as the subject being investigated rather than the overall program.

The documents, tools, and techniques used in a generic risk analysis can be leveraged and/or utilized in cost risk analysis. For example, documents such as the Project Opportunity and Risk Assessment provide an initial set of risks to be considered while the Project Charter contributes to the contextual understanding of the project (Department of National Defence, 2007). In terms of tools and techniques, the risk register can be used as a cost risk recording tool while Brainstorming and Structured Interview techniques represent systematic team approaches to identify risks and complement, if required, the risk data needed to quantify cost risk (Vose, 2008).

Identifying cost risks is an iterative process, because new risks may evolve or become known as the project progresses through its life cycle. The frequency of iteration and participation in each cycle will vary by situation (Vose, 2008). A degree of pragmatism is implied in the identification of cost risks, especially in a public sector setting, where the effects of budget and affordability decisions are not stable. In technically complex defence projects, requirements continually evolve and thus need to be properly defined and taken into account. Finally, the effects of inherent errors in the cost estimating technique(s) used also need to be recognized.

The rest of this chapter is focused on the risk identification process and is structured as follows: Section 2 details the risk identification steps from a costing perspective; Section 3 highlights the documents produced as part of the project approval process and how they can be leveraged in cost risk analysis; Section 4 discusses the status of risk data and what techniques can be used to complement risk data, while Section 5 outlines how cost risk drivers and their characteristics should be recorded.

2 Cost Risk Identification Steps

The DND/CAF Integrated Risk Management Guideline outlines a six step process for risk identification, which can be applied to cost risk identification. This section will outline the risk identification steps and how they apply within the context of cost risk analysis (Department of National Defence, 2007).

The first step in the process is *the identification of "the primary mission/ objective that may be at risk"*. In the case of cost risk analysis, the "primary mission/objective" is the actual point estimate developed in the costing process. Costing is fundamentally a forecasting activity and is therefore uncertain, and sensitive to many factors[1]. Therefore, the point estimate resulting from the costing process has to be analysed in order to determine what could make it deviate from its calculated value (Department of National Defence, 2007).

The second step is the *decision on the necessary people, expertise, tools and techniques to complete the risk assessment*. The stakeholder composition and expertise will be determined by the type of identified risks. In most cases, participation by the project manager and project team members is assumed along with stakeholders and subject matter experts.

The cost risk analyses undertaken to date in D Cost S have shown that stakeholders with expertise in economics, operational research, decision sciences, project approval process, project management, and applicable industry and military environment knowledge have to be engaged in the risk analysis process. The decision on tools and techniques will be guided by the characteristics of the project. To date, data availability and project maturity have been the key characteristics to affect cost risk analysis and their impact is highlighted in the next two sections.

The third step is the *consideration of possible causes and scenarios to explain why/how risks might occur*. The causes of why/how risks might occur will vary by risk and project and have to be articulated on a case by case basis. A strong understanding of the internal and external project environment

[1]Page 8, Large Military Acquisition: Life Cycle Cost Framework, 2013, Treasury Board Secretariat.

will enable the articulation of the risk drivers and their causes and lead to the articulation of risk scenarios. The risk scenarios will be developed in conjunction with the risk subject matter experts and describe a reasonable impact of the considered risk.

The fourth step in the process calls for the *definition of the problems or opportunities, scope, context (social, cultural, scientific evidence, etc.) and associated risk issues and the fifth step is the performance of a stakeholder analysis (determining risk tolerances, stakeholder position, attitudes).* These steps are beyond the scope of cost risk analysis, as highlighted in the Scope and Assumptions section.

The last step is the identification of the risk owner and the degree of control that exists over the risk. For cost risk identification, risk ownership is synonymous with the stakeholder that has the subject matter expertise to advise on the particular risk driver. Given that the subject of the cost risk analysis is the point estimate, which in turn is subject to many exogenous variables, the risk ownership principle has a peculiar application in cost risk analysis. The salient information will be the identification of the stakeholder with the appropriate expertise to provide recommendations on the risk driver in question (see step one above), rather than the risk owner.

The second part, related to the degree of control that exists over the risk will inform the calculation of contingency. The level and type of control over the risk will determine whether or not the risk should be included in the calculation of contingency. If the risk is within the control of the department, the risk management action may not require a contingency. If, however, the risk is outside of the department's control, it will have to be included in the calculation of the contingency. The calculation of contingency is covered in the assessment section (Chapter 4) of the framework.

The risk identification process concludes with a formal documentation of the findings. The identified risks and pertinent characteristics are captured in a Cost Risk Register. The register organizes risks according to the TBS Guide to Risk Taxonomies, and is focused only on the characteristics required to conduct cost risk analysis. Section 5 of the chapter outlines the details of the risk register in the context of cost risk analysis.

3 Sources of Information

The risk management process is well articulated and supported by departmental and central agencies policies, including the Framework for the Management of Risk and The Guide to Integrated Risk Management from TBS, complemented by DND's policies as highlighted in the Project Approval Directive (Department of National Defence, 2014).

For consistency and alignment with these high level guides and directives project management offices produce extensive documentation. The documentation includes details of risk factors, description of the project scope, and information on schedule, resources and assumptions. Therefore, this documentation is the primary source in informing the cost risk identification process. Reviewing these documents will contribute to a better understanding of the project, broaden the analyst's perspective on possible risk drivers, and enable an initial compilation of cost risk factors and their characteristics.

In DND the project documentation requirements are outlined in the Project Approval Directive. Chapters 1 to 5 outline the required documentation at each phase of the project, while Chapter 7 outlines the expected content of the various documents. For the purposes of cost risk analysis, the following documents are most likely to capture information related to cost risk drivers:

1. Project Complexity and Risk Assessment (PCRA) – The PCRA is a TBS mandated document that provides the basis for determining the level of project risk and complexity. Its use assists in identifying areas of project risk and complexity warranting further assessment and active risk management. The PCRA covers project characteristics, strategic management risks, procurement risks, human resource risks, business risks, project integration risks and overall project requirements. It is important for cost analysts to utilize this assessment as a starting point in developing a cost risk register, with the understanding that the project requirements may evolve and/or change as time progresses.
2. Project Opportunity and Risk Assessment (PORA) - PORA is a departmental project document that provides detailed evidence of risk analysis and assessment. It identifies the main risks that can impact the project and any risks posed to the Programme by the project. This document (PORA) is an important source of identification of cost risk drivers and their characteristics, as cost risk is a subset of the overall project risk. However, it cannot be considered in isolation since it tends to only focus on acquisition risks. Therefore, depending on the purpose of the cost estimate (i.e., life cycle costing (LCC)) the set of identified risks will not cover LCC elements other than acquisition (Department of National Defence, 2014).

3. Project Charter - This is a document issued by the project initiator or sponsor that formally authorizes the existence of a project and for cost risk identification purposes includes information on:
   (a) Scope Baseline – Project assumptions are found in the project scope statement. Uncertainty in project assumptions should be evaluated as potential causes of project risk. The WBS is a critical input to identifying risks as it facilitates an understanding of the potential risks at both the micro and macro levels. Risks can be identified and subsequently tracked at summary, control account, and/or work package levels.
   (b) Activity Duration Estimates (Schedule) – Activity duration estimate reviews are useful in identifying risks related to the time allowances for the activities or project as a whole, again with the width of the range of such estimates indicating the relative degree(s) of risk.
   (c) Stakeholders – Information about the stakeholders is useful for soliciting inputs to identify risks, as this will ensure that key stakeholders, especially the stakeholder, sponsor, and customer are interviewed or otherwise participate during the Identify Risks process.

The documents outlined above are not a complete list of resources to be used in the cost risk identification process, but rather a starting point that leads to an initial list of cost risks, identifies stakeholders, and helps the cost analyst determine what tools and techniques should be used to progress the cost risk analysis.

The Cost Breakdown Structure (CBS) can also be useful for the identification of risk factors and in particular for determining if any correlations may exist between any two cost elements. The identification of potential correlations between cost risk factors that can exacerbate or attenuate the overall impact is probably one of the key outputs (Tummala et al., 1994) and should be noted in the risk characteristics. CBS can also complement the generation of historical and concurrent data for risk analysis by using its structure to identify similar projects. Furthermore, CBS could be used to identify potential risk factors by ‘checklists’ method or to describe risk factors for review and future reference.

4 Tools and Techniques for Risk Data Collection

Risk data are crucial to a successful analysis of risk. As detailed in the next chapter, data availability determines the method to be used for cost risk assessment and impacts the quality of the risk analysis. For example, the expected monetary value method can be based on qualitative data collected from subject matter experts, while econometric techniques require historical data of comparative programs. The characteristics of the data, such as possible bias of the subject matter experts in providing information for the expected monetary value method or lack of standardized program cost definitions for econometric techniques will affect the quality of the risk analysis (AACE, 2012).

The policy covering risk analysis in the public sector is relatively new; therefore, to date there has been little quality risk data collected. DND has been recognizing and documenting risk factors affecting projects in various documents, ranging from submissions to closet-out reports. However, a centralized source of risk factors and their impacts does not exist. Furthermore, risks and risk characteristics have not been captured using a standardized method, therefore their utility in risk analysis is low. In compliance with the TBS Guide on Risk Taxonomies, DND's risk management policies now recognize and call for risks to be recorded under specific risk categories (Treasury Board Secretariat, 2011). Furthermore, D Cost S is working on compiling a cost database that will provide the required information for cost risk analysis.

Various supporting techniques can be used to improve accuracy and completeness of available risk data, however, not all are applicable to cost risk analysis. In the absence of quality risk data, the information can be complemented by engaging and extracting information from subject matter experts. Therefore the goal is to choose a supporting technique that is designed to target experts (individually or in a group setting) in order to generate and collect information. ISO 31010 Risk Management identifies a number of supporting techniques, from Brainstorming to Human Reliability Analysis, however, only Brainstorming and its close derivatives (Structure and Semi-Structured Interview and Delphi technique) are designed to engage a group of experts for the purposes of generating and collecting information (ISO, 2009). The detailed description – including use, inputs, process, outputs, and strengths and limitation – of each technique is outlined in ISO 31010, and has been reproduced in Annex A for the applicable techniques.

To date, D Cost S has used Brainstorming, and Structured and Semi-structured interviews to support cost risk analysis. Brainstorming sessions often assemble a team (or teams) in a workshop setting and clarify workshop objectives and review background information. There is a need for a facilitator to ask, in a structured way, what the risks are by type, function, scope, or cost element. The facilitator[2] is also expected to encourage discussions, clarify the risks and insure input from all (ISO, 2009).

Through Brainstorming, D Cost S was able to confirm and enhance the list of cost risk drivers affecting the cost estimate, establish the criteria for scenario analysis, determine the probability of occurrence, and identify the impacted elements. Effective facilitation was paramount during the exercise. It included stimulation of the discussion at kick-off, periodic prompting of the group into other relevant areas, clarification of conceptual misunderstandings, and the articulation of issues arising from the discussion for recording purposes (Department of National Defence, 2013).

The Delphi method is also another popular risk identification technique but it has not been used extensively in DND. The Delphi method is most appropriate for those occasions where the required personnel are dispersed geographically, or where one cannot get everyone in a room. In such scenarios one has to send background information and request written input from identified participants; compile the information (names are confidential); reissue to the whole team for further comment; and then work to develop consensus (ISO, 2009). Projects of a sensitive or controversial nature may also benefit from the Delphi technique, which is a procedure to obtain a reliable consensus of opinion from a group of experts on an individual and anonymous basis. As views are anonymous, unpopular opinions are more likely to be expressed and therefore more likely to lead to quality risk data that will enable cost risk analysis.

Structured and Semi-structured have been used on few occasions, when the circumstances did not permit organizing a brainstorming session. In a structured interview, individual interviewees are asked a set of prepared questions from a prompting sheet which encourages the interviewee to view a situation from a different perspective and thus identify risks from that perspective. A semi-structured interview is similar, but allows more freedom for a conversation to explore issues which arise (ISO, 2009). D Cost S's experience with this type of support technique is mixed. While the type of information collected was similar to that in the Brainstorming exercise, in some cases

[2] The facilitator can be the CFO or his/her representative, project manager staff that is familiar with the project, etc.

the data was later found to be biased.

In general, the methods discussed above rely on group interactions and help clarify the relevant risks. But group dynamics are not without challenges. For example, managers may dominate the interaction that may lead to group think. Recent studies based on experimental data compared brainstorming sessions with other methods that emphasize debate and critiquing and showed that debate instructions were superior to traditional brainstorming in generating new and usable ideas (Nemeth et al., 2004). Thus risk identification often requires skills and knowledge of behavioural psychology because methods such as brainstorming and structured interviews must deal with participant biases.

The choice of the supporting technique will be determined by the circumstances of the project, and is not limited to those described above. In addition to choosing the technique to engage stakeholders, consideration has to be given to the composition of the group. The stakeholder composition will be largely dictated by the type of risks identified and could include individuals with varied backgrounds, including knowledge of project management, operations, project approval process, costing, economics, and financial management governance. The stakeholders involved would normally reside within DND and, especially on the program side, already be involved with the project (i.e., project manager, project director, program analyst, etc). However, if the required expertise is not found, the search could be expanded to consultants, academia, etc. Engaging the right stakeholders ensures that the risks will be comprehensively analysed and contribute to an unbiased assessment of risks.

5 Outputs

As data is being gathered, whether from existing sources or stakeholder engagement, the identified cost risks and their characteristics are recorded into a risk register in accordance with Treasury Board of Canada Secretariat's Guide to Risk Taxonomies.

5.1 Cost Risk Taxonomy

The guide defines risk taxonomy as a comprehensive, common and stable set of risk categories that is used within an organization. If the risk categories are common then one can aggregate the risks from across the organization.

Stable implies the risk categories of an organization can be compared over time. The use of cost risk taxonomy can help strengthen and better integrate the risk management approach.

The application of the Guide to Risk Taxonomies to cost risk results in a structure not dissimilar to a CBS. During the development of this framework, one of the sub groups performed an extensive review of risk categories that affect cost, including their description and components. The Guide to Risk Taxonomies, Project Approval Directive, and corporate and project risk profiles were among the documents reviewed. The emerging theme was a two tier risk structure, comprised of the risk category and examples of risks that fall within the category. Therefore, for the purpose of cost risk identification, risks are organized in a two level structure (category and subcategory). Cost risk categories and subcategories are expected to vary by project, however, for reference purposes a sample of cost risk categories and sub-categories are provided in Annex B.

5.2 Cost Risk Register

The Department of National Defence has developed and implemented a risk register that is mandated for use by the Project Approval Directive. For the purposes of cost risk recording, the risk register has been adapted to only capture the characteristics required for cost risk analysis.

The required fields for cost risk analysis are centred on the cost risk characteristic. Risks are organized on a risk category and sub-category basis as specified above. The cause field describes why the risk is expected to occur and the event outlines the scenario considered. The Office of Primary Interest (OPI) identifies the stakeholder with the subject matter expertise to advise on the risk driver. The probability field captures the likelihood that the risk would occur; and the impact section identifies whether the risk affects one or all of schedule, cost, and scope.

The last two columns of the risk register do not capture risk characteristics, rather, they provide information on the Data Readiness Level (DRL [3] and mitigation strategy, and therefore inform the direction of the risk analysis. The DRL will determine whether a qualitative or quantitative analysis has to be undertaken, and the chosen mitigation strategy will highlight if the risk has to be incorporated in the contingency calculation or if it can be managed otherwise.

[3] For a more detailed discussion on DRL, see the Cost Risk Assessment Methodology chapter in this framework.

The information captured in the risk register will be used to perform the risk analysis. The risk characteristics and DRL will inform the quantification of risk, while the mitigation strategy will determine whether a contingency is required as a risk management strategy. A cost risk register template is included in Annex B.

6 Conclusion

The cost risk identification stage sets the ground work for the remainder of the risk analysis. The key tenet of this stage is the subject of the analysis, which is the point estimate developed as part of the cost estimating process. Therefore the generic steps, documentation, and recording for risk analysis have to be interpreted and applied from a costing perspective.

The importance of cost risk identification is accentuated by the relatively recent introduction of risk analysis in the public sector. In the absence of high quality historical data on cost risk, the opinions and facts collected as part of this stage becomes the sole source of data to the risk analysis. As such, a thorough review of available documents and rigorous application of available tools and techniques are paramount in enabling a successful cost risk analysis.

