

# The Forecasting Guidebook



**First Edition August 2009**

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**Luke 14: 28 - 29**

***“...[He should] sitteth down first, and counteth the cost, [to see] whether he have sufficient to finish it.”***

## **Preface to First Edition**

UK National Audit Office, Parliamentary and internal UK Ministry of Defence (MoD) defence programme acquisition reports since 1946 clearly show that remarkably few programmes/ projects have entered service on time, on cost and with the required performance.

Arguably, in the immediate post WW II and the subsequent cold war eras, Britain had a real need to re-build industry and maintain crucial skill sets, though with hindsight one might question how sound some of the judgements were in obtaining value for money.

A number of the reported over run disasters since the 1960s are attributable to real errors in the use of acquisition phase forecasts, the associated risks and in forecasting ability. Almost all programmes/ projects suffered from process errors that failed to capture the data and provide indicator analysis sufficiently early to enable appropriate action to avoid public embarrassment.

Changes brought about within the Defence procurement organisations through critical reports in the 1950s (Hill), 1960s (Downey), 1970s (Rayner), 1980s (Jordan, Lee & Cawsey) and the more recent 1990s “Smart Procurement” initiatives have improved procurement processes although they have not succeeded in removing all time and cost over runs. The Defence Acquisition Change Programme (DACP) continues to build on this earlier work and seeks to improve processes further.

This guide supports the DACP and is intended to help those who may be called upon to provide ‘forecasts’ of cost and schedule that may be used subsequently to assist budget formulation for future programme entry to the defence Equipment Programme.

Such early forecasts attempt to predict acquisition cost up to 30 years in the future and ‘in service’ support costs perhaps 50 years hence; obviously such forecasts cannot be ‘accurate’ in the normal sense of the word.

If nothing else in this guide remains important to you or your current work remember the following sentence! Forecasts of cost and schedule, performed by suitably qualified and experienced staff, are only as accurate as the data, programme information, assumptions and tool sets permit within the forecaster’s prevailing view of the industrial context necessary to develop and manufacture the new capability.

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## Glossary

Item	Description
ACostE	Association of Cost Engineers
AoF	Acquisition Operating Framework
ASIC	Application Specific Integrated Circuit
BBN	Bayesian Belief Network
CADMID	Concept, Assessment, Demonstration, Manufacture, In-Service, Disposal
CAAS	Cost Assurance & Analysis Services
CCEA	Certified Cost Estimator & Analyst
CDAL	Cost Data Assumptions List (also Master Data Assumptions List = MDAL)
CDF	Cumulative Density Function
CEP	Cost Estimating Plan
CER/SER	Cost Estimating Relationship/ Schedule Estimating Relationship
CMMI	Cap ability Maturity Model index
COTS	Commercial Off The Shelf (also Military = MOTS, Government = GOTS)
CPP	Certified Parametric Practitioner
CRBS	Cost, Resource Breakdown Structure
CRL	Cost Readiness Level
DE&S	Defence Equipment & Support
DESIB	DES Investment Board
DoD	Department of Defense (USA)
EA	Economic Analysis
EAC	Estimate at Completion (EVM usage)
ERP	Enterprise Resource Planning
ESLOC	Equivalent Lines of Code
EVM	Earned Value Management
FACET	Family of Cost Estimating Tools
FFRDC	Federally Funded Research & Development Corporation
GAO	General Accounting Office
HTA	Historic Trend Analysis
IA	Investment Appraisal
IAB	Investment Approvals Board
ICE	Independent Cost Estimate
IG	Initial Gate
IPT	Integrated Project Team
ISPA	International Society of Parametric Analysts
ITT	Invitation to Tender
JSP	Joint Services Publication
LCC	Life Cycle Costs
MG	Main Gate
MIS	Management Information System
MoD	Ministry of Defence (UK)
MRP	Materials Resource Planning
MTBF	Mean Time To Failure
MTTR	Mean Time To Repair
NAO	National Audit Office
NASA	National Aeronautics & Space Administration
NPV	Net Present Value
OB	Optimism Bias
OLS	Observed Least Squares
PDF	Probability Density Function
PV	Present Value
RFQ	Request for Quotation
SCEA	Society of Cost Estimators & Analysts
SDP	Software Dependent Project
SET	Supplier Engagement Team
SF	Strategic Forecasting
SLOC	Source Lines Of Code
SME	Subject Matter Expert
TRL	Technology Readiness Level
UK	United Kingdom
USA	United States of America
VAT	Value Added Tax
VLSI	Very Large Scale Integration
VnV	Validation and Verification
WLC	Whole Life Costs
WW II	World War II

## Definitions

This guide is about cost and schedule 'Forecasting', this and other terms need to be defined.

