Chapter 7 – UNCERTAINTY AND RISK

7.1 INTRODUCTION

Life cycle cost estimates of weapon system acquisition programmes are inherently uncertain and risky. Estimates are often made when only 5% of a programme's total cost is known. Years of system development and production, and decades of operating and support costs, need to be estimated. Estimates, in turn, are based on historical samples of data that are almost always messy, of limited size, and difficult and costly to obtain. Indeed, great efforts are usually required to squeeze usable information from a limited, inconsistent set of data. And no matter what estimation tool or method is used, historical observations never perfectly fit a smooth line or surface, but instead fall above and below an estimated value. To complicate matters, the weapon system under study is often of sketchy design. Only limited programmatic information may be available on such key parameters as schedule, quantity of units to be of the system may actually change as the system proceeds through development and even production. Increases in system weight, complexity, and lines of code are commonplace.

For all of these reasons, a life cycle cost estimate, when expressed as a single number, is merely one outcome or observation in a probability distribution of costs. That is, the estimate is stochastic rather than deterministic, with uncertainty and risk determining the shape and variance of the distribution. To better support senior leadership, some sense of risk and uncertainty needs to be presented along with the point estimate. This chapter, through the following sections, demonstrates how to do this by providing guidance on the following:

- Definitions.
- General approach.
- Risk data collection.
- Estimation process.
- Cost and budget Risk.
- Sensitivity analysis.
- Appendix 1: Optimism Bias.

7.2 DEFINITIONS

The terms "risk" and "uncertainty" are often used interchangeably, but they are not the same.

- **Uncertainty** is the indefiniteness or variance of an event. It captures the phenomenon of observations, favourable or unfavourable, falling to the left and right of a mean or median value.
- **Risk** is exposure to loss. Or, in a weapon-system acquisition context, it is a measure of the potential inability to achieve overall programme objectives within defined cost, schedule, and technical constraints, and has two components: (1) the probability/likelihood of failing to achieve a particular outcome, and (2) the consequences/impacts of failing to achieve that outcome.[1]

Risk and uncertainty, then, are related. Uncertainty is probability while risk is probability and consequence, as Figure 7-1 shows. The next section of this chapter outlines a procedure for estimating risk and uncertainty.

[1] "Risk Management Guide for DoD Acquisition," Fifth Edition, June 2003; U.S. Defense Acquisition University; p. 7.

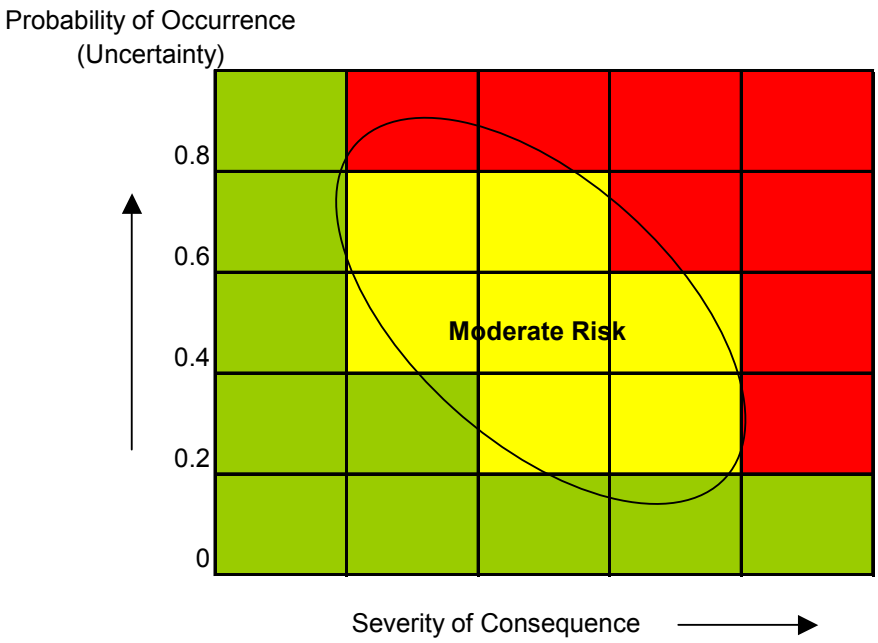

Figure 7-1: Risk Matrix.

7.3 GENERAL APPROACH

There are a wide variety of methods and models available for conducting risk and uncertainty analysis of life cycle cost estimates of weapons systems. These include simple techniques such as adding a risk factor or percentage to a bottom-line estimate (see: Appendix 1, "Optimism Bias") and sensitivity analysis. Each, if used properly, can give scientifically sound results, but first a word of caution – based on the collective experience in cost estimating within the government and in the private sector, it is fair to say that the sophistication and underlying theory of many popular models often far exceeds the quality of the basic data inputs.[2]

There is simply no substitute for taking the time and effort to understand the technical risks and challenges in developing and producing sophisticated defence systems.[3] Historical analogies must be obtained. Information from subject matter experts must be elicited. Risk and uncertainty analysis cannot be relegated to an eleventh hour exercise based on flimsy inputs.[4]

7.3.1 Overview

Figure 7-2 presents an overview of a process for estimating risk and uncertainty.[5] ***While other techniques and variations of this process are available, the paradigm shown below is highly recommended***.

[2] Informal survey by the Naval Center for Cost Analysis in 2004 of 12 cost-estimating organizations in the United States and "Portfolio Management for New Product Development: Results of an Industry Practices Study," Drs. Cooper, Edgett, and Kleinschmidt; Product Development Institute; 2001; page 20. The "popular models" referenced by these authors are Crystal Ball and @Risk, the same two commercial models used most frequently in defense cost analysis in the United States.

[3] Biery, Hudak, and Gupta refer to this as "the most crucial … but generally overlooked" step in performing risk and uncertainty analysis. "Improving Cost Risk Analyses," 1994, p. 1.

[4] Interestingly, Dr. Cooper reports that one firm in his sample studied the historical accuracy of their probability estimates and found an average error of 300%.