The completion of the cost risk identification stage triggers the start of cost risk quantification and determination of required contingency. The next chapter, Cost Risk Assessment Methodology, details the processes to be followed.

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A Description of Tools and Techniques as per ISO 31000

A.1 Brainstorming

Brainstorming involves stimulating and encouraging free-flowing conversation amongst a group of knowledgeable people to identify potential failure modes and associated hazards, risks, criteria for decisions and/or options for treatment. The term *brainstorming* is often used very loosely to mean any type of group discussion. However true brainstorming involves particular techniques to try to ensure that people's imagination is triggered by the thoughts and statements of others in the group. Effective facilitation is very important in this technique and includes stimulation of the discussion at kick-off, periodic prompting of the group into other relevant areas and capture of the issues arising from the discussion (which is usually quite lively).

Brainstorming can be used in conjunction with other risk assessment methods described below or may stand alone as a technique to encourage imaginative thinking at any stage of the risk management process and any stage of the life cycle of a system. It may be used for high-level discussions where issues are identified, for more detailed review or at a detailed level for particular problems. Brainstorming places a heavy emphasis on imagination. It is therefore particularly useful when identifying risks of new technology, where there is no data or where novel solutions to problems are needed.

Brainstorming may be formal or informal, both using a team of people with knowledge of the organization, system, process or application being assessed. Formal brainstorming is more structured with participants prepared in advance and the session has a defined purpose and outcome with a means of evaluating ideas put forward. Informal brainstorming is less structured and often more ad-hoc.

In a formal process the facilitator prepares thinking prompts and triggers appropriate to the context prior to the session, objectives of the session are defined and rules explained, the facilitator starts off a train of thought and everyone explores ideas identifying as many issues as possible. There is no discussion at this point about whether things should or should not be in a list or what is meant by particular statements because this tends to inhibit free-flowing thought. All input is accepted and none is criticized and the group moves on quickly to allow ideas to trigger lateral thinking. The facilitator may set people off on a new track when one direction of thought is exhausted or discussion deviates too far. The idea, however, is to collect as many diverse ideas as possible for later analysis.

The outputs depend on the stage of the risk management process at which it is applied, for example at the identification stage, outputs might be a list of risks and current controls.

A.1.1 Strengths and Limitations

Strengths of brainstorming include:

1. It encourages imagination which helps identify new risks and novel solutions;
2. It involves key stakeholders and hence aids communication overall; and
3. It is relatively quick and easy to set up.

Limitations include:

1. Participants may lack the skill and knowledge to be effective contributors;
2. Since it is relatively unstructured, it is difficult to demonstrate that the process has been comprehensive (e.g., that all potential risks have been identified); and
3. There may be particular group dynamics where some people with valuable ideas stay quiet while others dominate the discussion. This can be overcome by computer brainstorming, using a chat forum or nominal group technique. Computer brainstorming can be set up to be anonymous, thus avoiding personal and political issues which may impede free flow of ideas. In nominal group technique ideas are submitted anonymously to a moderator and are then discussed by the group.

A.2 Structured or Semi-Structured Interview

In a structured interview, individual interviewees are asked a set of prepared questions from a prompting sheet which encourages the interviewee to view a situation from a different perspective and thus identify risks from that perspective. A semi-structured interview is similar, but allows more freedom for a conversation to explore issues which arise.

Structured and semi-structured interviews are useful where it is difficult to get people together for a brainstorming session or where free-flowing discussion in a group is not appropriate for the situation or people involved. They are most often used to identify risks or to assess effectiveness of existing controls as part of risk analysis. They may be applied at any stage of a project or process. They are a means of providing stakeholder input to risk assessment.

While utilizing scientific expertise in the design of interview questionnaire is the ideal recommendation, at a minimum a clear definition of the objectives of the interviews need to formulated. In addition, a list of interviewees selected from relevant stakeholders and a prepared set of questions should round out the minimum inputs for structured or semi structured interviews.

Questions should be open-ended where possible, should be simple, in appropriate language for the interviewee and cover one issue only. Possible follow-up questions to seek clarification are also prepared. Questions are then posed to the person being interviewed. When seeking elaboration, questions should be open-ended. Care should be taken not to lead the interviewee. Responses should be considered with a degree of flexibility in order to provide the opportunity of exploring areas into which the interviewee may wish to go.

The outputs are the stakeholders views on the issues which are the subject of the interviews.

A.2.1 Strengths and Limitations

The strengths of structured interviews are as follows:

1. Structured interviews allow people time for considered thought about an issue;
2. One-to-one communication may allow more in-depth consideration of issues;
3. Structured interviews enable involvement of a larger number of stakeholders than brainstorming which uses a relatively small group.

Limitations are as follows:

1. It is time-consuming for the facilitator to obtain multiple opinions in this way;
2. Bias is tolerated and not removed through group discussion;
3. The triggering of imagination which is a feature of brainstorming may not be achieved.

A.3 Delphi Technique

The Delphi technique is a procedure to obtain a reliable consensus of opinion from a group of experts. In addition to its advantages it confers on spatially constrained projects as discussed in the body of this chapter, an essential feature of the Delphi technique is that experts expressed their opinions individually and anonymously while having access to the other experts views as the process progresses.

The Delphi technique can be applied at any stage of the risk management process or at any phase of a system life cycle, wherever a consensus of views of experts is needed and requires only a set of options for which consensus is needed for input.

The process essentially involves a group of experts are questioned using a semi-structured questionnaire. The experts do not meet so their opinions are independent. The final output, after an iterative process, is the convergence toward consensus on the matter in hand.

The iterative process, which is both time consuming and labour intensive, involves activities ranging from the formation of a team to undertake and monitor the Delphi process to developing a number of rounds of questionnaires and the reconciliation of responses until consensus is achieved.

B Cost Risk Register

The columns in the cost risk register, shown in Table B.1, are defined as follows:

- **Category**: Identifies the risk category, as described in the TBS Guide to Risk Taxonomies.
- **Risk Title & Description**: Brief definition or description of the actual risk. The description of the risk should be such that someone not working on the project is able to understand what the risk is.
- **Cause**: Description of why the risk would occur.
- **Effect**: Describe the scenarios that impact cost.
- **OPI**: Identifies the subject matter experts for the particular cost element.
- **Probability**: Indicate the likelihood that the risk will occur using the score information in the Defence Integrated Risk Guidelines.
- **Impact**: Provide the impact of the risk on each of the cost, schedule, and scope of the project.

- **DRL**: Data Readiness Level.
- **Mitigation Strategy**: Describe how the risk will be managed.

Table B.1: Cost Risk Register.

Category	Risk Title & Description	Causes	Effects	OPI	Probability	Impact			DRL	MS
						Cost	Schedule	Scope		
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…

Cost Risk Assessment Methodology for Defence Acquisition Projects

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Contents

1 Introduction

In a time of tightening budgets, with operational requirements driving the need for accelerated acquisition schedules, defence leadership needs an early, independent, and agile approach for assessing risk to help make difficult program decisions. These assessments can improve acquisition studies, which will better inform decision makers of potential risks and provide insight to support trade space analysis and requirements development.

To improve the defence acquisition decision making process, the Department of National Defence (DND) has developed Integrated Risk Management (IRM) guidelines (Department of National Defence and Canadian Armed Forces, 2007). IRM is defined as a continuous, proactive, and systemic process to understand, manage, and communicate risk from an organiz-ation-wide perspective. It would support informed decision-making to achieve strategic objectives. Risk management is currently being practiced in many areas of DND. In many cases, the application of risk management is very mature while others have less well developed processes (Department of National Defence and Canadian Armed Forces, 2007). Typical examples of DND acquisition projects involving risk management include the F-35 Joint Strike Fighter (JSF), Canadian Surface Combatant, and Joint Support Ship.

While the IRM document provides a high level guide for risk management of DND acquisition programs, there are some important gaps in risk assessment methodologies that need to be addressed. Gaps include a lack of common risk taxonomies, inconsistent application of statistical cost assessment methods for acquisition risk analysis, lack of historical acquisition program and technology data to support all risk elements to improve robustness and confidence, lack of integrated approach for risk assessment, and lack of understanding of interdependencies between each risk element to support trade space analyses.

In an effort to close some of these gaps in risk assessment, the DND Chief Financial Officer (CFO) in collaboration with Assistant Deputy Minister Science and Technology (ADM S&T) staff is developing a risk assessment framework for acquisition programs. The framework would provide DND/CFO with best practices and guidelines for understanding of acquisition risk assessment methodologies. While there are extensive academic and industrial standards on risk assessment techniques, they should be adopted in the framework within the constraints of existing public service policies, DND/CFO operating environment, and stakeholder requirements.

The risk framework is being developed in three different phases. Phase I focuses on the cost risk assessment and Phase II undertakes the schedule risk assessment. Phase III considers both cost and schedule risks and integrates other aspects of operational and technical risks for acquisition programs to develop an integrated framework for risk trade space analysis. In general, the risk assessment process can be divided into three steps: risk identification, risk analysis, and risk presentation. The main focus of the first step is the articulation of the principles to be followed in risk identification, including the development of a common taxonomy that can be standardized within DND and central agencies, identification of cost risk factors, and specification of data requirements. The risk analysis aspect of the framework considers leading standards and recent research developments in risk estimation techniques to develop guidelines for applying appropriate statistical and operational research techniques in risk assessment. The risk reporting aspect of the framework focuses on the exploration of the leading methods for risk presentation, visualization and communication.

This chapter focuses on the cost risk phase of the framework and examines the best practice methods for conducting cost risk analysis. The chapter is organized as follows. Section 2 provides a state-of-the-art of the different analytical methods of risk assessment and Section 3 identifies the required data for conducting a cost risk analysis. Section 4 highlights some typical risk assessment measures and Section 5 concludes. An illustrative example of cost risk analysis is provided in Annex A.

1.1 Qualitative Approach

Qualitative analysis uses subjective judgements to prioritize risks for further analysis or action using ordinal scaling techniques. This is done by assessing each risk to determine how likely it is to occur (probability) and how the risk would affect the project objectives if it does occur (impact). These subjective judgments will reflect the attitudes of decision makers and stakeholders to risks. The qualitative risk analysis is a quick and cost-effective method of prioritizing risks. However, the analysis should be reviewed during the project's life cycle to stay current with changes in project risks. The process can lead to further analysis in planning quantitative risk analysis or directly to risk response. The main benefit of this method is that it allows decision makers to reduce the level of uncertainty about the project and concentrate on high-priority risks (Arena et al., 2006; United States Air Force, 2007; NASA, 2008; Hulett, 2012).

To conduct a qualitative risk analysis, it is important to understand the input data, the tools & techniques, and the output results of the analysis. Inputs to qualitative risk analysis would include:

- Organizational process assets. Information from past projects (e.g., project files, lessons learned).
- Project scope statement. Projects of a common or recurrent type tend to have less risk. Projects using state-of-the-art or first-of-a-kind technology or highly complex projects tend to have more risk.
- Risk management plan. Major items for qualitative risk analysis include roles & responsibilities, budgets and schedule for risk management activities, risk categories, definitions of probability & impact, and the stakeholders' tolerance.
- Risk register. List of the identified risks.

The tools and techniques for performing a qualitative risk analysis would involve:

- Risk probability and impact assessment. Uncertainty is the variance associated with the data and assumptions (NATO Science and Technology Organization, 2015). Risk in this guide is defined as a measure of the potential variation in achieving the expected objective. It is characterized by three elements: (1) a feasible detrimental occurrence, (2) the potential impact of this future occurrence, and (3) the likelihood (or probability) at the present time of this occurrence (Sokri and Solomon, 2013).
- Risk probability and risk impact may be described in qualitative terms such as very high, high, moderate, low and very low. Risk probability is the likelihood that a risk will occur. Risk impact is the effect on project objectives if the risk occurs, which may be a negative effect (threat) or a positive effect (opportunity). These two dimensions of risk are applied to specific risks, not to the overall project. The levels of probability and impact are assessed in meetings or by interviews. Participants include Subject Matter Experts (SMEs) and project team members. Details justifying the assessment should be documented. Risks are rated according to the definitions given in the risk management plan.
- Probability/impact risk rating matrix. A matrix may be constructed that assigns risk ratings (low, moderate or high) to risks based on combining probability and impact scales of a risk on a project objective. The organization must determine which combinations of probability

and impact result in a risk's being classified as high risk (red condition), moderate risk (yellow condition), and low risk (green condition). The risk score helps put the risk into a category that will guide risk response actions. Risks with high probability and high impact are likely to require further analysis, including quantification, and aggressive risk management (both threats & opportunities). Lower risks would require less emphasis and it may be enough to include them in a watch list for monitoring.

- Risk data quality assessment. The use of accurate data is necessary for a reliable qualitative risk analysis. Assessment involves examining the extent of understanding of a risk, data available about the risk, and reliability of data. The use of data of low precision, for instance if a risk is not well understood, may lead to a qualitative risk analysis of little use to the project manager. It may be necessary to gather better data.
- Risk urgency assessment. Urgent risks require urgent responses. Urgency can be addressed by including time of response as an indicator of priority. Other indicators may include symptoms and warning signs, as well as the risk rating.

The outputs from a qualitative risk analysis could be used to perform updates on the risk register, including:

- Relative ranking or priority list of project risks. Risks and conditions may be prioritized by their group category (high, moderate, and low).
- Risks grouped by categories. Responses can be more effective if root causes are dealt with directly.
- Urgent risks. List of risks requiring response in the near-term.
- List of risks for additional analysis and response. Some risks might warrant more analysis, including quantitative risk analysis, as well as response action.
- Watch lists of low priority risks.
- Trends in qualitative risk analysis results. As the analysis is repeated, a trend for particular risks may become apparent, and can make risk response or further analysis more or less urgent/important.

1.2 Quantitative Approach

Using a quantitative approach for project cost risk analysis provides the means to examine the impact of individual risks on the overall project cost and to estimate the requisite contingency reserve needed for cost risk. From a technical perspective, the quantitative risk analysis assesses the variability in the point estimate of a project cost using various operational research and statistical methods such as modeling, simulation, trends analysis, etc. While the determination of a point estimate cost of a project is beyond the scope of this chapter, this chapter highlights key cost estimation methods and more importantly clarifies the confusion between cost estimation methods and cost risk analysis methods. There are five primary methods for preparing cost estimates of public or private projects (Arena et al., 2006; United States Air Force, 2007; NASA, 2008; Hulett, 2012):

1. Analogy Method: The analogy cost estimation method is based on historical data and uses actual costs from one similar program (single point estimate) with adjustments to account for differences between the requirements of the existing and the new systems. The method can be used early in the program's life cycle when sufficient actual cost data is unavailable but the technical and project definition is good enough to make necessary adjustments.
2. Parametric Analysis Method: This method involves the use of parametric models to derive cost data from key cost driver factors the most influence cost such as product, weight, size, complexity, power, etc. In the parametric analysis method, a statistical Cost Estimating Relationship (CER) is developed between historical costs and program physical & performance characteristics (multiple point estimates).
3. Weighted Average Method: This method involves the evaluation of three or more similar projects to derive a weighted average in support of estimated costs. The rationale for determining the weighting criteria includes similarities between projects, accuracy of historical data, etc.
4. Technical Consensus Method: This method seeks group consensus for estimated resources using experienced, qualified personnel to prepare cost estimates and considerations. Technical consensus is used when no structured resource estimating model can be applied.
5. Engineering Build-up Method: This is a step-by-step, bottom-up description of task requirements and estimated resources for labor, materials, and other direct costs. An engineering build-up estimate is constructed at the lowest level of detail. Quantity and schedule must be considered in order to capture the effects of learning. While this method provides detailed cost estimations and gives good insights into major cost contributors of projects, it can be expensive to implement and it is time consuming.

The above analytical methods could be used to provide a point estimate cost of a project without adjustments for data uncertainties and project risks. The next step in the cost estimation process is to conduct a cost risk analysis. Cost risk analysis is the continuation and conclusion of cost estimation. In the literature, quantitative risk analysis methods can be grouped into: Statistical and Stochastic Simulation methods.

1.2.1 Statistical Methods

Statistical methods apply statistical techniques to historical data to derive a risk cost or a cost contingency for a project. The most long-established of them are the expected monetary value, the econometric techniques, and the scenario based method.