## What is a Forecast?

*"A technological forecast is a prediction of the future characteristics of useful machines, procedures or techniques<sup>1</sup>."*

It therefore follows that a cost and or schedule forecast accounts for the cost and time needed for the subject of a technological forecast, the forecaster does not need to invent a machine or determine how any limitations may be surpassed only mention that they will be and to have a sound understanding of required technologies (see Technology Considerations).

The terms 'Estimating' and 'Forecasting' can be interchanged and often they are; however, Forecasting **is** different to Estimating and that difference lies within the definitions below:

- **"Forecasting"** predicts a view(s) of the future, it is conducted 'top down' using less detail when procurement needs and Industrial environment have both uncertainty and major risks present. Forecasting is used in early programme phases to predict likely budget needs and to compare potential solution options. Forecasting seldom considers development or production of items below 'black box', system or even platform level. Decimal points are rarely employed unless dealing in £Billions. Therefore a forecast **cannot** provide absolute costs or be 'accurate' in the normal sense of that word and is unlikely to be used for contract price setting unless considerable design detail is available.
- **"Estimating"** calculates a view of costs today, the word implies accuracy and often an estimate can be within a few percent (typically within 5%) of actual costs or time taken. Cost estimating is usually performed "bottom up" and requires good design and manufacturing process data.



## Introduction

Uniform guidance on cost / schedule Forecasting and Estimating practices and procedures on which to base formulation of valid, consistent, and comparable estimates is lacking within the MoD. In fact, a search shows that top level estimating guidance is available from the Treasury, MoD Joint Service Publications (JSPs) and MoD Defence Equipment & Support (DE&S) Finance sources though almost all is process related covering the manipulation of numbers rather than their creation in the first place.

MoD (DE&S) Acquisition Operating Framework<sup>2</sup> (AoF) and Cost Assurance & Analysis Service (CAAS) provide more detailed guidance on both Estimating and Forecasting but it is not as yet comprehensive and currently lacks consistency.

Additionally there is little evidence that cost forecasters or estimators are fully aware of all guidance available, application of knowledge is at best patchy and restricted to mandatory requirements within JSP 507 or Finance processes. Estimating and Forecasting basic theory and predictive tool sets are mostly the same, the difference is in how they are applied, the level of programme detail and breakdown that is considered and how an analyst treats Risk and Uncertainty.

Cost/ schedule Forecasting processes require realism and objectivity without bias, 'over optimism' tends to creep into forecasts that are prepared by advocates of platform or weapon systems. These advocates are predominantly non-forecasters and their resulting predictions (usually obtained from Industry Rough order of Magnitude (RoM) quotes rather than predictive methods) are overly optimistic.

Therefore, staffs who are not influenced by an organisation's determination to field a new system or by the contractor's intention to develop and produce a new system, should ideally prepare independent forecasts and be able to critically review third party supplied forecasts at major decision points in the acquisition process.

The current criticisms of 'cost estimating' are clear and present and this really means 'Forecasting' because of misuse of the term 'Estimating'. These criticisms are being acted upon to improve the delivery of initial forecasts for budget setting and for business case approvals; this work will also improve consistency of application to all costing. However, improved processes and better cost predictions will not prevent misuse of original forecasts in the overall MoD budget process by third parties and that introduces another source of error.

The cost assurance regime in DE&S will ensure:

- Forecasting processes are followed and become consistent,
- cost and schedule models are properly constructed, documented and their outputs valid,
- historical cost data used as a basis for prediction is valid, reliable and representative;
- the effects of inflation are included and uniformly treated.