[5] Much of the methodology presented herein was developed by Mr. Tim Anderson, Aerospace Corporation in collaboration with Dr. Steve Book MCR Federal Inc.

It provides outputs that have proven useful in responding to demands of senior executives for relevant information on budget risk on major acquisition programmes. More specifically, the process enables decision makers to budget a programme at a specific cumulative percentage level of risk, or, to fully understand the consequences of living within an already established budget. And it enables them to know the financial impact of specific, discrete risk events such as failure to successfully design a new fighter engine within fiscal and schedule constraints.

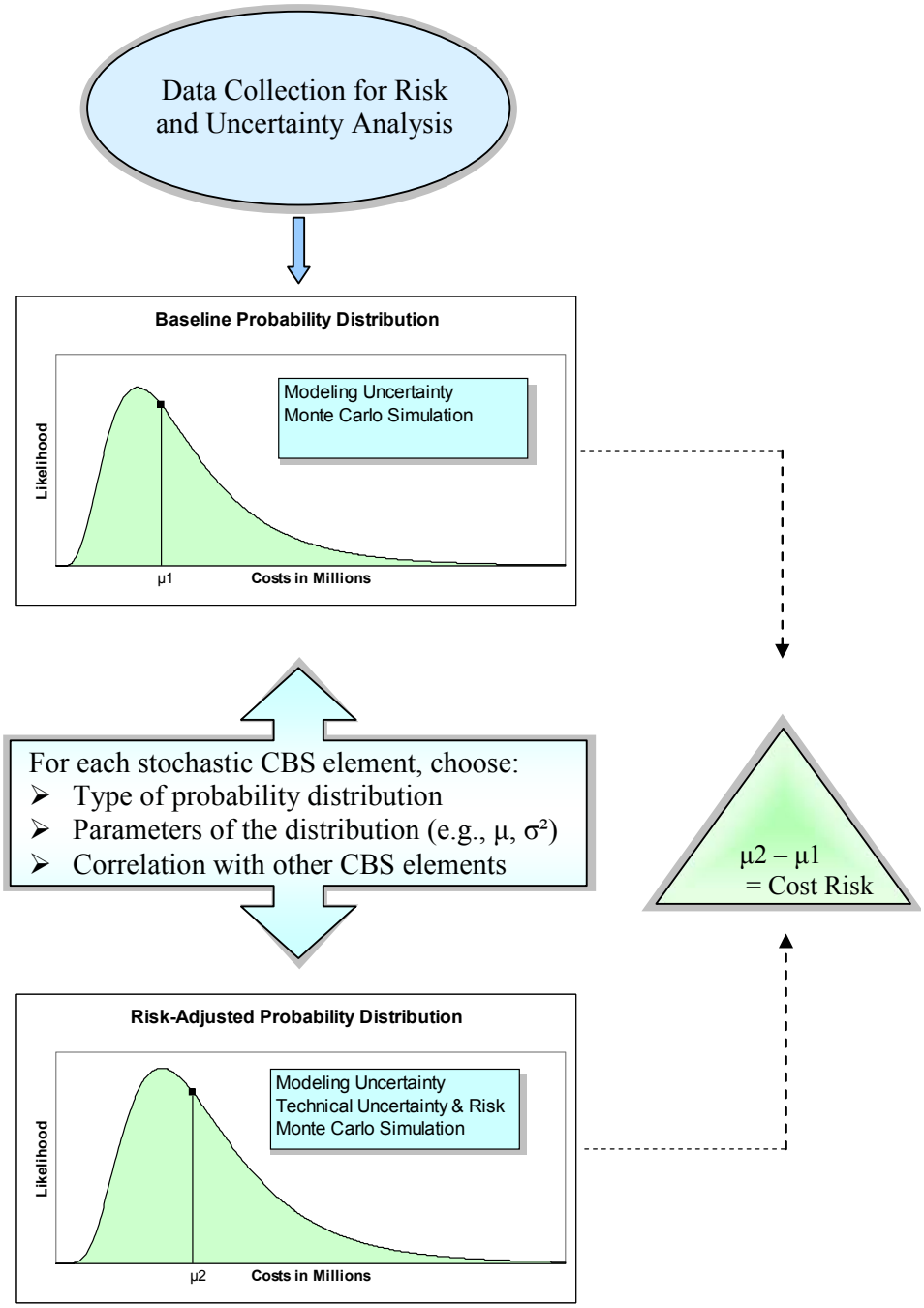

Figure 7-2: Process of Estimating Risk and Uncertainty.

The most important part of the process of estimating risk and uncertainty, and probably the most difficult, is data collection and analysis. All variables in the cost estimating model potentially affected by risk and uncertainty first need to be identified. These variables often include simple ratios and factors as well as more sophisticated CERs (cost estimating relationships) based on regression analysis. Probability distributions need to be estimated or selected for each variable. This entails first choosing the type of distribution to apply and then estimating the distribution's parameters such as high, low, and most-likely values. Popular distributions for this step include the normal, log-normal, and triangular. There are a number of techniques used to cull or estimate distribution types and parameters, such as using checklists or sound engineering judgment. Each is described in Sub-section 7.4.

It is also important in the analysis phase to identify discrete risk events, or unfavourable outcomes that might occur in developing, manufacturing, and operating weapons systems. An example might be failure of a new, state-of-the-art radar to work as intended when integrated on a ship or aircraft. For each of these risk events, probability distributions also need to be estimated or selected as well.

After the data collection and analysis phase, the analyst first generates a baseline cost estimate using Monte Carlo simulation followed by a risk-adjusted cost estimate. The output of each estimate is actually a frequency distribution of total costs, or, more technically, a probability density function, rather than a single number. It is essential to convey to senior leadership the notion that cost estimates are uncertain, that programmes can and do incur difficulties, and that the probability of a cost estimate becoming reality, when expressed as a single number, is actually zero.