Expected Monetary Value:

The expected monetary value method estimates contingency as probability times consequence. This view reduces risk to the expected value of damage. Kaplan and Garrick (1981) found this viewpoint misleading because a single number is not a big enough concept to communicate the idea of risk. In particular, this technique would equate a low probability high-damage scenario with a high-probability low-damage scenario. Mak et al. (1998) compared the variability and consistency of the contingency estimates between percentage addition and expected monetary value. The authors concluded that using expected monetary value for public works projects reduces unnecessary and exaggerated allowance for risk.

Econometric Techniques:

Econometric techniques generally examine the effect of some risk factors, such as fluctuations in price, on project cost overrun. The cost overrun, expressed in value or percentage, is measured by comparing the initial project cost and the final account sum. These techniques provide a confidence interval of the quantity being estimated. The confidence interval for an estimate is a range of values within which the true value of the considered estimate may lie. The confidence level is the probability that the confidence region holds this true value. While these approaches are well-founded and seem to be appropriate tools of risk analysis, they don't, however, provide a Cumulative Distribution Function (CDF) of the total cost.

One of the econometric techniques is the cost growth technique, which derives a growth factor from historical project costs that can be used to determine the risk cost. Techniques for determining the cost growth factor would include historical data analysis, expert opinions, trends analysis, multi-attribute regression analysis, analogy and cost estimation methods. The difference between the revised and the estimated costs and the width of the confidence intervals are used as measures of the overall risk cost. The cost growth risk analysis technique can be applied at the project level or for one or more Work Breakdown Structure (WBS) elements. The technique is easy to implement and provides a rapid assessment of the cost risk. However, it requires access to a credible historical database for selecting comparative projects and a high degree of adjustment to draw analogies (subjective exercise).

Scenario-Based Method:

The scenario-based method is a quantitative risk analysis method centred on articulating risk scenarios as the foundation for deriving a range of possible project costs and assessing cost estimate confidence. Risk scenarios are coherent stories about potential events that, if they occur, would increase the project cost beyond what was planned. Examples of risk scenarios for the acquisition of military systems would include change in inflation rate, increase of exchange rate, slip in projects schedule, change in technology readiness, reduction in production line, etc. The process of defining scenarios for analyzing cost risk is a good practice. Indeed, scenarios build the necessary rationale for traceable and defensible measures of cost risk.

The process for assessing cost risk estimate confidence using the scenario-based method involves three steps (Garvey, 2008):

- The first step consists of defining the project's point estimate cost. This cost estimate does not include allowances for reserve. It can be determined by adding up all the project cost elements across the work breakdown structure without adjustments for uncertainty.
- The second step involves defining a protect scenario. A protect scenario captures the cost impacts of major known risks to the project. Once the protect scenario is established its cost is then estimated using closed-form algebraic equation. The difference between the protect scenario cost and the point estimate cost represents the cost reserve. There may be refinements to the cost reserve based on management reviews and other considerations.
- The third step is to conduct a sensitivity analysis to identify critical drivers associated with the point estimate and the protect scenario costs.

While the scenario-based method is easy to implement and provides a stochastic measure of cost estimate, it has some limitations. In addition to its subjectivity, the method does not produce an S-curve for detailed cost risk analysis and is not useful in aggregating lower-level risks. A statistical version of the method has been proposed (Garvey et al., 2012) to address this limitation but the new version requires two statistical input parameters: the probability the point estimate cost will not be exceeded and the underlying coefficient of variation. Both parameters are judgmental values and may make the method relatively inaccurate. However, combined with historical data, this method could be useful.

1.2.2 Stochastic Simulation Methods

The stochastic simulation method uses mathematical models, probability distribution, simulation, and convolution techniques to determine cost estimate confidence of a project. In contrast with the high level statistical methods that assess cost estimate confidence, the stochastic simulation method provides a detailed quantitative analysis of cost estimate confidence. The most common stochastic simulation approach for determining cost estimate confidence is Monte Carlo simulation. The technique involves simulating the project cost impacts of all possible outcomes that might occur within a sample space of defined events. There are two main stochastic simulation methods for cost risk analysis (Hulett, 2012): Cost Driver and Risk Driver methods.

Cost Driver Method:

The traditional way to represent cost risks is to place uncertainty on the estimate for the cost of each project element (i.e., cost driver). The cost driver method uses the cost breakdown structure of a project and represents each cost line item by a probability distribution indicating the variability in the cost estimate. Common probability distributions used in the cost risk analysis are the uniform, triangular, Program Evaluation and Review Technique, and beta distributions. The overall project cost is determined by adding up all the project cost elements. There are statistically sound ways to combine the probability distributions of the individual project elements to derive information about the total project cost. In particular, convolution is used to combine distribution analytically. Three main ways are used to derive closed-form solutions: manipulation of integrals, moment generating functions, and characteristic functions. The most common used way that has flexibility and power for combining probability distributions in most circumstances is Monte Carlo simulation.

While the cost driver method is simple and easy to implement, it has some limitations for representing risk. First, the method focuses on the impact of risks rather than the risks themselves. This approach would cloud the underlying forces that cause the uncertainty in cost and would not facilitate a sensitivity analysis to indicate which risks are crucial for the project cost. Second, there is no provision for specifying the probability that a risk may or may not occur on a project. The representation of project risks using their uncertain impacts on project element costs ignores the possibility that these risks may or may not occur. This assumption misses one of the two well-documented dimensions of project risk events, the probability of occurring. Third, a cost element may be influenced by several different risks and a risk may impact multiple cost elements. This structure cannot easily be represented using the cost driver method. Fourth, it is known that correlation between cost elements exists in most projects. Using the cost driver method requires the specification of correlation coefficients to represent this phenomenon. However, correlation coefficients are particularly difficult risk data to collect. As such, a new method based on the risk drivers has been proposed for cost risk analysis.

Risk Driver Method:

Unlike the cost driver method that uses the cost breakdown structure of a project, the risk driver method uses the risk breakdown structure to perform cost risk analysis. The method starts with the risk register's prioritized risks (i.e., strategic risks that have been identified and assessed as having serious impact on the project cost) and drives the elements' cost risk directly from the risk themselves. Each risk item in the risk register database has two important characteristics: the probability that the risk may occur and the risk impact range. The impact range of a risk is specified in multiplicative terms (i.e., cost elements are multiplied by non-dimensional factors representing the risk impact). As for the cost driver method, the risk driver method uses probability distribution functions to represent the uncertainty in the risk impact and Monte Carlo simulation to combine the probability distributions of the individual cost elements for determining the total project cost.

Unlike the cost driver method, the risk driver method allows for:

- Multi-activity assignment. A risk could be assigned to multiple cost elements;
- Compounded impact. A cost element may have several risks; and

- Implicit correlation. As the risk driver method distinguishes the impact of individual risks, it captures all of the risks' impacts on all of the element costs they affect. As such, cost elements become implicitly correlated as the simulation proceeds. In addition, the correlation between cost and schedule of a project is implicit using the risk driver method.

The main output of the stochastic simulation methods (cost driver or risk driver) is a probability distribution of the project cost estimate (and an S-curve). The S-curve is a decision analysis tool that could be used by decision makers to define a contingency or a project reserve for cost risk. The stochastic simulation methods provide also a means for conducting sensitivity analysis to determine key risk drivers (or cost drivers) for further investigation and risk mitigation.

1.3 Selecting a Cost Risk Analysis Method

After presenting the different methods for cost risk analysis, their benefits and limitation, it is important to discuss the conditions for selecting a method over another. In other words, what are the criteria for adopting a specific risk analysis method for a given project? Figure 1 summarizes the cost risk analysis methods discussed in this chapter and presents a decision flowchart for selecting a cost risk analysis method. As indicated in Figure 1, the key decision point in the cost risk analysis is the availability of data. Data in the context of cost risk analysis refers to the project requirements, technical data, details of the project elements, historical data, risk drivers, etc. To measure the availability of data for risk assessment, a Data Readiness Level (DRL) metric, inspired from the technology readiness level concept developed by the National Aeronautics and Space Administration (NASA, 2008), is used. Three DRLs may be used for the selection of risk cost analysis methods. A DRL of 1 indicates that there is no data available or there is little information about the project (e.g., early stages of the project development) to perform a quantitative cost risk analysis. As such, a qualitative approach could be used for the analysis. This process should be reviewed during the project's life cycle until the data becomes available for a detailed risk analysis. A DRL of 2 represents the case where some historical data and limited project information are available. Statistical methods could be used to provide a high level estimate of the cost risk. A DRL of 3 indicates that sufficient data is available to perform a detailed quantitative risk analysis using simulation methods.

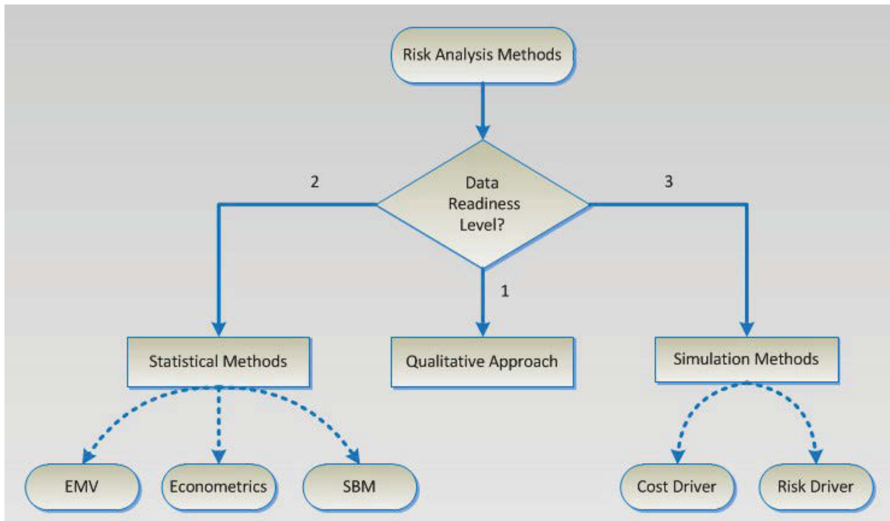

Figure 1: Pictorial representation of cost risk analysis methods.

2 Cost Risk Data Requirements

The quality of the cost risk analysis depends to a large extend on the quality of the risk data used in the analysis. Collecting data about project risk can be difficult. Risk data is sometimes unavailable, imprecise, incomplete, expensive, and time consuming to collect. This section presents the data requirements of the cost risk analysis methods and focuses primarily on the quantitative methods (input data requirements for the qualitative approach are highlighted in Section 2.1). Each method requires different types and levels of detail of input data. However, all methods require a point estimate cost of the project at the start of the risk analysis process.

Expected Monetary Value. The expected monetary value method is applied at the project level and requires the identification of key risk factors as well as their probabilities and their consequences on the project cost. This data is usually derived using subject matter experts.

Econometric Techniques. The data requirement for the econometric techniques depends on the technique used to estimate the cost risk. For example, the cost growth technique requires historical cost data of comparative programs to derive a cost growth factor for adjustments of the project cost estimate. The technique can be applied at the project level or for one or more WBS elements. To use the cost growth technique at the project element level, different cost growth factors, corresponding to different WBS elements, should be developed.

Scenario-Based Method. The scenario-based method is applied at the project level and requires the identification of a list of risk scenarios, along with their probabilities and impacts distributions. If the statistical scenarios-based method is considered, two additional statistical input parameters are required: the probability the point estimate cost will not be exceeded and the underlying coefficient of variation.

Cost Driver Method. The cost driver method is applied at the lowest level of detail of the project and requires the development of the project WBS. In addition, probability distributions representing the uncertainties in the project element costs should be identified. This means that, for example, optimistic, pessimistic, and most likely cost estimates of each element cost should be determined. Furthermore, coefficients of correlation between project element line item costs are often calibrated.

Risk Driver Method. The risk driver method can be applied at the project level or at the project element level. If the analysis is conducted at the project element level, a project WBS should be established (i.e., identify the project elements and their cost estimates). In addition, the following data is required for the risk driver method:

- List of risk drivers (from the risk register) that would potentially affect the project. The individual risks are characterized by both their probability of occurring on the project and their impact range (in the form of multiplicative factors) if they occur.
- Risk assignment matrix. A matrix should be constructed that assigns risks to project cost elements. A risk may be assigned to multiple cost elements and a cost element may have been assigned multiple risks. Using this assignment matrix, the project cost elements become implicitly correlated as the simulation proceeds (i.e., no need for correlation coefficients).

3 Risk Assessment Measures

While the previous section examined the input data requirements for cost risk analysis, this section discusses the output results of a cost risk assessment and focuses on the output of the quantitative methods. The results of a simulation-based cost risk analysis can be used to develop a cost risk profile, determine a cost contingency, and identify key risk factors through sensitivity analysis.

3.1 Cost Risk Profile

The results from a project cost risk simulation can be presented using various statistical tools such as histograms, CDFs, tables of costs, and percentiles. The histogram, for example, indicates the overall shape and range of possible project costs, and identifies the most likely or mode of the total project cost distribution. The cost risk profile can be derived and presented using the CDF of the cost risk. More commonly known as an S-curve in quantitative cost risk analysis, this mathematical curve shows for each cost the likelihood of not exceeding it. This key tool helps decision makers in understanding the cost impact of risks and developing risk mitigation strategies.

To understand the concept of S-curve and how it can be used in this context, let the cost C be a continuous random variable and F the corresponding CDF. As shown in Equation 1, for each potential cost c, *F(c)* is the probability of obtaining a value less than or equal to c.

$$F\left(c\right) = P\left(C \leq c\right) = \int_{-\infty}^{c} f\left(c\right) dc. \tag{1}$$

F(c) is bounded between 0 and 1. If we assume that F is continuous and strictly increasing, for each probability p $(0 \leq p \leq 1)$, there is a unique real number c such that $p = F(c)$. In this expression, $c = F^{-1}(p)$ is the $100p^{th}$ percentile, p is the probability of achieving this cost, and F^{-1} is the quantile function (the inverse function of F). The median is the middle observation. As F is continuous the median is the same as the 50^{th} percentile $F^{-1}(0.5)$. It is the value separating the higher half of the probability distribution from the lower half. An example of S-curve is provided in Figure 2. As shown in this graph, the lower the percentile value, the lower is the cost contingency, and the higher is the likelihood of exceeding cost (United States Air Force, 2007; Sokri and Solomon, 2013).

3.2 Contingency Assessment

The results of a risk analysis allow decision makers to identify a project cost contingency, or rather several alternative reserves depending on their desire for cost uncertainty. A cost contingency is defined as "the amount of

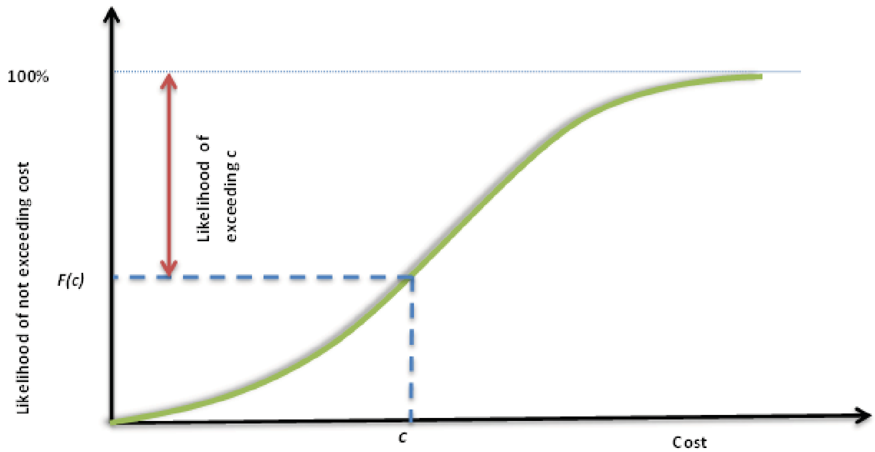

Figure 2: Cost risk cumulative distribution.

money needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization" (Clark and Lorenzoni, 1997; Patrascu, 1988; Querns, 1989; Wideman, 1992; Rad, 2002; Yeo, 1990; Project Management Institute, 2000). Baccarini (2004) identified key attributes of the concept of project cost contingency. First, the need (and the amount) of contingency reflects the existence of risks and uncertainty in projects and caters for events within the defined project scope that are unforeseen, unknown, unexpected, unidentified, or undefined. Second, contingency is a financial treatment for retained risks that is used in conjunction with other risk treatment strategies. Third, contingency should avoid the need to appropriate additional funds and reduces the impact of overrunning the cost objective. Fourth, contingency can have major impacts on project outcomes. If contingency is too high it might cause the project to be inefficient and aborted. If too low it may be too rigid and generate unsatisfactory performance outcomes (Baccarini, 2004).