Also there is a need for readily retrievable cost data that will serve as a basis for improving the prediction of cost and schedule of new capability. A more organised

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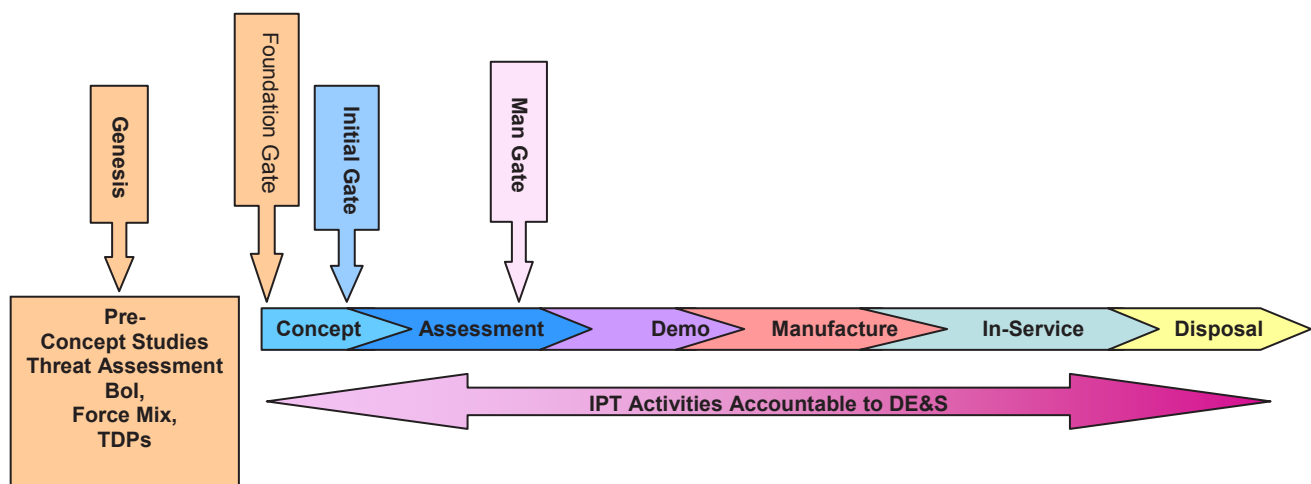
<sup>2</sup> [www.aof.mod.uk](http://www.aof.mod.uk)

and systematic effort to gather actual cost information thus assisting comparisons between platform/ weapon systems will be developed.

This guide will provide an overview of Forecasting good practice and gives information and links to more detailed information.

## Forecasting application in Approvals

The UK MoD Approvals process has several key decision points where investment options are considered. The diagram below outlines the 'Concept, Assessment, Demonstration, Manufacture, In Service, Disposal (CADMID)' phases and illustrates where the 4 investment decision milestones occur. Forecasting services are required at each of these decision points as well as at intermediate stages in the lifecycle; sound predictive capability is crucial to realistic budget setting at Genesis and Foundation. Service contracts have a 'Termination' phase giving rise to CADMIT.



### Genesis

The UK MoD operates a 10 year view of the future acquisition programme known as the Equipment Programme Plan (EPP); later years beyond year 10 are referred to as 'second and third decade' and comprise a shopping list of potential future programmes to maintain and enhance military capability. To move a project into the 10 year EPP requires a robust look at early costs and schedules, this is called the Genesis Gate. For equipments and platforms that enter service there is a costed Equipment Support Plan (ESP) that covers the 'in service and disposal phases'.