In generating the baseline cost estimate, the analyst first regards as fixed the values of the explanatory or independent variables (Xs) in each of the cost model's CERs. Values of the Xs are usually found in the programme's CARD (Cost Analysis Requirements Description), or in the APB (Acquisition Programme Baseline). The baseline estimate does capture uncertainty in the relationship between dependent and independent variables in each CER. This uncertainty, in turn, results from three possible, though not mutually exclusive, sources:

- **Limited data.** In explaining changes in the cost of any CBS element, the list of relevant factors may be extended ad infinitum. However, due to data availability, perhaps only two or three of these factors are included in the analysis. Indeed, sometimes it is lucky to get just one relevant explanatory variable. The CER, then, becomes an over simplification of the complexities of reality. Errors result.
- **Human unpredictability.** Over and above the total effect of all relevant factors, there is a basic and unpredictable element or randomness in human responses that can be adequately characterised only by the inclusion of uncertainty in the analysis. This will hold as long as people rather than machines acquire and build weapons systems.
- **Errors of observation or measurement.** Cost and technical data are almost always difficult to obtain and are often of less than perfect accuracy. For example, overhead costs from different contractors may not be of the same scope or consistency due to differences in ways of doing business. Further, even data from the same contractor may differ significantly over time due to changes in the company's accounting system. Again, errors result.

In generating a risk-adjusted cost estimate, not only is basic CER uncertainty captured, as above, but technical risk and uncertainty as well. Unlike before, the Xs in each of the model's CERs are now regarded as stochastic. Technical, acquisition, and cost-estimating risks are now considered. Variables affected might include:

- Quantity of units to be developed or procured.
- Weight of a platform or system.

- External parameters such as the price of oil.
- System-to-platform integration challenges.
- Number of drawings.
- Number of SLOC (source lines of code) or percentage of SLOC reuse.
- Number of test flights.
- Key schedule milestones such as date of critical design review or date of first flight.
- Cost parameters such as learning curve rates, T1s (first unit costs), and percent award fee, assuming these variables are not already covered in uncertainty analysis.

Further, discrete risk events such as failure to effectively design a new aircraft engine or a new circuit card are captured here as well. As before, for each of these risk variables, probability distributions are estimated or selected, and Monte Carlo simulation is used to generate a probability density function.

Finally, the difference in mean values of the two probability distributions, risk-adjusted and baseline, represents cost risk. Senior leadership can then set budgets based on how much risk they are willing to tolerate.

The following sub-sections describe the process in more detail.

7.4 COLLECTING DATA FOR RISK ANALYSIS

Data is the raw material of risk and uncertainty analysis. It is critical to every estimate. Without good, solid data, whether based on historical analogies or on sound engineering understanding of the acquisition at hand, the risk and uncertainty estimate will be viewed as merely a guess or an opinion of the cost analyst. The more solid the data, the better will be the estimate.

At the start, it is important to understand the fundamental objectives of the programme, including requirements, scope, schedule, technical goals, and evolutionary phases. With this backdrop in mind, the following steps should be executed:

- Identify all potential variables in the cost model affected by risk and uncertainty. It is usually helpful to have these in a single input area in a workbook.
- Identify potential data sources for estimating risk and uncertainty for each of these variables. That is, identify various ways of trying to determine a variable's type of probability distribution and its associated parameters such as high, low, and most-likely values. Options include:
  - Using statistical equations from the cost model that give estimated means and variances.
  - Using scorecards, and derivatives thereof.
  - Culling ideas and information from subject matter experts.
  - Finding good historical analogies.
- Identify correlations between stochastic CBS elements.
- Identify sources for cross-checks. These might include use of alternative methodology, comparisons with historical cost growth on similar programmes, and, time permitting, sanity checks for completeness and reasonableness with subject matter experts.
- Develop and execute a data collection plan.

The following sub-sections discuss specific techniques employed in gathering and analysing the information required to conduct risk and uncertainty analysis.

7.4.1 Techniques

Data collection techniques are conveniently grouped into these categories, although there is some overlap between the three:

- Use of scorecards and their derivatives.
- Use of historical cost data.
- Use of subject matter experts (SMEs).

7.4.1.1 Scorecards

Scorecards and their derivatives usually present a vector of numerical values from which SMEs choose to assess risk in a given area, such as schedule. Scales, which indicate probability of occurrence or amount of risk, might range from 1 to 10 or perhaps from 1 to 3. These numerical values are then translated into impact on cost.[6]

7.4.1.2 Historical Data

An excellent source of information on risk and uncertainty is historical data and its use in the cost estimation process. Least squares regression analysis, for example, automatically generates an estimate of the mean and variance of an equation's random error term. These values can be input directly, without modification, into the Monte Carlo simulation. Further, metrics on growth in key parameters such as lines or code or aircraft weight from start of development through initial operational capability are very useful in shedding light on possible areas of risk.

7.4.1.3 Expert Opinion

Risk analysts have traditionally used historical data as an information source in probability assessments, but sometimes the required data is quite difficult to obtain. An important factor, which often causes relevant data to be scarce, is that risk analysis typically deals with rare events. Furthermore, the systems under study often represent new concepts and technologies for which little or no experience exists. In risk analysis where there is little or no relevant historical data, expert judgment is frequently applied. In other words, expert judgment is typically appropriate when:

- Data is sparse or difficult to obtain.
- Data is too costly to obtain.
- Data is open to different interpretations, and the results are uncertain.
- There is a need to perform an initial screening of the problems.

An expert, in this instance, is a person with special knowledge or skills in a particular area. The selection of the expert is important for the accuracy of the results to be obtained. The following criteria may be used for the selection process:

- Experience in performing judgments and making decisions, based on evidence of expertise like degrees, research, publications, positions and experience, etc.
- Availability and willingness to participate.
- Impartiality.
- Inherent qualities like self-confidence and adaptability.