The S-curve produced using the results of the simulation (or statistical) cost risk analysis can be used by decision maker to determine different confidence levels for cost contingency. While no specific confidence level is considered as a best practice (United States Government Accountability Office, 2009; Treasury Board Secretariat, 2012), it is common to fund projects between 50% and 80% levels. In general, the chosen value should correspond to the level of confidence that meets decision makers' risk tolerance. The lower the level value, the lower is the cost contingency, and the higher is the likelihood of exceeding cost. The 50% level is usually deemed to be the lower bound.

3.3 Risk Prioritization

In risk management, risk prioritization is important for developing mitigation strategies and cost contingency. The relative importance of the different risks can be examined by performing sensitivity analysis using the simulation-based risk analysis method. Sensitivity analysis correlates the input uncertainties with the uncertain total project cost estimate. It aims to see what would happen to the total cost if the major sources of uncertainty vary. It allows for better informed decisions to be made on which risk mitigation strategies would have the most impact (KPMG, 2012).

Using sensitivity analysis, the key parameters and inputs used for the cost contingency estimation are varied. Sensitivity results can be generated and graphically displayed using different analytical techniques. Numeric simulation, bivariate correlation and regression analyses are the most useful methods for determining the significance of input variables. These techniques compute the pairwise association between the output and one of its simulated predictors. The correlation coefficient, for example, determines the strength and direction of the association. The higher the correlation between the risk factor and the incremental cost, the more significant the factor is in determining the total cost.

4 Conclusions

In this chapter , common methods for cost risk analysis are presented and discussed. The advantages and limitations of each method are highlighted. In general, cost risk analysis methods are grouped into qualitative and quantitative approaches. Qualitative methods provide a quick subjective assessment of risks and their impacts on the project cost using ordinal scaling techniques whereas quantitative methods provide a numerical assessment of risks and their impacts using different statistical and stochastic simulation techniques. Qualitative methods are used to provide a quick and high level assessment of cost risk when there is limited data and project information to conduct a detailed risk assessment. The key factors and considerations for the selection of qualitative or quantitative methods include: data availability, resources availability, and the amount of information that each method can provide on cost risk estimation.

The quality of the cost risk analysis depends to a large extend on the quality of the risk data used in the analysis. Collecting data about project risk can be difficult. Risk data is sometimes unavailable, imprecise, incomplete, expensive, and time consuming to collect. Given the importance of data in cost risk analysis, details about the data requirements for each quantitative risk analysis method are presented and discussed in this chapter . The tools to present and exploit the output results of a cost risk assessment for decision making are also investigated. A cost risk analysis example using the CAF F-35 project was presented for illustration purposes.

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A Illustrative Example

This annex presents an illustrative example of cost risk analysis for the acquisition portion of the Canadian Armed Forces (CAF) F-35 JSF.

A.1 Background

The F-35 JSF (Figure A.1) is a single-engine, stealthy, supersonic multi-role aircraft fighter manufactured in three versions: a Conventional-Takeoff-and-Landing (CTOL) variant (F-35A), an aircraft-carrier version (F-35C), and a short-takeoff-vertical landing version (F-35B). Over three thousand F-35 JSFs are currently planned to be built for different international partners. Pratt & Whitney is manufacturing the propulsion systems and the Lockheed Martin Corporation is manufacturing the air vehicle and is responsible for final assembly of the aircraft. In 2001, the F-35 program started its 10-year System Development and Demonstration phase building 22 test aircraft. Low-rate initial production1 started in 2007 and by the end of 2011 about thirty new aircraft are scheduled to have rolled off the production line.

Figure A.1: Example of F-35 aircraft.

Canada is examining options for renewing its fighter capability to replace its aging CF-18 fleet expected to retire between 2017 and 2020. One option considered is the Lockheed Martin F-35A CTOL. Canada is a partner in the multi-national JSF Program and intends to acquire 65 F-35A. In 2012, Government of Canada launched a Seven-Point Plan to ensure that the Royal Canadian Air Force acquires the aircraft it needs through an open and transparent process. The JSF F-35 project planning horizon is estimated to be 42 years and a risk-free total cost (a point estimate) of the project is calculated over the project horizon ($8,648 million).

As part of the Government of Canada's comprehensive response to the Auditor General of Canada report, DND was requested to conduct a cost risk assessment and provide annual updates to Parliament on the JSF F-35A costing forecasts. A pilot cost risk assessment session, led by an independent risk management consultant and involved SMEs from across National Defence organizations, was held in 2012. Four major risk factors were identified for the acquisition portion of the F-35 project (Sokri and Solomon, 2013):

- Currency Risk: The financial risk associated with the exchange rate between the American and Canadian currency. This risk is assessed as very high and represents the number one cost risk associated with the acquisition phase of the project.
- Inflationary Risk: The risk associated with the erosion of purchasing power as a result of increases in American domestic inflation. This risk is assessed as high.
- Demand Risk: The risk that demand forecast may not meet the actual partners demand. This risk is assessed as high.
- Learning Curve: The risk that the producer may not realize expected production efficiencies. This risk is assessed as medium.

A.2 Cost Risk Assessment

Following the pilot risk assessment session, a quantitative cost risk analysis of the F-35 project was performed to determine an estimation of the project cost contingency. Two quantitative methods, one using a stochastic simulation method (risk driver) and one using a statistical method (scenario-based) were considered in the analysis. Given that there was no detailed data about the project cost elements, both methods were applied at the project level (high level analysis). For the stochastic simulation method, the cost risk factors identified by SMEs are used as risk drivers. For the statistical method the same risk factors are interpreted as risk scenarios. SMEs provided their assessment of the likelihood that the maximum impact of the cost risks factors would be realized. Table A.1 presents the range, mean, mode, and standard deviation of the impact of each risk factor on the project cost.

Table A.1: Central tendency and dispersion within the dataset.

Risk driver	Min	Max	Mean	Mode	Std
Foreign exchange	0	1,394	267	1.6	225
Inflation	0	430	83	0.5	70
Demand	0	506	100	0.6	85
Learning curve	0	1,427	267	1.6	225
Total Cost	10	2,500	717	603	369

For the risk driver-based assessment, a Monte Carlo simulation model was developed to generate stochastic cost risk impacts and to aggregate them for estimating the cost contingency of the F-35 project. Figure A.2 presents the probability and cumulative distributions for each percentile. It indicates that an average cost contingency of $717 million is required for the F-35 project cost based on the identified risk factors. Using the median, the amount of the risk contingency will be approximately $662 million. If the budgets are set at the 80$^{\text{th}}$ percentile, for example, these amounts will become $1,012 million. The 95% confidence interval of the cost contingency is [$167 million, $1567 million]. Adding these incremental costs to the base estimate will constitute the risk adjusted estimate.

For the statistical scenario-based method, a point estimate cost of $8,648 million and a protect scenario cost of $9,251 million were used in the analysis. The protect scenario cost estimation is the result of a series of discussions, refinements, and iterations from the initially defined scenario by SMEs. To compute the project cost contingency, two statistical inputs are needed: The probability the point estimate cost will not be exceeded (α_{pe}) and the coefficient of variation (cv) also known as the coefficient of dispersion.

Let C be a random variable representing the total cost of the program. The coefficient of variation is the ratio of the distribution standard deviation (σ) to its mean (μ). Suppose that α_{pe} is assessed to be 0.10. That is:

$$P\left(C \leq 8,648\right) = 0.10 \tag{A.1}$$

Suppose that 4% variability in cost around the mean has been observed. That is:

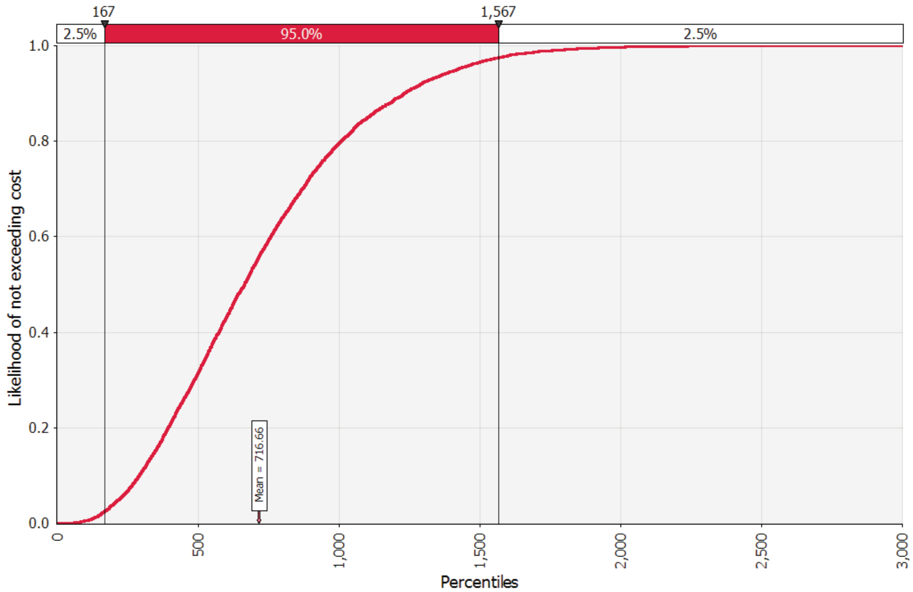

Figure A.2: Results of the cost contingency distribution using the risk driver method.

$$cv = \frac{\sigma}{\mu} \simeq 0.04. \tag{A.2}$$

A Normal distribution was used to compute μ and σ and plot the distribution of C. The distribution mean μ and standard deviation σ are calculated as follows:

$$\mu = 8,648 - z\frac{(0.04)\,(8,648)}{1 + 0.04z}, \tag{A.3}$$

$$\sigma = \frac{(0.04)\,(8,648)}{1 + 0.04z}. \tag{A.4}$$

z is a real number such that:

$$P\,(Z \leq z) = \alpha_{pe} = 0.10 \text{ and } Z \sim N\,(0,1)\,. \tag{A.5}$$

Using a Normal distribution function, the calculated mean and standard deviation of the variable C are \$9,115 million and \$365 million, respectively. To determine the project contingency, we need the probability α_{ps} (i.e., probability the protected scenario cost will not be exceeded) such that:

$$P\left(C \leq 9,251\right) = \alpha_{ps}, \tag{A.6}$$

$$z_{ps} = \frac{9,251 - \mu}{\sigma} \simeq 0.37, \tag{A.7}$$

$$P\left(Z \leq 0.37\right) \simeq 0.64. \tag{A.8}$$

Therefore, the protect scenario cost is approximately at the 65$^{\text{th}}$ percentile of the distribution with a contingency value of \$603 million. The results of this analysis are represented in Figure A.3.

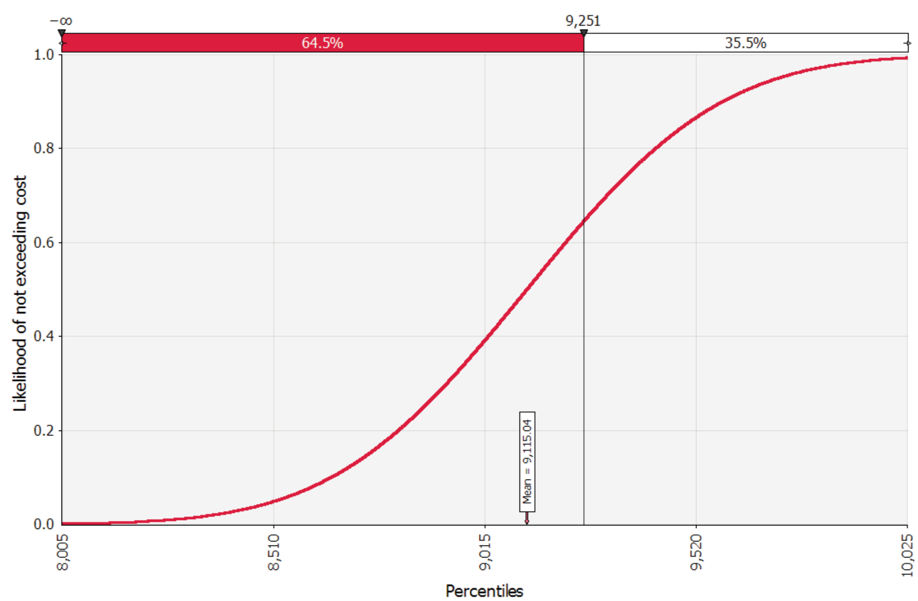

Figure A.3: Results of the cost contingency distribution using the scenario-based method.

Like the Normal distribution, the Lognormal can also be used for this problem. The Lognormal distribution has a number of desirable properties of real costing problems: It is skewed and has a positive and unbounded range. Another useful property is that when the coefficient of variation is small, the skew is small and the distribution approaches a Normal distribution.

A.3 Sensitivity Analysis

A sensitivity analysis was conducted to assess the impact of each individual risk factor on the cost contingency and to prioritize the risk factors (based on their impacts on the cost contingency) for developing mitigation strategies of cost risk. The sensitivity analysis was performed using the risk driver-based simulation method. Figure A.4 presents the result of the sensitivity analysis and shows a tornado graph indicating the range of possible high and low costs around the mean. The risk drivers are ranked based on their effect on the mean total cost, referred to below as the baseline scenario. This sensitivity analysis mainly emphasizes the following key points:

- Compared to the baseline scenario, an increase in the efficiency risk, currency risk, or demand risk would have the effect of substantially increasing the incremental acquisition cost (up to 82%, 69%, or 64%, respectively). It was also found that a decrease in these risk factors would decrease the incremental acquisition cost by up to 44%, 34%, and 39%, respectively.
- The inflationary risk has a small impact on the incremental acquisition cost. Inflation could vary this cost from -9% to +19%. This relatively small effect is due to the slight variation in inflation hypothesized by the SMEs, i.e., 1%. This small variation would, however, have a significant impact on the sustainment cost due to the long project planning horizon.

Another analysis was conducted with the simulation model to determine the correlation between the cost contingency and each risk driver. The results of the analysis indicated a positive correlation between the cost contingency and each risk driver (Table A.2). Any increase in the drivers would expectedly push the costs upward. The higher the correlation between the risk factor and the cost contingency, the more significant the factor is in determining the total cost. For example, analyzing the inflationary risk yielded correlation coefficient of 0.17 with the cost contingency. It would be therefore expected that the inflationary risk would have a small impact on the acquisition cost.

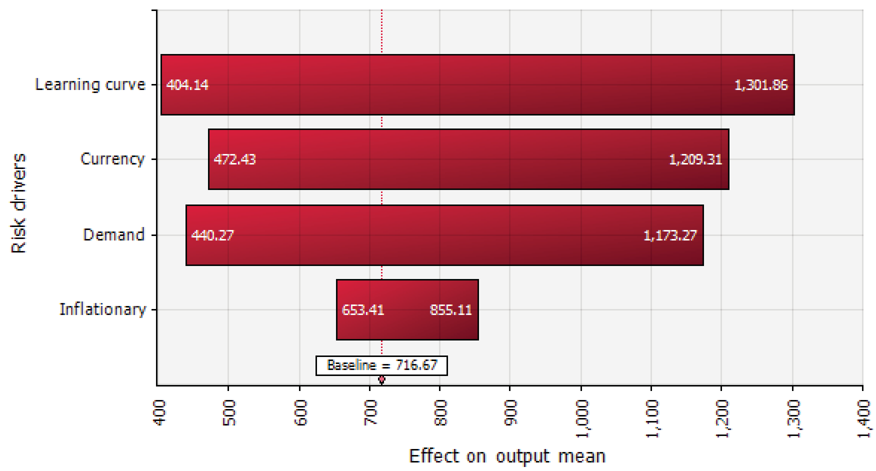

Figure A.4: Effects of the main risk factors on the incremental cost.

Table A.2: Correlations between the acquisition cost and the risk drivers.

Risk driver	Coefficient of correlation
Foreign exchange	0.58
Inflation	0.17
Demand	0.56
Learning curve	0.71

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Cost Risk Visualization

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Contents

1 Introduction

The ultimate purpose of cost risk identification, estimation, and reporting is to support capital investment decisions. To base these decisions on evidence requires sound assessment, analysis, and disclosure of a project's risks, risk responses, and subsequent residual risks. It is therefore important for a cost report to guide the decision maker through the assumptions, results, and conclusions (recommendations) in a manner that is transparent, cogent, and accessible.