### Foundation

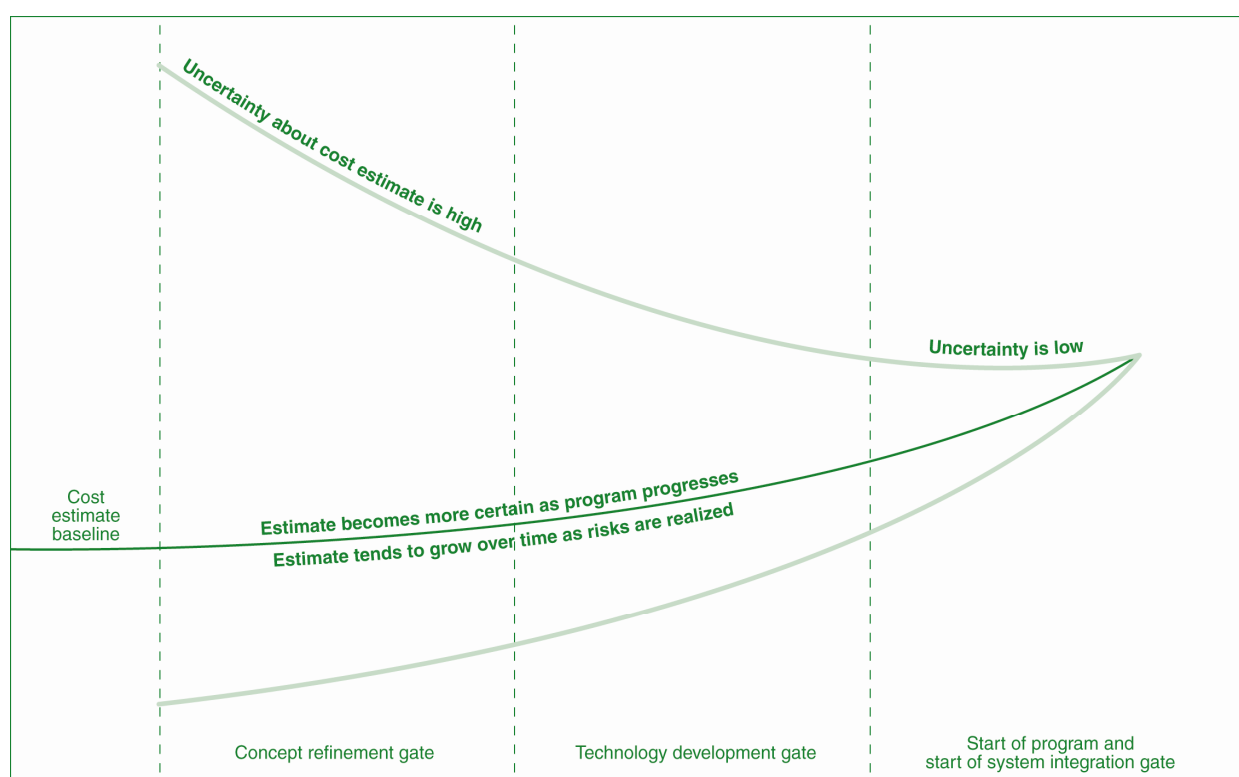
Before a future project formally moves into DE&S control, the Foundation Gate firms up budgets and profiles, adjusts the EPP and marks the creation of the project team.

### Initial Gate/ Main Gate

There are variations on the McKinsey CADMID cycle depending upon project type and more detailed information may be found on the AoF and in the SMART Approvals guidance that covers these two key investment decision points. Note that the treatment of 'Urgent Operational Requirements (UORs)' is different.

## Forecasting Accuracy

The graph below is taken from the US General Accounting Office (GAO) Cost Estimating and Assessment Guide<sup>3</sup>, it illustrates how confidence in a predicted set of numbers alters over programme life and more importantly captures the ‘creep’ or ‘growth’ in the programme forecast itself. The bounds are asymmetric and this reflects actual history of defence acquisition in the USA, the UK pattern is remarkably similar. Typically the dotted vertical lines may be taken to represent (in the UK) set up of the IPT at Concept, followed by Initial Gate (IG) and finally Main Gate (MG). At each ‘gate’, confidence levels improve until sufficient actual data is to hand to remove almost all doubt. At no point in the lifecycle can one say that either the predicted costs or the ‘actual’ values are absolute as there will always remain some source of error.



Source: GAO.

Cost/ schedule Forecasting is a difficult task even in the best of circumstances and it requires both science and judgment. Since answers are seldom if ever precise, even with that desire expressed by Central Staffs, the main goal must be to find the most “reasonable” or “plausible” forecast and substantiate it with robust data, assumptions and toolsets. When preparing a forecast an analyst must not be concerned with ‘affordability’ since knowledge or use of previously set budgets or time limits could bias the prediction.