[6] See **Cost Programmed Review of Fundamentals** (CostProf), Chapter 9, "Cost Risk Analysis," Society of Cost Estimating and Analysis, 2002, for an important discussion of scorecards, especially the advantages of interval versus ordinal ranking.

Further, culling of information from SMEs can be facilitated and made more rigorous by employing some of the following tools and procedures.

- **Checklists**. These can be based on experience of earlier programmes – risk issues can be identified and quantified through an examination of what occurred on previous programmes plus an overall understanding of the issues that are likely to be problematic on future programmes. These issues can be formalised into lists and structured in a way that suits the particular type of programme. New programmes can then be examined against the list and an opinion formed about each point raised.
- **Structured Interviews**. These would be held with responsible or knowledgeable staff, perhaps using the checklist as the basis. Interviews of this type are best done on a one-to-one basis, free of any hint of an inquisition. They can refine the perception of where difficulties may lie as well as drawing attention to areas that might not be covered in the checklists.
- **Brainstorming Sessions**. These are normally held with a group of knowledgeable staff in an atmosphere of free speculation and without peer criticism. People are invited to produce as many ideas as possible of the risks that might arise. This can lead to a very large number of ideas, some of which may be wild speculation. All risk ideas put forward have to be analysed and categorised into those that are real and need to be dealt with and those that are largely imagined or are extremely unlikely and can be ignored.
- **Assumption Analysis**. This is where all the basic assumptions are listed and challenged. This is often more difficult than it might seem as many assumptions are unspoken and simply never considered. They are things that are so familiar that they are taken for granted, even in new situations. Assumptions should be tested against both their importance to the programme overall and the likelihood that they might prove false. Any that cannot be unreservedly accepted as being valid are potential sources of risk and can be treated as such.

7.5 ESTIMATION PROCESS

As mentioned above, each of the factors, ratios, and CERs in a cost-estimating model is usually stochastic. The uncertain or random nature of these variables can be expressed as a probability distribution with a certain mean and variance. Combining the probability distributions of each of the variables in a large cost model for a major weapon system acquisition programme to obtain a total cost probability distribution cannot be done mathematically. The number of variables is simply too numerous and the resulting calculus too unwieldy. A good, statistically sound alternative is Monte Carlo simulation.

In this technique, a random sample is taken from the probability distribution associated with each CER and each risk variable. Based on the functional form of the factor or CER, arithmetic operations are performed to obtain a single estimate of the cost of that CBS element. This is done for each uncertain factor and CER in the model. Results are summed into a *single* estimate of the cost for the entire weapon system. This estimate, then, is one observation or experimental result out of an infinite number available. The procedure of random number selection and subsequent cost computation is then repeated thousands of times to develop a frequency histogram (or probability distribution) of total system cost.

7.5.1 Baseline Cost Estimate

In this step, input values such as a SLOC (Source Lines of Code) count, aircraft weight, and radar performance are regarded as deterministic. Values of each of these variables are plugged into CERs as fixed numbers. Figure 7-3 illustrates the process for one CER corresponding to one cost element. In this example, the CER represents the relationship between software development cost and the number of source lines of code. The relationship is curvilinear, as are those of many CERs in defence cost analysis.

Beyond a certain SLOC count, the software development project becomes so big and complex that the probability of success diminishes sharply and costs escalate precipitously.

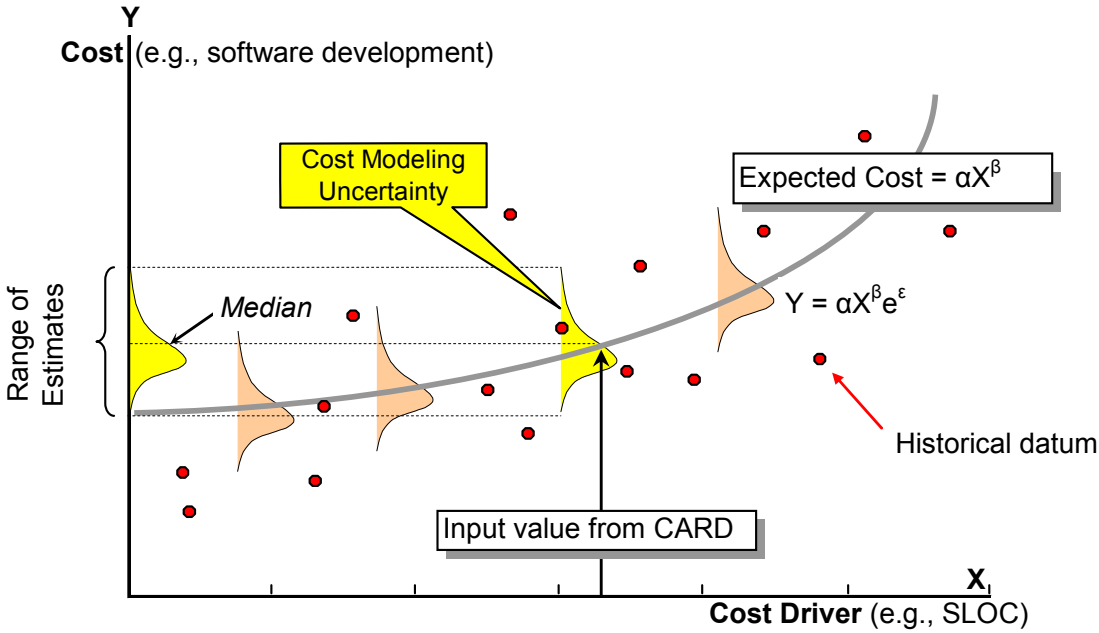

Figure 7-3: Baseline Cost Estimate.

To generate the **baseline** cost estimate, a fixed value for SLOC count is input into the CER. For this fixed value, there is an entire probability distribution of associated costs.[7] The distribution represents cost uncertainty. Cost, in this case, is log-normally distributed.[8] In the Monte Carlo simulation, the computer generates a random number for this distribution, based on the value of SLOC. An identical process is followed for other CERs (not shown here) in the model. Costs are aggregated for all CBS elements. The baseline cost estimate emerges after sufficient repetition of the process.