Decision makers, particularly in government departments, must operate within existing financial rules and guidelines around resource utilization and formal attestation on the financial aspects of budget approval processes (Cabinet submissions). One key framework, which became effective on January 1st 2014, provides specific guidelines for Chief Finance Officers (CFO) in the Government of Canada on how to conduct due diligence reviews[1]. This CFO attestation framework identifies six fundamental assertions linked to the CFOs roles and responsibilities. The second assertion states that:

> Significant risks having a bearing on the financial requirements, the sensitivity of the financial requirements to changes in key assumptions, and the related risk-mitigation strategies have been disclosed[2].

To respond to the first and second items of this assertion[3], decision makers require: identification and assessment of a project's cost's risks; a sensitivity analysis for the cost risk breakdown structure, including scheduling, budgeting, and project control; and a contingency analysis that represents the cost of the risk responses. The ability to perform these analyses is dependent upon the type of model used (i.e., qualitative or quantitative); however, if possible a cost report should include[4]:

1. Assumptions used to calculate the project's base estimate cost, including selected bounds, distributions, and uncertainty in the data;
2. Risks associated with the project's cost;
3. A sensitivity analysis of the cost risk breakdown structure's elements;
4. The correlations between the risks;

[1] See http://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=27256&section=text.
[2] See footnote 1.
[3] Risk mitigation is beyond the scope of this framework.
[4] This list is similar to the steps to develop a credible S curve that are described in the Government Accountability Office (2009). See page 159.

5. The project's base estimate cost and its probability level;
6. A cumulative distribution (S curve) of the project's cost in budget year dollars, including the probability of the base estimate and selected contingency level; and
7. Risk adjusted, in budget year dollars, costs by year to show phasing of risks.

While the above information is straight forward, risk communication is a daunting task. Although our brains are better at processing information in a visual form rather than in a tabular or written form, decision makers are often provided risk information in the latter. In addition, probabilities (both independent and dependent events), which are vital to understanding risk analysis, are notoriously difficult for many decision makers to understand. While the risk visualization and communication literature is vast, this chapter deals with the narrower aspect of cost risk visualization.

The aim of this chapter is to provide guidance on how best to design visualizations that provide the required information to respond to the aforementioned seven points. In order to provide effective responses, we focus on two key areas: first, the psychology of how people understand and estimate risk; and second, visualization related to easing the communication of uncertainty (i.e., the variance associated with data and assumptions) and risk (i.e., the effect of uncertainty on objectives) information. Given this focus, the remainder of this chapter is organized as follows: Section 2 briefly describes the psychology of how people understand and estimate risk; Section 3 discusses visualization guidelines, including how to visually encode data and how to communicate data uncertainty; Section 4 presents a framework whose aim is to help analysts design risk visualizations; Section 5 describes how the framework may be applied to design visualizations for the seven points; and Section 6 presents a conclusion.

2 Psychology of Risk

The majority of psychology research that examines how people understand risk has been conducted in the framework of 'heuristics and biases' developed by Tversky and Kahnenman (1974); Kahnerman and Tversky (1979). A major finding of this framework is that individuals rely on heuristics, or 'rules of thumb', to help interpret information. This framework describes three key heuristics: availability, representativeness, and anchoring and judgment.

When an individual is asked to estimate the frequency of an event they tend to rely on (proportionally) the ease by which an example of the target event can be recalled (i.e., events that can be recalled more easily tend to have a higher probability). This is the availability heuristic. People also have a tendency to use similarity to guide their judgment. Known as the representativeness heuristic, such tendencies can lead people to overestimate the likelihood that something has a very rare property, or underestimate the likelihood of a very common property. The anchoring and judgment heuristic is witnessed when individuals rely too heavily on the first piece of information offered (anchor) when making decisions. Once an anchor is set, subsequent judgments are made based on the anchor, and thus a bias toward interpreting other information around the anchor is introduced.

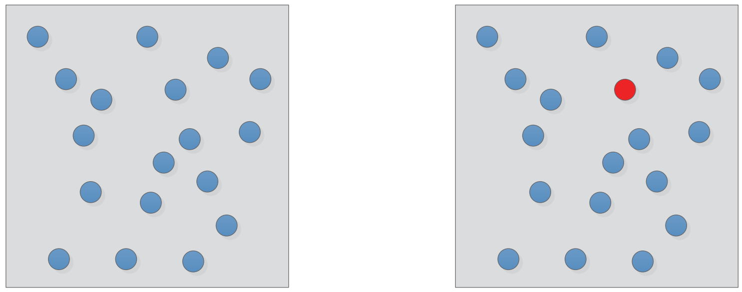
Various techniques may reduce the effects of these heuristics. For example, Gigerenzer and Hoffrage (1995) showed that the representative heuristic might be diminished by presenting information as natural frequencies rather than probabilities; that is, 1/100 is much more intuitive than 1%. As well, Inbar (2007) performed an experiment (based on Kahneman and Tverskys original exercise) and showed that a graphical representation of data, equivalent for its numerical representation, was also an effective approach.

3 Visualization

Research focusing on visualization uncertainty and risk is limited. However, the existing studies, in addition to those focused on general visualization guidelines, have produced several important results that can inform the design of cost risk visualizations. These are:

- How our pre-attentive vision leads to visual encodings of that minimizes the amount of effort required to identify features in a visualization;
- Preferences for visual encodings of quantitative, ordinal, and categorical data that simplify the interpretation of visualizations;
- General principles that lead to good visualizations;
- Approaches to visualize data uncertainty and frameworks to discuss uncertainty; and
- A systematic framework for risk visualization.

Together these provide analysts with guidance on how to design cost risk visualizations for communicating with decision makers. In this section, we discuss the first four items. The risk visualization framework is presented



(a) (b)

Figure 1: Target detection based on colour. (a) A set of blue circles. (b) A target circle that is coloured red in a set of blue circles.

in the next section. Annex A has an extended discussion of pre-attentive vision and visual encodings.

3.1 Visually Encoding Data

Regarding visualization, one of the most important concepts to understand is pre-attentive vision. In general, pre-attentive vision involves visual features that can be detected by the human visual system without focusing attention on particular regions in an image. Detecting a red circle in a group of blue circles as shown in Figure 1 is one popular example of pre-attentive vision. To perform such a quick assessment the target object must be defined by a unique visual property (e.g., orientation, length, size, etc.) (Healey and Enns, 2012).

With this knowledge of pre-attentive vision, guidance has been developed on how to best to use visual encodings to represent data. Four sources that are often cited are Bertin (1983), Green (1998), Cleveland and McGill (1985), and Mackinlay (1986). The work of Bertin (1983) and Green (1998) focused on identifying visual encodings that lead to good quality visualizations. Bertin made two important contributions. First, Bertin identified four tasks that are common to information visualization. Two of these are about perceiving encodings as similar (association) or different (selection), perceiving encodings as ordered (order) or proportional to each other (quantity). Second, Bertin suggested six visual encodings that can be used to help individuals perform these tasks: size, value, texture, colour, orientation and shape.

Green (1998) argued that Bertins work, which was developed for visualization on a printed page, was neither complete nor entirely accurate and that dynamic visualization should be included. One example of dynamic visualization is the use of motion or velocity as an encoding for selection, ordering and quality. Cleveland and McGill (1985) performed experiments to assess the relationship between visual encodings and how well an individual could assess quantitative data (i.e., data that can be measured numerically). The study results show that, among others, position along an axis is a preferred encoding over length, which is preferred over angle. The least favoured encodings are colour and density.

Similarly, Mackinlay (1986) studied visually encoding quantitative and non-quantitative data. He created rankings of visual encodings for quantitative, ordinal data (i.e., arbitrary numerical scale where values have no significance beyond the ability to establish a ranking), and categorical data (i.e., data that cannot assume a numerical value but can be classified into two or more nonnumeric categories). The results are shown in Table 1, with the most accurate encodings at the top of the table and the least accurate encodings at the bottom of the table. As an example, for categorical data position is preferred over colour, which in turn is preferred over texture.

3.2 General Visualization Guidelines

In addition to guidelines on how best to visually encode data, general guidelines have been developed to support the design of good visualizations. Though several references exist, two that are often cited are Tufte (2001) and Ware (2013).

Tufte (2001) described general guidelines for graphic excellence and integrity that lead to good visualizations. In order to create graphic excellence he suggested:

- Show the data;
- Induce the viewer to think about the substance rather than the methodology;

Table 1: Relative difficulty of assessing quantitative, ordinal, and categorical data as suggested by Mackinlay (1986). Most accurate encodings are at the top and the least accurate encodings are at the bottom.

Quantitative	Ordinal	Categorical
Position	Position	Position
Length	Density	Colour hue
Angle	Colour saturation	Texture
Slope	Colour hue	Connection
Area	Texture	Containment
Volume	Connection	Density
Density	Containment	Colour saturation
Shape	Length	Shape
	Area	Length
	Slope	Angle
	Area	Slope
	Volume	Area
		Volume

- Avoid distorting data[5];
- Present a large amount of data in a small space[6];
- Make large data sets coherent;
- Encourage the eye to compare data;
- Reveal the data set at several levels of detail;
- Serve a clear purpose: description, exploration, tabulation, or decoration; and
- Closely integrate statistical and text descriptions.

In order to create graphic integrity, avoid deception, and avoid misrepresentation of data he provided six guidelines:

1. Graphic presentations related to numbers should be directly proportional to the quantities represented;

[5]For example, three-dimensional pie charts can lead to poor interpretation due to perspective.

[6]The goal of this suggestion is to create visualizations that allow individuals to understand a large amount of data at a glance; that is, communicate a story as effectively and efficiently as possible.

2. Clear and detailed text should be used whenever needed to avoid ambiguity;
3. Show data variation and not design variation;
4. Money in time series should be adjusted for inflation;
5. The number of dimensions used for reading data should not exceed the number of data dimensions being represented; and
6. Do not show data out of context.

Ware (2013) wrote a comprehensive book on information visualization that includes many theories on visual perception and comprehension. The book emphasizes cognitive psychology and physiological research rather than practical grounded research such as Tufte (2001). Ware (2013) offers over 150 practical guidelines (e.g., design graphic representations by taking into account human sensory capabilities, important data elements should be represented by graphical elements that are more visually distinct) to support the design of visualizations. These are too numerous to list here; Kelleher and Wagener (2011) suggested ten guidelines, based on Tufte (2001), Ware (2013), and several other researchers, to inform the design of data visualizations in scientific publications. These guidelines are:

- Create the simplest graph that conveys the information you want to convey;
- Consider the type of encoding object and attribute used to create a plot;
- Focus on visualizing patterns or on visualizing details, depending on the purpose of the plot;
- Select meaningful axis ranges;
- Data transformation and carefully chosen aspect ratios can be used to emphasize rates of change for time series data;
- Plot overlapping points in a way that density differences become apparent in scatter plots;
- Use lines when connecting sequential data in time series plots;
- Aggregate larger datasets in meaningful ways;
- Keep axis ranges as similar as possible to compare variables; and
- Select an appropriate colour scheme based on the type of data.

Several sources use these guidelines to provide advice for commonly used chart types. For examples, Gary Klauss from Illinois State University summarized rules for pie, bar, time series (line) and scatterplots[7]. The rules are:

- Pie charts
  - Avoid using pie charts.
  - Use pie charts only for data that adds up to something meaningful.
  - Never use three-dimensional pie charts.
  - Avoid forcing comparisons across more than one pie chart.
- Bar
  - Do not use three-dimensional effects.
  - Set the reference to zero.
  - Sort the data on the most significant variable.
  - Use rotated bar charts if there are more than eight to ten categories.
  - Place legends inside or below the plot area.
  - With more than one data series, beware of scaling distortions (i.e., numbers of different magnitudes).
- Time series (line)
  - Time is almost always displayed on the x-axis from left to right.
  - Make sure the reader can distinguish between the lines for separate data series.
  - Beware of scaling effects.
  - When displaying monetary data over-time, it is often best to use deflated data.
- Scatterplot
  - Use two interval-level variables (i.e., difference between two values is meaningful).
  - Fully define the variables with the axis titles.
  - The chart title should identify the two variables and the cases.
  - Place the independent variable on the x-axis and the dependent variable on the y-axis.

[7] See http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm#Types. Other sources include a short course on creating more effective graphs by N. Robbins (see http://www.ssc.ca/ottawa/documents/SSO2009FallRobbins.pdf) and the Statistics Canada publication Power from Data! (see http://www.statcan.gc.ca/edu/power-pouvoir/ch9/pie-secteurs/5214826-eng.htm).

- Scale the axes to minimize the plot area for displaying the data points.
- Add data labels to identify cases.

3.3 Visualizing Uncertainty

The majority of visualizations separate the presentation of data and its uncertainty, or worse yet simply ignore uncertainty. The complexity and type of data visualized has a strong impact on whether this occurs or not. For example, a visualization of quantitative data that is one- or two-dimensional often uses errorbars to show uncertainty; however visualizations of quantitative data with higher dimensionality, or those of ordinal or categorical data, often do not include uncertainty (Johnson and Sanderson, 2003; Sanyal et al., 2009). Research in visualizing uncertainty is limited; studies that have been conducted may be grouped into two categories: first, visual encodings of uncertainty; and second, frameworks to discuss uncertainty. The remainder of this section discusses the literature in these two topics as they relate to cost risk visualization.

Pang et al. (1997) introduced a variety of techniques to encode uncertainty in scientific visualizations. Table 2 lists these encodings. Though these are designed for scientific visualizations, Gresh et al. (2012) noted that 'Modifying Attributes' and 'Animation' are appropriate approaches to be used in information visualizations. For example: modifying attributes may include adding texture, transparency, or colour to indicate uncertainty; and animation may include transitioning between visualizations of two differing models.

Table 2: Visual encodings for uncertainty. See Pang et al. (1997).

Technique	Uncertainty Mapping
Glyph	Shape, Colour
Adding Geometry	Contourlines, Isosurface
Modifying Geometry	Scaling, Rotation
Modifying Attributes	Colour, Lighting
Animation	Speed, Duration
Sonification (not visual)	Sound
Psycho-visual	3D, Subliminal messages

User studies conducted into the effectiveness of uncertainty visualizations are generally domain specific. Recently, Sanyal et al. (2009) performed a general user study of four common visual encodings for uncertainty: size of glyphs, color of glyphs, color of data surface, and errorbars. Their study, which was limited to one- and two-dimensional visualizations of quantitative data, asked participants to perform a series of search tasks (i.e., searching for areas of high and low uncertainty) and counting tasks (i.e., counting the number of data or uncertainty features). Their results did not provide clear direction: some encodings were more effective for searching and some encodings were more effective for counting. A result that does stand out is that the most commonly used visual encoding, errorbars, performed poorly compared to the other evaluated techniques.

Zuk and Carpendale (2006) evaluated eight uncertainty visualizations using the perceptual theories of Bertin (1983), Tufte (2001), and Ware (2013). The authors concluded that these theories are applicable to uncertainty visualizations and can provide 'light-weight' guidance during their design. Furthermore, using the theories the authors identified a set of heuristics to inform a quality visualization:

- Ensure visual variables have sufficient length;
- Preserve data to graphic dimensionality;
- Put the most data in the least space;
- Provide multiple levels of detail;
- Remove the extraneous;
- Consider Gestalt laws[8];
- Integrate text whenever relevant;
- Don't expect a reading order of colour;
- Colour perception varies with size and colour of item;
- Local contrast affects color and gray perception;
- Consider people with colour blindness;

[8] Gestalt laws attempt to describe how people organize visual elements into groups. For static visualizations the principles are: similarity (objects look similar to each other), continuity (the eye is compelled to move through one object to another object); closure (an object is incomplete, but enough of its shape is indicated that we perceive the whole); proximity (elements placed close together are perceived as a group); figure-ground (some objects take a prominent role and others recede into the background); symmetry (we perceive objects as symmetrical that form around their centre); and connectedness (people tend to group objects together if they are connected by other objects). For a detailed description see Ware (2013).

- Pre-attentive benefits increase with field of view; and
- Quantitative assessment requires position or size variation.