Contributors to bad forecast outcomes are:

- unrealistic timescales

<sup>3</sup> US GAO document downloadable from [www.gao.gov/products/GAO-09-3-SP](http://www.gao.gov/products/GAO-09-3-SP)

- inexperienced and poorly trained staff
- poorly adhered to processes
- poorly defined, documented and tracked assumptions,
- too few comparator programmes,
- inadequate, out-of-date or improperly recorded data,
- inappropriate Forecasting methodologies and,
- no supported rationale or basis for the forecast.

A final point that must be considered is that all forecasters and estimators only provide 'advice/ guidance' thus leaving the acceptance and use of the predicted cost and schedule up to the customer. Obviously the customer can choose to ignore or only partially use the advice and thereby introduce errors; other sources of error are changes to time and cost forecasts that are not referred back to the Forecasting community (a clearly invalid process).

All such errors are normally blamed on the original Forecasting or estimating source without consideration of the real reasons for the error.

## What skills are needed in a Forecasting Team

When setting up a Forecasting or estimating team the following will serve as a checklist for good practice<sup>4</sup>:

### The Team:

- ✓ includes experienced and trained cost analysts.
- ✓ includes analysts experienced in the programme's major sector (air, land etc)
- ✓ Develops a Cost-Forecasting/ estimating plan.
- ✓ has the proper number and mix of resources.
- ✓ has access to the necessary subject matter experts.
- ✓ members are from a centralised Cost-Forecasting organisation.
- ✓ members' responsibilities are clearly defined.
- ✓ composition is commensurate with the task.
- ✓ members' experience, qualifications, certifications, and training are identified.
- ✓ participated in on-the-job training, including plant and site visits.

Because cost forecasts are often needed to inform the down selection process to determine whether to upgrade or procure new systems then having an awareness of engineering, computer science, mathematics, and sound knowledge of applying statistics will help identify cost drivers and the type of data needed to select the appropriate tool(s) and develop the forecast. It also helps if the forecaster has adequate technical knowledge when meeting with functional experts so that credibility and a common understanding of the technical aspects of the programme can be quickly established. Each discipline in Figure 1 below will be applied to Forecasting in its own unique way.

<b>Systems Engineering</b> <b>Production Processes</b> <b>Performance parameters</b> <b>Scheduling</b> <b>Engineering Management</b> <b>Cost Breakdown Structures</b> <b>Reliability &amp; Maintainability</b> <b>Logistics</b>	<b>Accounting</b> <b>Financial Analysis</b> <b>Cost data analysis</b> <b>Budgeting</b> <b>Apportionment C/R/IRDEL</b>
<b>Statistics</b> <b>Regression analysis</b> <b>CER development</b> <b>Forecasting</b> <b>Sensitivity Analysis</b> <b>Learning curve application</b> <b>Normalisation</b>	<b>Economics</b> <b>Inflation</b> <b>Exchange rates</b> <b>Present value analysis</b> <b>Economic Appraisal</b> <b>Cost benefit analysis</b> <b>Cost risk analysis</b>

Figure F1

For example, having an understanding of economics and accounting will help the forecaster better incorporate quantity<sup>5</sup> and inflation effects into a prediction and realise how different accounting systems capture costs and may impact data

<sup>4</sup> SEI, Carnegie Mellon University, Pittsburgh

<sup>5</sup> "Using the Learning Curve as a Management Tool," James A. Cunningham, IEEE Spectrum, June 1980, p. 46.

analysis. Budgeting knowledge is important to decide how to properly allocate resources over time so that funds are available when needed. Development of evidence is crucial to forecasters who can then sell and present their work by supported by solid facts and reliable data; the forecast itself will stand a better chance of being used as a basis for decision making and programme funding. In addition, sound interpersonal skills enable the successful working and communication with subject matter experts that is vital for understanding programme requirements.

A competent Forecaster with 'practitioner' status is likely to be certified and have around 5 years experience in the function.