7.5.2 Risk-Adjusted Cost Estimate

The next step is to generate a risk-adjusted cost estimate.

As Figure 7-4 shows, input parameters such as a SLOC (source lines of code) count are now regarded as stochastic rather than deterministic. Hence, distributions for these parameters need to be chosen. These are often triangular. Most-likely values, defined by the mode in this case, may now differ from those values presented in the CARD (cost analysis requirements description). Once again, a Monte Carlo simulation is conducted. First, the computer randomly chooses a SLOC count from the triangular distribution, somewhere within the low to high range. These low and high values correspond to median values on the population relationship (or curve) between Y and X. For each of these median values, in turn, there is an

[7] This is because the underlying relationship between cost, Y, and SLOC count, X, is stochastic. The relationship is specified by the equation $Y = \alpha X^{\beta} e^{\varepsilon}$, where α and β are population parameters to be estimated, e is the residual value and ε is a normally distributed random error term with mean 0 and variance σ^2_{ε}. This error term imparts uncertainty to cost.

[8] Interestingly, as Goldberger indicates, when a power-function form is used for a CER, attention shifts, "… apparently unwittingly, from the mean to the median as a measure of central tendency." That is, plugging a value of X into the CER yields an estimate of the *median* value of Y rather than the mean. This is a little known fact in econometric modelling and in defense cost analysis. See Goldberger, Arthur S., "The Interpretation and Estimation of Cobb-Douglas Functions," Econometrica, Vol. 35, July-October, 1968, pp. 464-472, for more details.

entire log-normal distribution of costs. The endpoints highlighted above represent the range of possible values of cost in the sampling simulation.[9] The frequency distribution illustrated on the Y-axis is the risk-adjusted cost estimate.

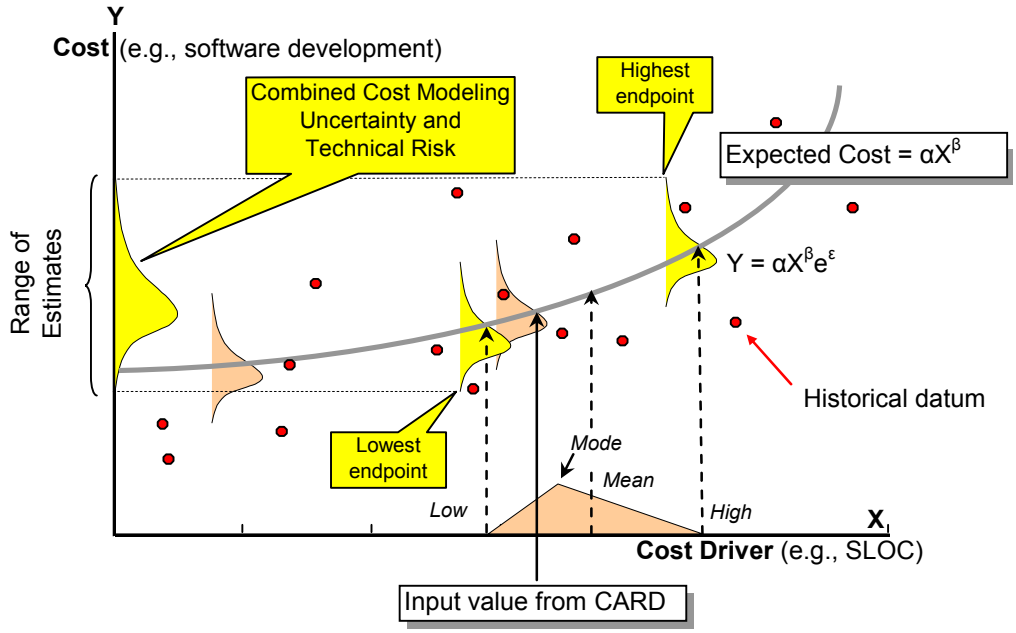

Figure 7-4: Risk-Adjusted Cost Estimate.

7.6 COST AND BUDGET RISK

7.6.1 Cost Risk

The baseline cost estimate contains modelling uncertainty while the risk-adjusted cost estimate contains both modelling uncertainty and technical uncertainty and risk. The risk-adjusted probability distribution will therefore have a higher mean value and a higher variance than the baseline estimate. Its distribution will typically appear flatter and more skewed to the right, as Figure 7-5 shows. The difference in mean or expected values of the two distributions is cost risk. This value is usually expressed in monetary rather than percentage terms. It accounts for the cost impact of unfavourable outcomes in a major acquisition programme such growth in lines of code or failure of a new computer chip to work correctly. Aggregate cost risk can be allocated to any cost breakdown structure element, as appropriate.

[9] More precisely, since the log-normal distribution extends to infinity, upper-bound costs illustrated here should be regarded as holding for some fixed percentile, such as the 99th.

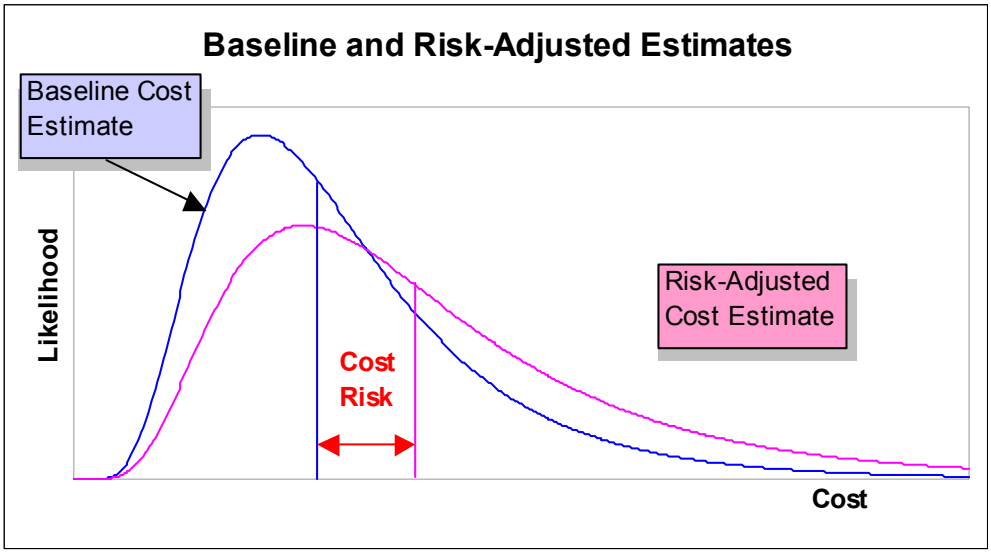

Figure 7-5: Cost Risk Analysis Output.