Zuk (2008) provided further directives to support uncertainty visualization:

- Provide support for cognitive task simplification;
- Support emphasis and de-emphasis of uncertainty information;
- Support viewing of uncertainty as metadata and separately as data;
- Allow the user to select realizations of interest;
- Mitigate cognitive heuristics and biases with reasoning support;
- Provide interaction to assist knowledge creating; and
- Assess the implications of incorrectly interpreting the uncertainty.

The second category of interest is frameworks to describe uncertainty. Two recent studies are of importance. First, Olston and Mackinlay (2002) discuss statistical uncertainty and bounded uncertainty. These are defined as[9]:

- Statistical uncertainty: a distribution of possible values, which may potentially be negative or positive infinity, with a peak indicating the most likely; and
- Bounded uncertainty: no assumptions can be made about a distribution of the possible values, but the exact value is known to exist inside an interval defined by a lower and upper bound.

Olston and Mackinlay (2002) suggest that visualizations should differentiate between these two types of uncertainty. To convey statistical uncertainty, they suggest using errorbars or other glyphs. To convey bounded uncertainty, they suggest using ambiguation; that is, widening the boundaries of positions of graphical elements.

Skeels et al. (2008) identified that most uncertainty classification research occurs within specific domains. They proposed an uncertainty classification framework designed to span multiple domains for the purposes of information visualization. They recognized that multiple types of uncertainty may be associated with a dataset and that these can be expressed as levels of uncertainty. They noted that separating uncertainty into levels was important because it is often difficult to transform or account for uncertainty when decision-making requires a transition between levels. Their framework is shown in Figure 2.

Uncertainty in measurement precision (Level 1) is associated with variations in the data, imperfection, or theoretical limitations in measurement. This

[9] Definitions are taken from the United States Department of Commerce National Institute for Standards and Technology.

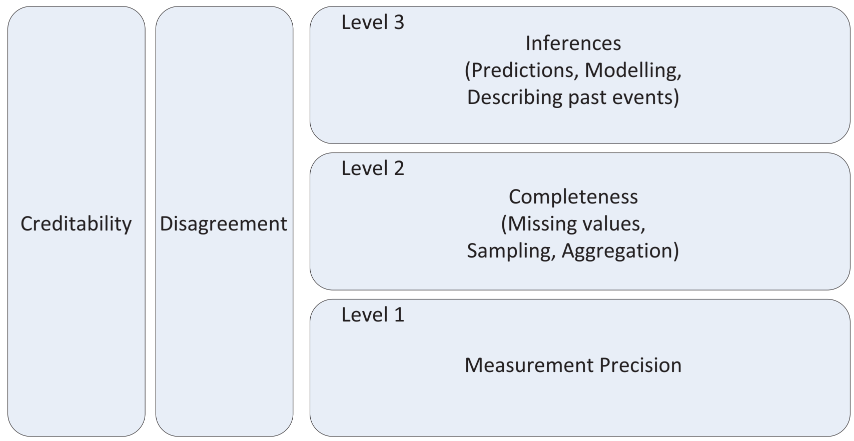


Figure 2: Uncertainty classification (Skeels et al., 2008).

uncertainty is represented as a confidence interval, or simply as stating that a data point is flawed. Uncertainty in completeness (Level 2) is associated with sampling data from a population, missing values, or information lost due to data aggregation. An important element of missing data is unknown unknowns; that is, important data that an analyst does not know is missing. Uncertainty in inferences (Level 3) is due to modelling of any kind, prediction of future events, or using data to describe past events.

Two types of uncertainty span all levels: disagreement and credibility. Disagreement includes data measured at multiple times or from different sources if not the same (Level 1), nonidentical data sets (Level 2), and different conclusions drawn from the data (Level 3). Credibility includes information sources that generate data that conflicts with other data. It should be noted that uncertainty due to credibility is difficult to measure.

4 Cost Risk Visualization Framework

Given the ability of visualization to ease the communication of information between individuals, visualization can be employed to help decision-makers better understand and manage risks. With this in mind, Eppler and Aeschimann (2008) proposed a risk visualization framework with three specific aims:

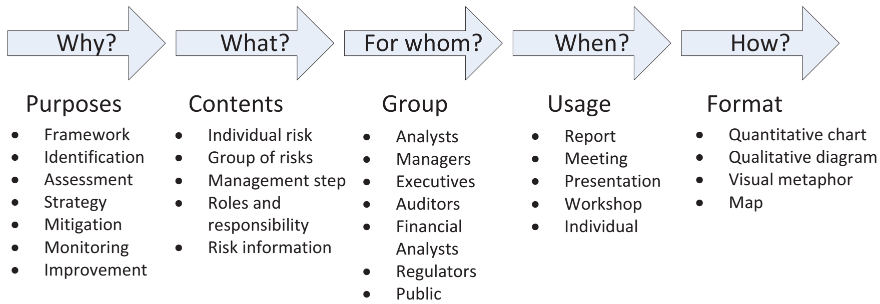


Figure 3: Risk visualization framework (Eppler and Aeschimann, 2008).

- Show the scope of risk visualization; that is, where and when can it provide tangible benefits;
- A checklist of factors to take into account when visualizing risks; and
- Show various representation formats to visualize risks.

This framework is designed to answer the why, what, for whom, when, and how questions of a risk visualization. The framework is shown in Figure 3.

The *why* component of the framework addresses the potential uses of a risk visualization. For example, a visualization whose purpose it is to communicate a risk framework is different than one whose aim it is to show the distribution of a project's cost. The *what* component of the framework focuses on the contents that are depicted in a risk visualization. For example, a visualization may focus on an individual risk and its attributes, a group of risks and their relationships, or the risk response plan and various organizations responsibilities. The *for whom* component of the framework addresses which stakeholders the visualization is designed for. For example, analysts may want to understand risks only in their area of responsibility, managers and executives will require a much wider understanding of the organizations risks, and auditors will want to focus on residual risks and non-effective controls. The *when* component of the framework focuses on the actual usage of the visualization. For example, a risk report may require a publication quality visualization, whereas a meeting with an individual only requires a basic illustration. Lastly, how addresses the format of the risk visualization: quantitative charts, qualitative or conceptual diagrams, maps, etc.

These five components provide the scope for when risk visualizations can provide tangible benefits. Likewise, the factors components that provide a checklist that should be considered should when designing visualizations.

5 Cost Risk Visualization

The preceding discussion provides a conceptual framework and guidelines to help analysts design risk visualizations. In this section, we apply these concepts and show visualizations that provide answers to the seven points raised in the introduction. This section is divided in six parts: one part for each point, with the exception of points five and six (i.e., project cost distribution and contingency level) that are presented together. In each part, we first frame the visualization using the Eppler and Aeschimann (2008) framework, and then suggest visualizations to respond to each point. The data shown in the visualizations is similar to that shown in the 2013 Next Generation Fighter Capability Annual Update (Department of National Defence, 2013). The annual update does not include information regarding some of the seven points, and for these situations fictional data is used.

Several different visualizations may be used to respond to each of the seven points. Those shown in this section are a subset, however those described are the ones most often used. Furthermore, interactive visualization has been identified as being effective to help decision makers understand risks (Roth, 2012). The visualizations discussed in this section could be implemented as interactive visualizations, however this aspect is not discussed since the software required to implement these features (e.g., D3, Tableau) are currently not available on the Defence Wide Area Network.

5.1 Assumptions, Bounds, Distributions, and Uncertainty

Any model is an abstraction of reality and as such assumptions have to be made to organize the analyst's thoughts. Within the context of risk analysis, the risk model helps the analyst to logically isolate and sort out complicated chains of cause and effect and influence between the numerous interacting risk factors. Certain cost risk assumptions may be dictated by the project stakeholders while others by the risk analyst. Key assumptions are those that are most likely to significantly affect the determinations and/or estimates of risk presented in the risk analysis. The assumptions therefore, need to be discussed in any cost risk report and the impact or implications if any of the assumptions do not hold or are relaxed. This reporting of assumptions can be done through the critiquing of the model (limitations) or through a discussion on why a given risk model or modelling strategy is chosen.

There are several methods to calculate contingencies or to provide a risk-adjusted cost estimates. These are discussed in detailed in previous chapters. The more popular and relatively established methods use probabilistic models either using the summation of various independent distributions (known as convolution) or simulations. Once again it is useful to document and discuss why simulation or convolution is used in the risk analysis and the associated advantages and disadvantages of the chosen approach. Some of these discussions are necessarily complex. In such situations the technical aspects can be relegated to an annex.

A short description of probability models and the importance of including information on model's strengths and limitations are detailed in Annex B at the end of this chapter. As a guiding principle, when reporting cost risk model assumptions, we suggest the following:

1. Major model assumptions and the impact on the results if incorrect. This can be relegated to an annex but needs to be part of a the decision support document.
2. Model strength and weaknesses.
3. Rationale for picking the model given its strengths and weaknesses. This can be relegated to an annex.
4. Model validation.
5. Guide on how to interpret model results (particularly statistical and graphical outputs).
6. Data issues and problems; in particular, problems from the perspective of answering the decision questions and impacts on cost estimates.

5.2 Risks Associated With a Project's Cost

The second point is to identify the risks associated with the project's cost. Table 3 shows the components of the Eppler and Aeschimann (2008) risk visualization framework and descriptions of how a visualization that shows the risks associated with a project's cost fit within the framework. The format description used is taken from Lohse et al. (1994).

A risk universe diagram may be used to convey the risks associated with a project's cost (Eppler and Aeschimann, 2008). The task associated with this visualization is association (i.e., perceive as similar); that is, the risks in each category should be perceived as similar since they are grouped together.

Table 3: Cost risk framework – risks associated with a project's cost.

Risk Framework Component	Description
Purpose – Why?	Framework/Identification/Assessment. To present the identified risks within the context of the risk framework.
Contents – What?	The risk framework and identified risks.
Group – For whom?	Executives
Usage – When?	Cost report
Format – How?	Table (graphical) / Graph

The groups of risks are visually encoded using position, which is the most effective encoding for categorical data (see Table 1). An example of a risk universe diagram is shown in Figure 4. The figure is interpreted as follows: there are ten categories[10] and a total of 37 relevant risks. In the figure, each risk is labeled as R_i, where i is a risk identification number, whereas in an actual implementation a short description of each risk would be provided.

The uncertainty associated with the data shown in this visualization is due to disagreement and creditability. For example, different sources may not agree on the set of risks. Techniques to include such types of uncertainty include colouring the risk descriptions and scaling the risk descriptions' text.

A risk matrix may be used to convey the risks' likelihood and impact (Roth, 2012). The task associated with this visualization is order (i.e., perceive as ordered); that is, the risks should be perceived as ordered based on their likelihood and impact. The risks are visually encoded using position, which is the most effective encoding for ordinal data (see Table 1), and their category is visually encoded using colour, which is the second most effective encoding for categorical data. Figure 5 shows an example risk matrix, where the likelihood and impact categories are taken from the Department of National Defence (DND)/Canadian Armed Forces (CAF) Integrated Risk Management Guidelines (Department of National Defence and Canadian Armed Forces, 2007). The figure is interpreted as follows: Risk 4 is categorized as Capital Infrastructure with a likelihood of Likely and an impact of Major.

[10]The categories are a subset of those listed in the Treasury Board of Canada Secretariat Guide to Risk Taxonomies. See http://www.tbs-sct.gc.ca/tbs-sct/rm-gr/guides/grt-gtr01-eng.asp.

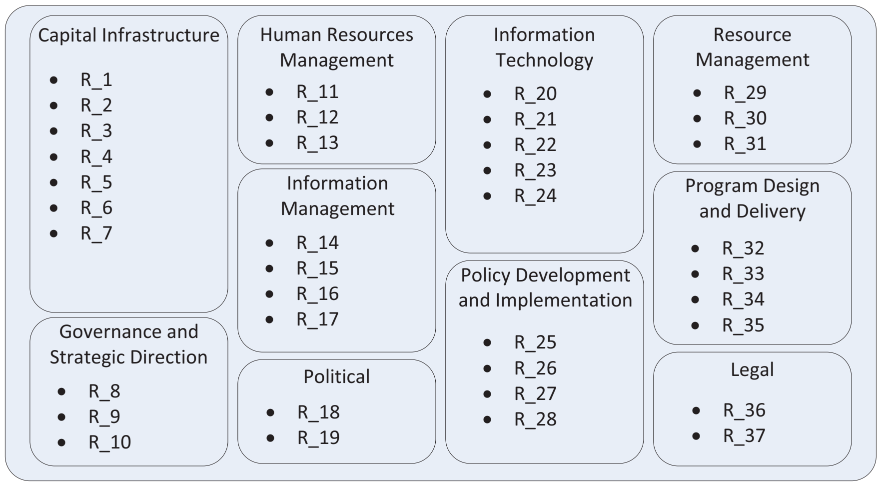


Figure 4: Risk universe. Each category is represented by a rounded rectangle whose size is proportional to the number of risks identified in the category. Each risk is labeled as R_i, where i is the risk identification number.

The uncertainty associated with the data shown in this visualization is due to measurement precision, disagreement, and creditability. For example, different sources may not agree on the set of risks, definition of risk assessments may be misunderstood, and the likelihood and impact assessments for a risk may differ between sources. These uncertainties may be encoded by modifying the shapes of the risks or adding texture.

5.3 Sensitivity Analysis

The third point to be addressed by the cost report is to provide a sensitivity analysis of the project's cost, including the scenarios that lead to the uncertainty. Table 4 shows the components of the Eppler and Aeschimann (2008) risk visualization framework and descriptions of how a visualization that shows a sensitivity analysis fits within the framework.

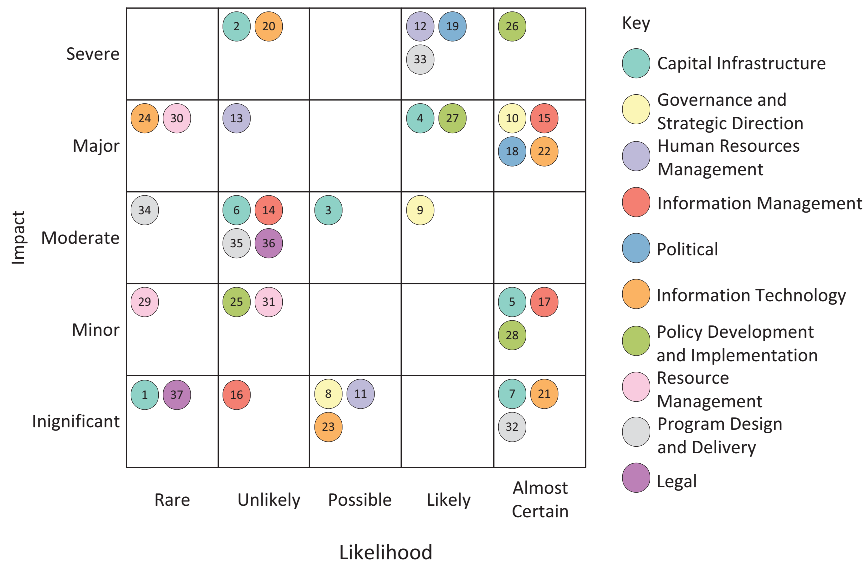


Figure 5: Risk matrix. Each risk i is represented by a circle, where i is the risk identification number and the circle's colour represents its category.

Table 4: Cost risk framework – sensitivity analysis.

Risk Framework Component	Description
Purpose – Why?	Assessment. To present the project's cost's sensitivity within the cost/risk breakdown structure, and identify events that lead to the uncertainty.
Contents – What?	Project's base cost and its sensitivity. The scenarios that are the cause of the high and low values of each category are listed.
Group – For whom?	Executives
Usage – When?	Cost report
Format – How?	Graph

A tornado diagram[11] may be used to convey the sensitivity of a project's cost (in budget year or constant year dollars) with respect to the cost/risk breakdown elements. The tasks associated with this visualization are selection (i.e., perceive as different) and quantity (i.e., perceive as proportional); that is, the cost/risk breakdown elements that lead to the largest uncertainty should be perceived as different and the size of uncertainties should be perceived as proportional. The breakdown elements are visually encoded using position (i.e., larger uncertainty near the top and smaller uncertainty near the bottom), which is the most effective encoding for categorical data (see Table 1). Furthermore, the uncertainty associated with each element is visually encoded using length, which is the second most effective encoding for quantitative data. Lastly, at the end of each bar appears a short description of the scenario associated with the high/low cost. An example of a tornado diagram[12] is shown in Figure 6. The figure is interpreted as follows: a flyaway unit cost of $140 million is used to calculate the project's base estimate of $8.5 billion, a low flyaway unit cost of $110 million results in a base estimate of less than $7.5 billion, and a high flyaway unit cost of $180 million results in a base estimate of $9.75 billion.