There are two costing organisations that provide specific certification founded on a comprehensive examined syllabus of costing topics:

- Society of Cost Estimators and Analysts (SCEA).
- International Society of Parametric Analysts (ISPA).

The UK based Association of Cost Engineers (ACostE) offers an experienced based approach but without tested certificate award.

More information is provided in the section “**So you want to be a Forecaster**”.



## How to start a Forecasting Task

As with any task, good practice is to breakdown the challenge into smaller more easily managed elements. The recent United States General Accounting Office (GAO) “Cost Estimating and Assessment Guide” contains a wealth of detail on how to perform forecasts or estimates. The following 12 steps are universal and represent ‘good practice’ for anyone considering the creation of a forecast. The steps are anglicised to fit our terminology and are given in more detail at Annex A. Annex A may also be used a checklist although it does not replace the formal Forecasting processes created and agreed by DE&S Forecasting staff.

1. Define forecast’s purpose.
2. Develop Forecasting plan.
3. Define programme characteristics.
4. Determine Forecasting structure<sup>6</sup>.
5. Identify ground rules and document assumptions.
6. Obtain data, validate<sup>7</sup> and document.
7. Develop forecast<sup>8</sup>, validate model and compare to an Independent Cost Estimate (ICE)<sup>9</sup>, if the Project is Category A or B and at Main Gate this is mandatory.
8. Conduct sensitivity analysis.
9. Conduct uncertainty and risk analysis and identify drivers against uncertainty.
10. Document the estimate.
11. Present the Forecast for approval.
12. Update the forecast to reflect actual costs and changes<sup>10</sup>.

In following good practice, a forecaster or estimator will need to follow some or all of the sub-elements set out in the table below:

Characteristic	Description
Clear identification of task	Forecaster must be provided with the system description, ground rules and assumptions, and technical and performance characteristics.  The forecast’s constraints and conditions must be clearly identified to ensure the preparation of a well-documented estimate.
Broad participation in preparing estimates	All players/ stakeholders should be engaged in deciding mission need, requirements, in defining parameters and other system characteristics and agreeing assumptions.  Data should be independently verified for accuracy, completeness, and reliability.
Availability of valid data	Numerous sources of suitable, relevant, and available data should be used.  Relevant, historical data should be used from similar systems to project costs of new systems. The historical data should be directly related to the system’s performance characteristics.
Standardised structure for the	A standard Cost and Resource Breakdown Structure (CRBS), as detailed as possible, should be used, refining it as the cost estimate matures and the system

<sup>6</sup> A standard cost and resource breakdown structure (CRBS) is loaded on the Acquisition Operating framework (AOF).

<sup>7</sup> Verify & Validate models – DE&S process refers.

<sup>8</sup> See “The Basics”

<sup>9</sup> ICE, a non advocate estimate created from outside the normal team, using the same base data but alternate processes and methods.

<sup>10</sup> Many of these activities relate to Through Life activities and fall outside of a Forecaster’s direct responsibility though they are crucial to checking prediction accuracy and improving the Forecasting tool set.

Characteristic	Description
estimate	becomes more defined.  The CRBS ensures that no portions of the estimate are omitted and makes it easier to make comparisons to similar systems and programs.
Provision for programme uncertainties	Uncertainties should be identified and allowance developed to cover the cost effect.  Known costs should be included and unknown costs should be allowed for.
Recognition of inflation	The forecaster should ensure that economic changes, such as inflation, are properly and realistically reflected in the whole life cost estimate.
Recognition of excluded costs	All costs associated with a system should be included; if any cost has been excluded, it should be disclosed and given a rationale.
Independent review of estimates	Conducting an independent review of a forecast is crucial to establishing confidence. The independent reviewer should verify, modify, and correct a forecast to ensure realism, completeness, and consistency.
Revision of forecasts for significant programme changes	Forecasts should be updated to reflect changes in a system's design requirements. Large changes that affect costs can significantly influence programme decisions.