7.6.2 Budget Risk

Budget risk is the probability that the actual cost of a weapon system acquisition programme will end up exceeding a given budget, as Figure 7-6 shows. In this case, the budget is set at the mean value of the risk-adjusted cost estimate. Costs to the right of the mean are all legitimate possibilities, as are those to the left of the mean. Since the budget is finite, there's a certain probability it will be exceeded. The percentage of the area of the distribution to the right of the budget is defined as budget risk. It is usually expressed as a number such a 40%, or 50%, or 60%. The value of risk analysis is that it quantifies this probability. Decision makers can then determine what degree of risk to accept, given the value of the weapon system and given the values and risks of alternative systems in a warfighting portfolio. A low budget implies a high probability of an overrun while a high budget implies a low probability of an overrun. It's up to the decision maker to decide where he/she wants to set the budget.

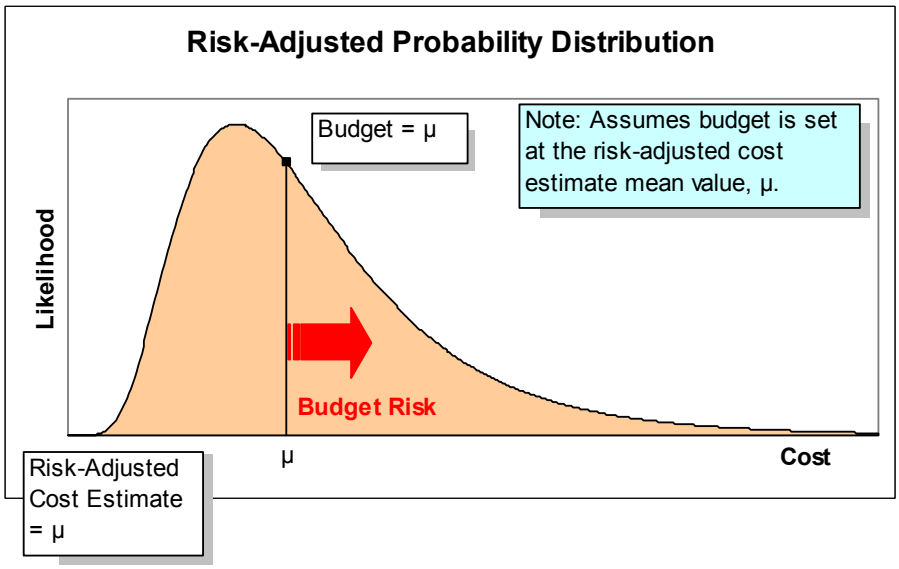

Figure 7-6: Budget Risk Analysis Output.

7.7 SENSITIVITY ANALYSIS

Another popular method for taking risk into account in generating life-cycle cost estimates is sensitivity analysis. This process, in its simplest form, measures the impact on cost of changing one or more key input values about which there is uncertainty. For example, a pessimistic, baseline, and optimistic value might be chosen for an uncertain variable, such as the slope of a learning curve. Then, an analysis could be performed to see how the life-cycle cost of the weapon system changes as each of the three chosen values is considered in turn, with all other factors held the same.

Further, a more complex analysis could be undertaken where values associated with several variables such as learning curve rate, degree of hardware commonality, and growth of out-year business base are grouped or bundled together to form pessimistic, baseline, and optimistic scenarios. For each scenario, a cost estimate is then generated.

A similar analysis can be conducted by varying a set of parameters from low to high and determining the impact on total cost of each. Results of this kind of analysis are often displayed in a tornado chart, as shown in Figure 7-7, where parameters are ranked according to their relative influence on cost.