The uncertainty associated with the data shown in Figure 6 is due to measurement precision, completeness, disagreement, and creditability. For example, different sources may not agree on the scenarios that lead to the sensitivities, elements may be missing (i.e., known unknowns) because data was not available, and elements may be missing because they are unknown unknowns. Techniques to include such types of uncertainties include: modifying the bar's colours to show the degree of data quality; using multiple bars for each element to show different data sources; and including text to list elements that were identified but a sensitivity analysis was not performed.

5.4 Correlation Between Risks

The fourth point addressed by the cost report is the correlation between the identified cost/risk breakdown elements. Table 5 shows the components of the Eppler and Aeschimann (2008) risk visualization framework and descriptions of how a visualization of risk correlation fits within the framework.

[11] A tornado diagram is bar chart where categories are listed vertically and the bars are sorted with the largest uncertainty at the top and smallest at the bottom (Vose, 2008).

[12] The format of this diagram is different from that shown in the 2013 Next Generation Fighter Annual Update (Department of National Defence, 2013). In the annual update, the element are not sorted and the base, low, and high values in each category are not shown.

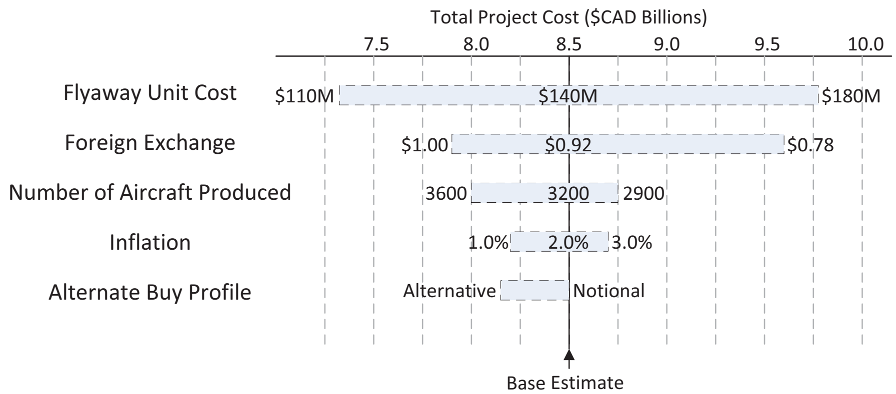


Figure 6: Sensitivity analysis. Each category shows the base value used to calculate the project's base cost, and the low and high values in each category used to calculate the cost's sensitivity.

Table 5: Cost risk framework – correlation between identified risk events.

Risk Framework Component	Description
Purpose – Why?	Assessment. To present the correlation between identified cost/risk breakdown elements.
Contents – What?	Cost/risk breakdown elements and their interdependencies.
Group – For whom?	Executives
Usage – When?	Cost report
Format – How?	Chart (network) / Table (graphical)

An influence diagram may be used to convey if a positive or negative correlation exists between cost/risk breakdown elements. The task associated with this visualization is association (i.e., perceive as similar); that is, breakdown elements that are correlated should be perceived as related. The cost/risk breakdown elements are visually encoded using position, which is the most effective encoding for categorical data (see Table 1). The relationships between the breakdown elements are encoded using connections (lines), which is the simplest way of showing relationships (Spence, 2007). An example of an influence diagram is shown in Figure 7. The figure is interpreted as follows: fuel price is influenced by inflation and foreign exchange, and in turn influences the yearly flying rate.

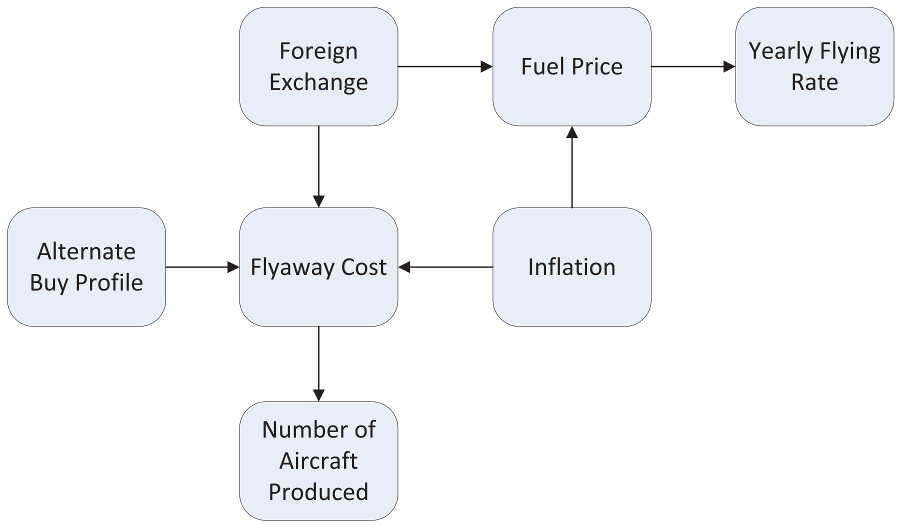


Figure 7: Influence diagram. Breakdown elements are shown as rounded rectangles and relationships are shown as lines, where arrows indicate the direction of the relationship. For example, alternate buy profile influences the flyaway unit cost.

The uncertainty associated with the data shown in Figure 7 is due to measurement precision, completeness, disagreement, and creditability. For example, different sources may not agree on the relevancy of the breakdown elements or the relationships between them. These uncertainties may be encoded by modifying the elements' attributes and the relationships' attributes, such as using colour to represent the degree of agreement between sources.

A heat map may be also be used to convey the strength of correlation between the breakdown elements. The tasks associated with this visualization are association (i.e., perceive as similar) and quantity (i.e., perceive as proportional); that is, breakdown elements with similar patterns should be perceived as similar and the strength of the correlations should be perceived as proportional. The elements are visually encoded using position, which is the most effective encoding for categorical data (see Table 1). The position of the elements may be determined by sorting the elements: highest to lowest single correlation, highest to lowest mean correlation, highest to lowest number of correlations, etc. The strength of the correlations are visually encoded using colour saturation, which is the one of the least effective encodings for quantitative data but the second most effective encoding for ordinal data. If a decision maker focuses on the patterns of the correlations (i.e., Element A and B have a higher correlation than A and C) rather than the quantitative data, then a heat map is a good representation of correlations. An example of a heat map is shown in Figure 8. The figure is interpreted as follows: a positive correlation between 0.6 and 0.8 exists between foreign exchange and flyaway cost, and a negative correlation between -0.4 and -0.6 exists foreign exchange and fuel price.

The uncertainty associated with the data shown in Figure 8 is due to measurement precision, completeness, disagreement, and creditability. For example, different sources may not agree on the relevancy of the breakdown elements or the strength of the correlations between the elements. These uncertainties may be encoded by modifying the attributes, such as using texture to represent the degree of agreement between sources.

5.5 Distribution of a Project's Cost and Selected Contingency Level

The fifth and sixth points to be discussed in the cost report are the project's base cost estimate, the probability of the base cost estimate, the distribution of the project's cost, and the selected contingency level. Table 6 shows the components of the Eppler and Aeschimann (2008) risk visualization framework and descriptions of how a visualization of the distribution of a project's costs fits within the framework.

A histogram, box plot, or cumulative distribution (S curve) may be used to convey the project's base cost estimate, its probability level, the distribution of the project's cost, and its contingency level. The task associated with these visualizations is selection (i.e., perceiving as different); that is, the project's base cost and contingency level should be perceived as different. Each visualization is good to show some of these items, but not all of them.

In a histogram, the project's base cost and contingency level are encoded using position, which is the most effective encoding for quantitative data. The distribution of the project's cost is encoded using length, which is the

Figure 8: Heat map. Breakdown elements are shown as columns and rows, and the correlation between elements is represented by colour – red is negative and green is positive.

second most effective encoding for quantitative data. While a histogram is a good visualization to show a project's base cost estimate and the distribution of the project's cost, it is difficult to understand the contingency level (Gresh et al., 2012). An example of a histogram is shown in Figure 9. The figure is interpreted as follows: the probability of the project's base estimate ($8.5 billion) occurring is 25% and the selected contingency is $1.25 billion, giving a total project cost of \$9.75 billion (red dashed line). However, the reason for selecting the contingency or its interpretation is difficult to understand.

Table 6: Cost risk framework – project base cost, distribution, and contingency level.

Risk Framework Component	Description
Purpose – Why?	Assessment/Strategy. To present the project's base cost, its probability level, the distribution of the project's cost, and the selected contingency level.
Contents – What?	Project cost, distribution, and contingency level.
Group – For whom?	Executives
Usage – When?	Cost report
Format – How?	Graph

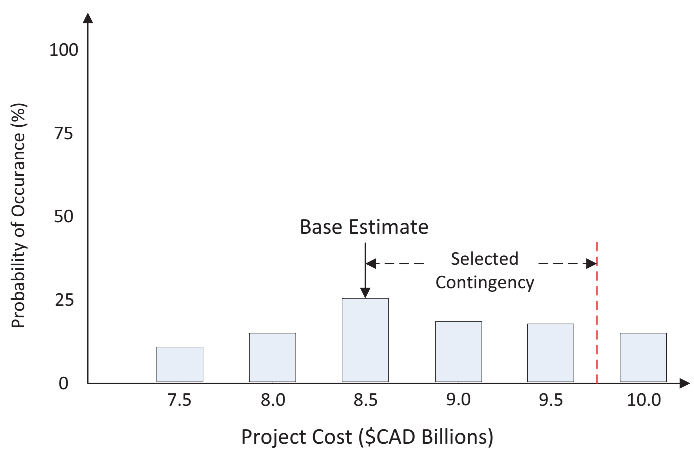


Figure 9: Histogram of a project's cost distribution. The red dashed line represents the project's base cost estimate plus the selected contingency.

In a box plot, the project's base cost estimate and contingency level are encoded using position, which is the most effective encoding for quantitative data. The distribution of the project's cost is encoded using length, which is the second most effective encoding for quantitative data. While a box plot is a good visualization to show a project's base cost estimate and the distribution of the project's cost, it is difficult to understand the contingency level (Gresh et al., 2012). An example of a boxplot[13] is shown in Figure 10. The figure is interpreted as follows: the project's base estimate is $8.5 billion and the selected contingency is $1.25 billion, giving a total project cost of $9.75 billion (red dashed line). However, the reason for selecting the contingency or its interpretation is difficult to understand. Furthermore, the probability of a specific project cost occurring is not immediately obvious.

In a cumulative distribution (S curve), the project's base cost estimate, distribution, and contingency level are encoded using position, which is the most effective encoding for quantitative data. While a cumulative distribution is a good visualization to show a project's base cost estimate and the contingency level, it is difficult to understand the distribution of the project's cost (Gresh et al., 2012). An example of an S curve is shown in Figure 11. The figure is interpreted as follows: the project's base estimate is $8.5 billion and the selected contingency is $1.25 billion, giving a total project cost of $9.75 billion. The probability that the project's cost will not exceed the base estimate is approximately 50% and the probability that the project's cost will not exceed the base estimate plus contingency is approximately 95%. However, the probability of the base estimate occurring is not as clearly communicated as compared to the histogram and boxplot.

The uncertainty associated with the data shown in these visualizations is due to inferences. For example, different models may not agree on the project's base cost or its distribution. These uncertainties may be encoded by using multiple plots (i.e., comparing several histograms, box plots, S curves).

[13] A boxplot shows five measures for a distribution: lower whisker, first quartile, median, third quartile, and upper whisker. The lower and upper whiskers (horizontal lines outside the box) are the most extreme data points that are no more than 1.5 times the height of the box away from the box. The first quartile (bottom of the box) is the data point where 25% of the distribution is lower. The third quartile (top of the box) is the data point where 25% of the distribution is higher. The median (thick black line) is the data point where 50% of the distribution is higher and 50% of the distribution is lower. The data points outside the whiskers are outliers in the individual distributions.

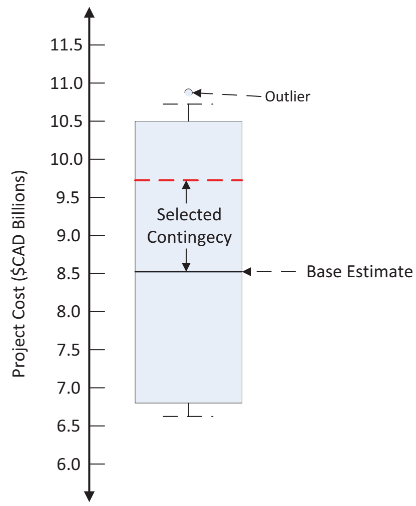


Figure 10: Boxplot of a project's cost distribution. The solid black line is the project's base cost estimate and the red dashed line is the project's funding including selected contingency.

5.6 Project Cost by Year

The last question to be answered by the cost risk report is to discuss the risk adjusted, in budget year dollars, project's cost by year to show phasing of risks. Table 9 shows the components of the Eppler and Aeschimann (2008) risk visualization framework and descriptions of how a visualization that shows a risk correlation fits within the framework.

A time series graph may be used to convey the project's risk-adjusted cost, in budget year dollars, over time. The task associated with this visualization is quantity (i.e., perceiving as proportional); that is, the risk-adjusted cost should be perceived as proportional between years. The project's cost is visually encoded using position, which is the most effective encoding for quantitative data.

The uncertainty associated with the data shown in this visualization is due to inferences. For example, different models may not agree on the projects base cost or its distribution, which in turn leads to different costs over time. These uncertainties may be encoded by showing multiple lines for different models.

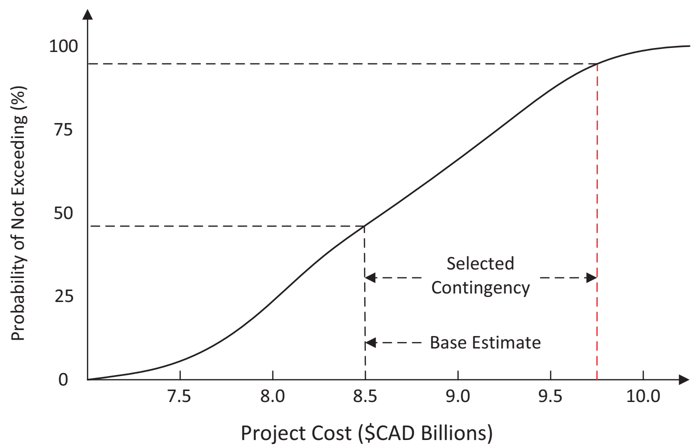


Figure 11: S curve of a project's cost distribution. The vertical dashed black line represents the project's base cost estimate and the red dashed line represents the selected funding level. The difference between these two values represents the selected contingency.

Table 7: Cost risk framework risk-adjusted project cost by year in budget year dollars.

Risk Framework Component	Description
Purpose – Why?	Mitigation. To discuss the risk adjusted, in budget year dollars, projects cost by year to show phasing of risks.
Contents – What?	Risk-adjusted project cost, in budget year dollars, by year.
Group – For whom?	Executives
Usage – When?	Cost report
Format – How?	Graph

6 Conclusion

In this chapter, visualizations to communicate cost risk analyses with decision makers are presented and discussed. Seven topics related to a project's cost risk are identified that, if possible, should be included in a cost risk

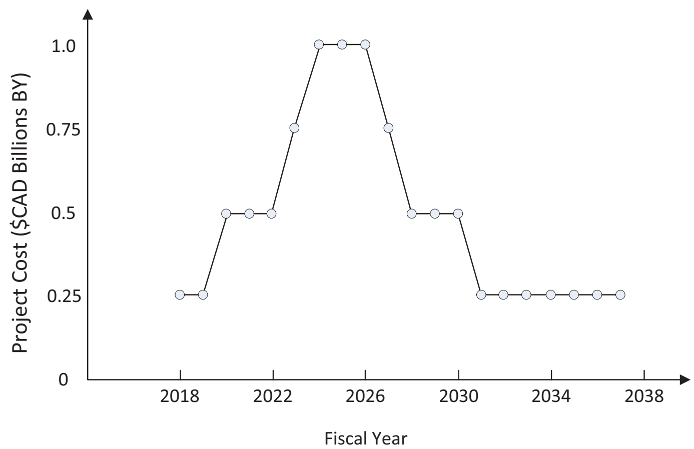


Figure 12: Time series graph of a project's risk-adjusted spending profile in budget year dollars.

report. For each topic that can be addressed using visualization, examples visualizations are presented. Each example is discussed in the context of a risk visualization framework, best practices to visually encode data, and a data uncertainty framework.