## The Basics

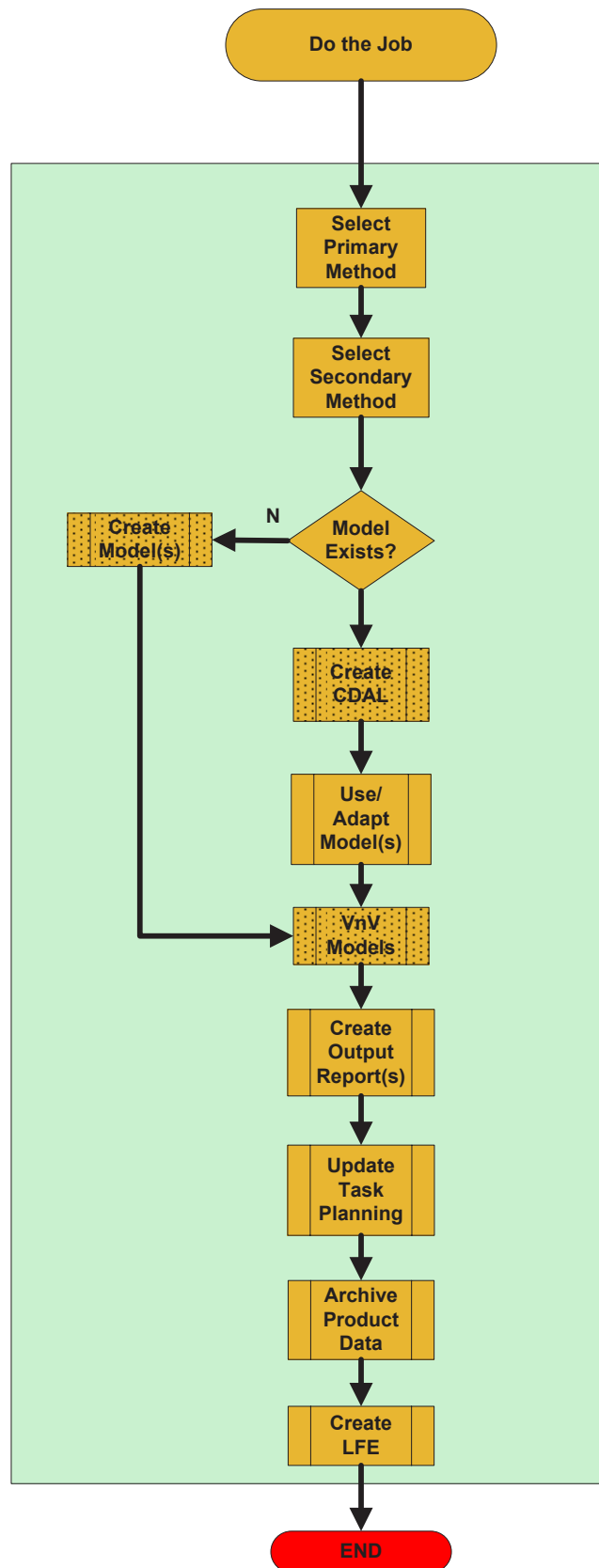
When attempting a forecast it is essential to have an understanding<sup>11</sup> of what is to be included through use of a Cost and Resource Breakdown Structure (CRBS) and to select the most appropriate method/ tool to predict cost/ schedule; these may vary across individual breakdown structure elements. The precise methods will depend upon the position of the item being considered within its life cycle, technologies to be employed, data availability and likely procurement strategy. All of this must be documented within a 'Cost Estimating Plan CEP'.<sup>12</sup>

Whatever method is selected to create the forecast, consideration must be given to the selection of a secondary or cross-check method to be used to gauge the output obtained from the primary method. The high level flow chart overleaf provides a guide to the process, the element 'LFE = Learning from Experience' is meant to communicate anything that is beneficial to the forecasting process and prevent repeated mistakes. In addition, industry rules of thumb may also constitute a sanity check.

The main purpose of cross-checking is to determine whether alternative methods produce similar results. If so, then confidence in the forecast increases, leading to greater credibility. If similar results are not obtained then the analyst must examine and explain the reason for the difference and determine whether it is acceptable.