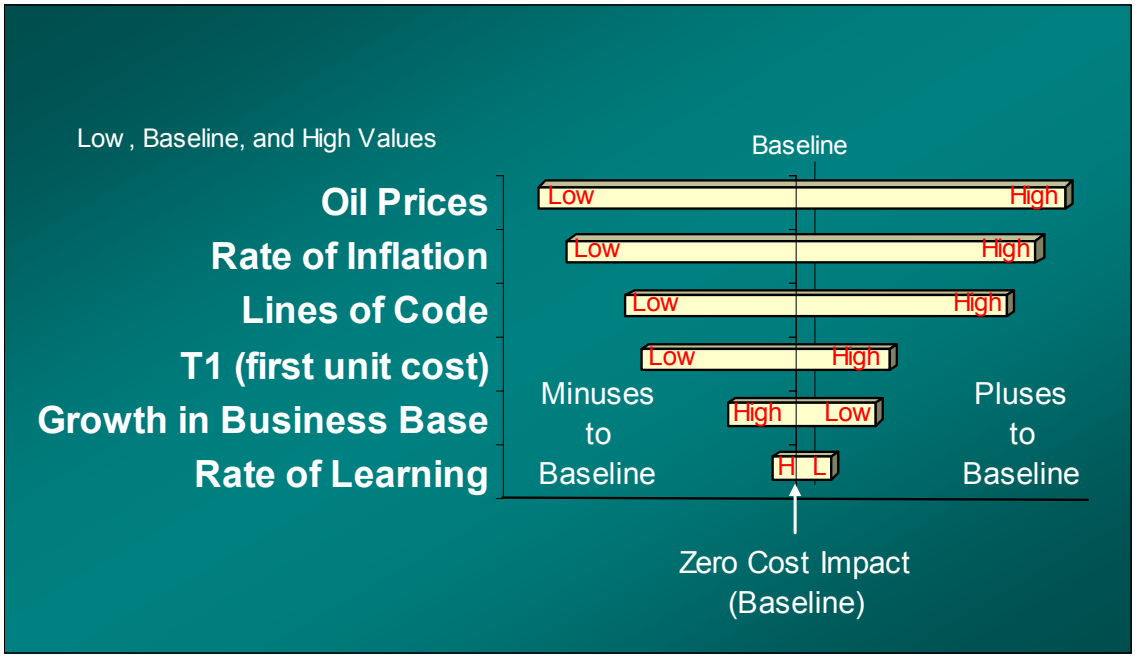

Figure 7-7: Example of Sensitivity Analysis Tornado Chart.

Finally, a shortcoming of sensitivity analysis is that it makes no statement about the probability that a low, baseline, or high value of a parameter might be obtained. Nevertheless, the technique can be performed rather quickly and inexpensively. Experience suggests that in many concrete applications it provides a reasonable and relatively trustworthy estimate of life-cycle costs.

7.8 FINDINGS

This sub-section describes a summary of the methods and models related to risk and uncertainty that are being used by the participating nations, based on the analysis of the matrices completed by the study participants and introduced in Chapter 1. Figure 7-8 shows the results of this analysis graphically.

Risk		Mission need	Pre-feasibility	Feasibility	Project Definition	Design & Developm.	Production	In-service	Disengage-ment
Methods	Expert opinion	●	●	●	●	●	●	●	●
	Monte Carlo simulation	◒	◒	◒	◒	●	◒	◒	◒
	Sensitivity analysis	●	●	●	●	●	●	●	●
Models for risk analysis	In-house	●	●	●	●	●	●	●	●
	Commercial	●	●	●	●	●	◒	◒	◒
Models for uncertainty analysis	In-house	●	●	●	●	●	●	●	●
	Commercial	●	●	●	●	●	●	●	●

Legend

blank	*No nation*
○	*1 nation*
◒	*2-3 nations*
●	*>3 nations*

Figure 7-8: Summary of Methods and Models Used to Measure Risk and Uncertainty.

The findings at Figure 7-8 appear to show that risk and uncertainty analysis is widely used by NATO and PfP-nations. We all say that we are doing this. However, this figure does not present the whole story. Discussions in our Task Group showed something completely different. All nations are familiar with methods and models to be used for quantifying risk and uncertainty, but among NATO and PfP nations, the application of risk and uncertainty analysis varies widely. No NATO standard procedure is used or recommended. Collectively, the group of nations is certainly not guilty of Emerson's aphorism that "a foolish consistency is the hobgoblin of little minds[10]". Just the opposite seems to hold. We are widely inconsistent in the application of risk and uncertainty methods between nations, within nations, and even sometimes within the same organisation in a single nation!

More specifically, the survey results indicate that, sometimes, risk and uncertainty analysis is not undertaken at all in generating a life cycle cost estimate. Instead, single, point estimates are provided to the decision makers. At other times, when risk and uncertainty analysis is conducted, the two most commonly used techniques seem to be expert opinion and sensitivity analysis. Detailed risk and uncertainty modelling, such as Monte Carlo simulation, seems to be undertaken, with varying degree of frequency, by only two to three nations.

7.9 RECOMMENDED PRESENTATION OF RESULTS

Figure 7-9 presents a recommended approach for communicating results of a life cycle cost estimate to senior decision makers.[11] The top line shows a three point range of estimates, and conveys the idea that a cost estimate is not a single number, but rather a continuum or distribution of possible values.

[10] Essays (First Series) "Self-Reliance" by **Ralph Waldo Emerson** (1803–1882): "A foolish consistency is the hobgoblin of little minds, adored by little statesmen and philosophers and divines."

[11] U.K. Ministry of Defence and **Impossible Certainty**, RAND, 2006, pp. 84-86.

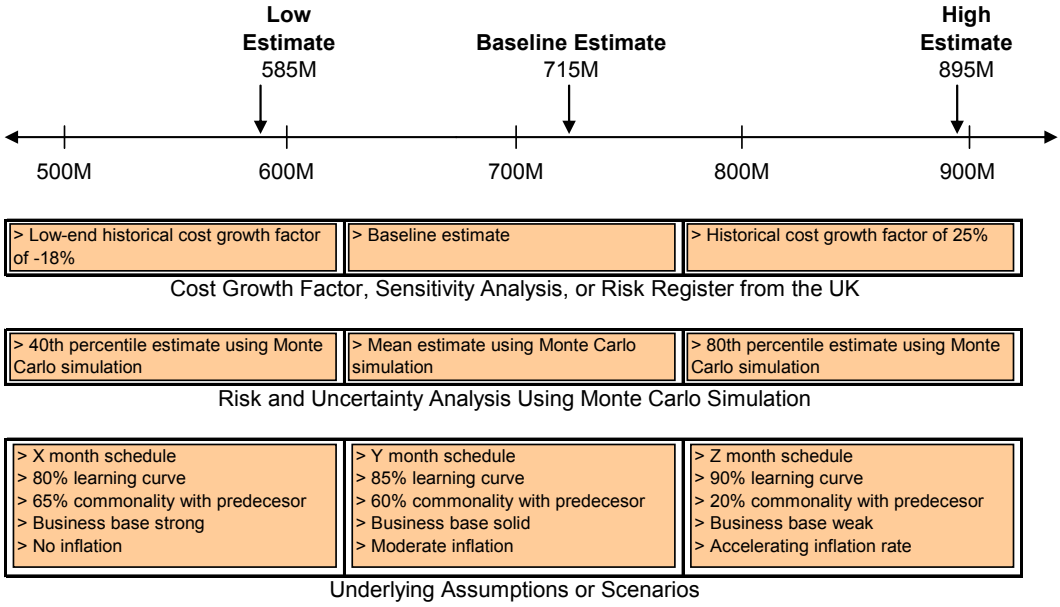

Figure 7-9: Recommended Presentation of Cost Estimating Risk Analysis.