The quality of the cost risk visualizations ultimately is determined by the ability of an analyst to turn the concepts discussed in this chapter into reality. Armed with the visualization guidelines, risk visualization framework, and data uncertainty framework an analyst has the necessary tools to create simple and effective visualizations that ease the communication a project's cost risks with decision makers.

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A Visualization Literature

A.1 Pre-Attentive Vision

The selection of how data is visually encoded strongly affects a visualization's ability to ease communication of information with decision makers. Good visual encodings are those that take advantage of how human vision works, in particular how it can rapidly assess images. This rapid assessment is referred to as pre-attentive vision (Healey and Enns, 2012). Pre-attentive vision is so important to visualization that Ware (2013) wrote:

> "An understanding of what is processed pre-attentively is probably the most important contribution that visual science can make to data visualization."

Tasks, such as identifying an object, which can be performed in 200-250 milliseconds are considered pre-attentive. Figure A.1 shows examples of pre-attentive visual encodings. Objects that are defined by two or more visual properties typically cannot be detected pre-attentively. Although there are several theories that attempt to explain pre-attentive vision (e.g., Feature Integration Theory, Texton Theory, Similarity Theory, etc.), they usually agree on which visual encodings we can attend to.

A.2 Visual Encodings

Bertin (1983) identified four tasks[14] that are common to information visualization and within these tasks. Within these tasks, he considered six visual encodings can could be used to perform these tasks: size, value, texture, colour, orientation, and shape. Bertin (1983) ordered these roughly according to the number of tasks that each encoding can support, as shown in Figure A.2.

Bertin (1983) focused on visualizations on the printed page. Green (1998) argued that was neither accurate nor complete and should include dynamic visualizations. The resulting differences between Green (1998) and Bertin (1983) visual encoding assignments, shown in Table A.1 can be divided into two groups: changes to Bertin (1983) encodings and additional encodings. Changes in Bertin (1983) encodings by Green are:

- Shape can be selective. Green (1998) points out that several studies show that a large number of shapes can be selective and/or associative,

[14]Since Bertins work, others have proposed classifications of tasks: for example, Wehrend and Lewis (1990), Springmeyer et al. (1992) and Shneiderman (1996).

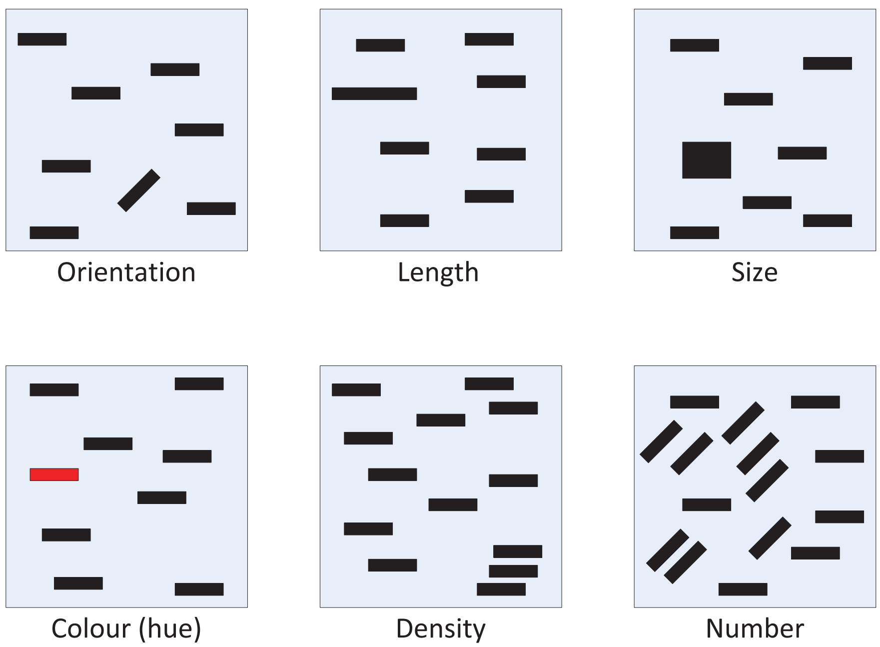

Figure A.1: Examples of pre-attentive visual encodings.

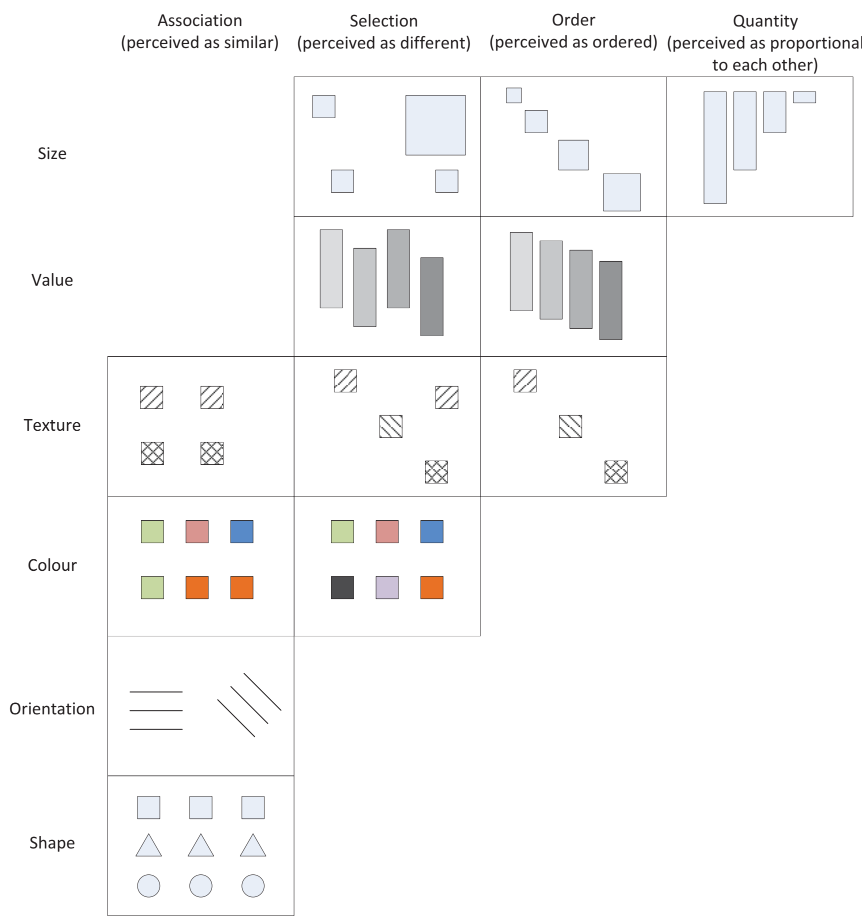

Figure A.2: Suitability of various visual encodings to support common information visualization tasks as proposed by Bertin (1983).

and that Bertin (1983) did not identify shapes as selective due to a very narrow definition of shape used in his work.

- Colour can be ordered. Green (1998) points out that over a small range hue[15] can be ordered (e.g., an ordered scale of yellow-green continuum). For example, the Farnsworth-Munsell Test[16], a commonly used test for colour blindness, asks individuals to order tiles base on their hue.
- Brightness is ordered, but is only sometimes quantitative. This is because brightness results in a psychometric function (i.e., relationship between a physical stimulus intensity and a perceived magnitude) that is nonlinear (i.e., perceived magnitude grows more slowly than physical intensity). However, if brightness is correctly scaled such that a doubling in brightness results in a doubling in perceived magnitude, then it may be quantitative. It must be noted that brightness can be used in such a manner on a computer screen, not in print.

Meanwhile, additional encodings identified are:

- Motion (velocity) can be used for selection, ordering, and quantity. Green (1998) points out that:
  - Several studies have shown pre-attentive search based on motion differences;
  - Velocity is likely to be ordered, since it is a continuum of magnitude and it is relatively simple to discriminate steps of increasing value; and
  - Velocity is typically not quantitative since it produces a nonlinear psychometric function, however this can be compensated for by appropriate scaling.
- Motion (direction) can be used for selection.

Figure A.3 shows the Cleveland and McGill (1985) study results, which are ordered with most accurate at the top and least accurate at the bottom.

[15] Colour hue defines pure colour (i.e., red, green blue). Colour saturation defines a range from pure colour (i.e., from pure colour to gray) at a constant lightness level. The website ColorBrewer (http://colorbrewer2.org/) may be used to select colour schemes.

[16] See http://www.color-blindness.com/farnsworth-munsell-100-hue-color-vision-test/.

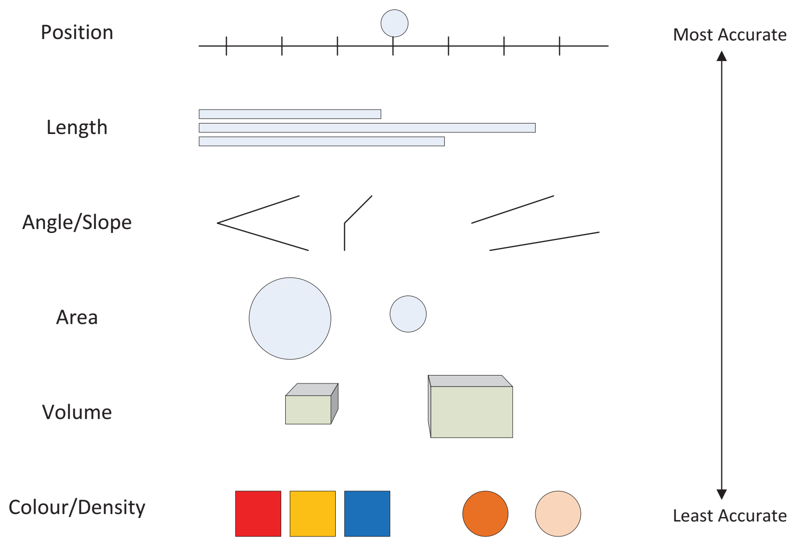

Figure A.3: Relative difficulty of assessing quantitative value as a function of visual encoding as suggested by Cleveland and McGill (1985). Most accurate encodings are at the top and least accurate are at the bottom.

Table A.1: Suitability of various visual encodings for common tasks in information visualization as proposed by Green (1998).

	Association	Selection	Order	Quantity
Planar	Yes	Yes	Yes	Yes
Style		Yes	Yes	Yes
Brightness		Yes	Yes	Yes – if scaled
Texture	Yes	Yes	Yes	
Colour (hue)	Yes	Yes	Yes (limited)	
Orientation	Yes	Yes		
Shape	Yes	Yes		
Motion (velocity)		Yes	Yes	Yes – if scaled
Motion (direction)		Yes		
Flicker (frequency)		Yes	Yes	Yes – if scaled
Flicker (phase)		Yes		
Disparity		Yes	Yes	

B Examples of details about Cost Risk Models and Methods

In this section some examples are provided on cost risk models and methods that can be relegated to an annex. We begin by providing a simple explanation on why a given cost risks method was chosen for a hypothetical project.

B.1 Probability Models

The attractive feature of probability models is that each identified cost risk factor is represented in a distribution function as opposed to a point estimate, giving the decision maker a better sense of the uncertainties around the risk factors. But often there are more than one cost risk factors and these need to be simulated and aggregated to generate a new distribution with associated percentiles. One key assumption behind the aggregation is that each cost risk factors is independent. This may be a restrictive assumption that could lead to an underestimation (if there are positive correlations-reinforcing the risk factors) or overestimation (if the relationship is negative where an increase in one risk factor leads to a decline in another) of the estimated cost.

As an example consider the use of the Expected Value (EV) method to quantify cost risk factors and provide a risk adjusted cost estimate for the Next Generation Fighter Capability (NGFC) project in the annual update to parliament (Department of National Defence, 2013). Most often EV methods are closely tied to experts engagements. Implicit in EV models is the assumption that the Subject Matter Experts (SME) are consulted to identify and/or confirm risks, identify probability of occurrence of risks and recognize the consequences of the realization of the risk (in financial terms). The level of knowledge expected from the SMEs is not trivial. Decision makers need to be assured that the SMEs selected are indeed knowledgeable about the project and the consequences of the cost risk factors. For the NGFC project it should be noted that SMEs were provided with a detailed sensitivity analysis of the risk factors including the maximum impact and the associated distributions. Thus the SMEs are not performing the complex task of forecasting, for example, foreign exchange in year X but to assign the probability that the worst case or maximum impact associated with a given exchange rate is going to be met or exceeded. Thus the assumption implied by the use of the model in the NGFC case is the milder version: the only unknown here is the probability of occurrence.

As pointed out in the NGFC annual report, the expected value method is relatively superior to the assignment of a percentage amount subjectively. However, the report should also identify some the limitations of the model. For example, the EV method reduces risk to the expected value of damage. Kaplan and Garrick (1981) found this viewpoint misleading because a single number is not a big enough concept to communicate the idea of risk. In particular, this technique would equate a low-probability high-damage scenario with a high-probability low-damage scenario (Kaplan and Garrick, 1981). The EV method also ignores the inherent uncertainty around the impact factor. In addition, the method does not make allowances to potential correlations among the cost risk factors that can exacerbate or dilute the total impact of the cost risk factor.

B.2 Convolution

Convolution is the addition of independent random variables. It involves solving analytical formulas to derive closed-form solutions. Three main approaches are used to combine distributions analytically: manipulation of integrals, moment generating functions, and characteristic functions. Using moment generating functions is a straightforward way to analyze linear combinations of many independent random variables and avoid the manipulation of integrals. However, the moment generating function does not always exist. Sometimes the integral calculating its mathematical expectation does not converge. A powerful alternative for analysing sums of independent random variables is the use of characteristic functions.

Unlike the moment generating function, the characteristic function always exists. Whatever convolution approach is used, it is always necessary to estimate the underlying probability density functions based on observed data. Data are crucial for making inferences on the type of probability distributions and the corresponding parameters. It is usually thought of as a random sample from a large population. The problem of lacking data simply makes convolution inoperative. In this study, we use a simulation-based approach instead of an exact mathematical derivation of the convolution. This is due to the potential existence of correlation between some of the cost risk factors (violating the independence assumption) and lack of detailed data.

B.3 Subject Matter Experts

Cost risks can be identified organically from the cost analysis and data integrity assessment. Specifically the assumptions and models used to estimate portions of the life cycle cost will point to either the need for sensitivity analysis or the models used will provide ranges around a cost point estimate. In addition, a cost risk assessment session can be convened using Subject Matter Experts (SMEs) to identify additional cost risk factors. In the session the SMEs will confirm the cost risks already identified during the sensitivity analysis and discuss the inclusion of new cost risks.

If the SMEs are also the departments risk stakeholders they can also determine the likelihood of the cost risk occurring. In such scenarios, the EV method is used where the probability of the risk occurrence is multiplied by the impact (if the event occurs). Such methodology was employed in the recent Report to Parliament (Sokri and Solomon, 2013). The use of the expected value method in this case is more robust than assigning a percentage amount to a cost estimate. If the cost risks identified are fairly complex then simulations-based method can be employed to derive likelihoods. It is important to note that the contingency amount derived using expected value method can be re-cast from the perspective of the SMEs risk tolerance. After the SMEs agree upon cost risk factors they can pronounce their preferred risk tolerance. For example the SMEs may indicate a risk tolerance of 75% meaning they are willing to accept the risk that there will be a 25% chance that the estimated project cost plus contingency.

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This document describes a framework that is designed to standardize the identification, analysis, and reporting of a project's cost risk within the Department of National Defence (DND) and Canadian Armed Forces (CAF). While there are extensive academic and industrial standards on risk identification, analysis, and reporting, the distinguishing characteristics of this framework are its particular emphasis on DND/CAF operating environment, the constraints of existing public service policies, and stakeholder's unique requirements. These important public sector considerations include: the Data Readiness Level metric to measure the availability of data for risk assessment; a checklist to link the Chief Financial Officer's attestation process to the selection of appropriate visualization and reporting techniques; and the contextualization of cost risk in DND as a subset of the Government of Canada's own challenge of funding its policies and programs within available fiscal room.

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