Analysts can use one or more estimation techniques in performing risk and uncertainty analysis. Some of these are shown in the top two bars or sections of the figure. The bottom section, which should always be included in the presentation of the estimate, shows all of the assumptions or scenarios associated with the low, baseline, and high estimates. Including this section enables decision makers to see clearly the cost implications of events that can influence the outcome of an acquisition programme.

7.10 REFERENCES

[88] See www.dau.mil/gdbks/risk_management.asp to obtain a copy of "Risk Management Guide for [U.S.] DoD Acquisition".

[89] See http://www.ispa-cost.org/PEIWeb/newbook.htm to obtain a copy of the "Parametric Estimating Handbook" from the International Society of Parametric Analysts. See Chapter 11 for details on risk analysis.

[90] See http://www.scea-alabama.org/pubs.shtml to obtain a copy of "Cost Risk Analysis Without Statistics," Garvey, Paul, MITRE, October 2003.

[91] See http://www.sceaonline.org for details on how to order a moderately priced copy of "Cost Programmed Review of Fundamentals" (CostProf) from the Society of Cost Estimating and Analysis. See Chapter 9 for details on cost risk analysis.

[92] See http://ceh.nasa.gov/ to obtain a copy of NASA's "Cost Estimating Handbook." Various sections relate to risk and uncertainty analysis.

[93] Risk Analysis – A Quantitative Guide 2nd Edition, Dr David Vose, John Wiley & Sons, 2002.

[94] Project Risk Analysis and Management 2nd Edition, Association of Project Management, 2006.

[95] Impossible Certainty, Cost Risk Analysis for Air Force Systems, RAND Corporation, 2006.

[96] Daneshkhah, A.R. (2004), Uncertainty in Probabilistic Risk Assessment, University of Sheffield.

Appendix 1: Optimism Bias

In the absence of the time or resources required to perform the detailed analysis prescribed in this chapter, an alternative is to apply percentages to a bottom-line estimate, as shown below.

There is a demonstrated, systematic tendency for project managers to be overly optimistic. To redress this tendency cost analysts should make empirically-based adjustments to the estimates of a programme's costs, benefits, and duration.

These adjustments should be based on data from past, similar projects, and calibrated for the unique characteristics of the programme at hand. In the absence of a more specific evidence base, analysts are encouraged to collect data to inform future estimates of optimism, and in the meantime use the best available data.

The main aim of applying this guidance is to provide a better estimate of the likely life cycle cost of a major weapon system acquisition programme.[12]

Table 7-1 shows the percentage build up when using an "optimism bias" approach. These percentages should be added to the cost estimate when the relevant programme information is immature or not available.

Table 7-1: Optimism Bias Estimate Uplift Percentages

Project Information	Relevant Percentage Uplift
Complexity of contract	7%
Late contractor involvement in design	7%
Poor contractor capabilities	4%
Information Management	5%
Design complexity	10%
Degree of innovation	17%
Inadequacy of business case	18%
Poor management team	5%
Poor project intelligence	4%
Legislation/regulations	5%
Technology	18%

Figure 7-10 provides an illustration on the application of "optimism bias" in a programme review. It compares the known quality of the data (judged from the list above) added to the programme estimates against the stochastic output from a cost risk analysis utilising a three point estimate.

[12] A detailed description of the recommended adjustment ranges and a detailed approach is described in the "Supplementary HM Treasury Green Book" guidance on optimism bias, UK.

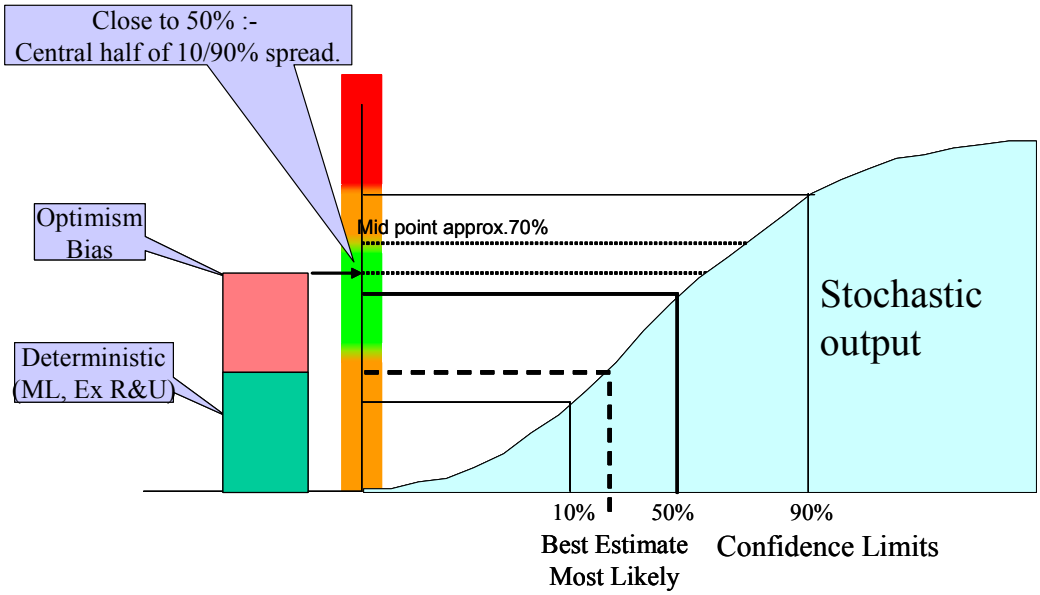

Figure 7-10: Application of Optimism Bias.