<sup>11</sup> *Engineering Cost Estimating*, 3rd ed., Phillip F. Ostwald, Prentice-Hall, 1991 and *Cost Estimating Handbook*, 2nd ed., Rodney D. Stewart, Wiley, 1991

<sup>12</sup> CEP –part of the approved DE&S Forecasting process SF2002 1/10/2008



Good practice is always to obtain predictions using at least two different methods and this part of the approved Forecasting process.

Forecasts may be used in one of two different types of analysis:

- The more prevalent 'Economic Analysis (EA)' relates to option down selection using discounted constant costs and EA plays no part in deciding value for money. Often common costs are omitted from this option analysis. JSP507 and Treasury Guidelines outline the process.
- The second type, 'Financial Analysis' converts the forecast constant cost figures into Resource Accounting and Budgeting format with Value Added Tax (VAT) and thus permit comparisons with budget provision to gauge affordability. This process is outlined in Departmental Finance guides.

There are three main methods of creating a forecast of cost and schedule, the Table below lists them and subsequent paragraphs provide information about them.

Method	Strength	Weakness	Application
Analogy	<ul style="list-style-type: none"> <li>• Requires few data</li> <li>• Based on actual data</li> <li>• Reasonably quick</li> <li>• Good audit trail</li> </ul>	<ul style="list-style-type: none"> <li>• Subjective adjustments</li> <li>• Accuracy depends on similarity of items</li> <li>• Difficult to assess effect of design change</li> <li>• Blind to cost drivers</li> </ul>	<ul style="list-style-type: none"> <li>• When few data are available</li> <li>• Rough-order-of-magnitude estimate</li> <li>• Cross-check</li> </ul>
Engineering build-up	<ul style="list-style-type: none"> <li>• Easily audited</li> <li>• Sensitive to labour rates</li> <li>• Tracks vendor quotes</li> <li>• Time honoured</li> </ul>	<ul style="list-style-type: none"> <li>• Requires detailed design</li> <li>• Slow and laborious</li> <li>• Cumbersome</li> </ul>	<ul style="list-style-type: none"> <li>• Production estimating</li> <li>• Software development</li> <li>• Negotiations</li> </ul>
Parametric	<ul style="list-style-type: none"> <li>• Reasonably quick</li> <li>• Encourages discipline</li> <li>• Good audit trail</li> <li>• Objective, little bias</li> <li>• Cost driver visibility</li> <li>• Incorporates real-world effects (funding, technical, risk)</li> </ul>	<ul style="list-style-type: none"> <li>• Lacks detail</li> <li>• Model investment</li> <li>• Cultural barriers</li> <li>• Need to understand model's behaviour</li> </ul>	<ul style="list-style-type: none"> <li>• Budgetary estimates</li> <li>• Design-to-cost trade studies</li> <li>• Cross-check</li> <li>• Baseline estimate</li> <li>• Cost goal allocations</li> </ul>

## Analogy Costing Method

Analogy takes into consideration the fact that no new programme, no matter how technologically state of the art it may be, represents a totally new system. Most new programmes evolve from programmes already fielded that have had new features added on or that simply represent a new combination of existing components. The analogy method uses this concept for estimating new components, subsystems, or total programmes. Analogy uses 'actual costs' from a similar programme with adjustments to account for differences between the existing and new systems requirements (see example below). A Cost Forecaster typically uses this method early in a programme's life cycle, when insufficient actual cost data are available but the technical and programme definition is good enough to make the necessary adjustments.

Parameter	Existing system	New system	Cost of new system
Engine	F-100	F-200	
Thrust	12,000 lbs	16,000 lbs	(assuming linear relationship)
Cost	\$5.2 M	<b>\$6.9M</b>	$(16,000/12,000) \times \$5.2 \text{ M} = \$6.9 \text{ M}$

An Example of the Analogy Cost Estimating Method<sup>13</sup>

<sup>13</sup> Source: © 2003, Society of Cost Estimating and Analysis (SCEA), "Costing Techniques."

## Engineering Build-Up Costing Method

The engineering build-up method is sometimes referred to as a grass-roots or bottom-up estimate it builds the overall cost by summing or “rolling-up” detailed estimates done at lower levels of the CRBS. This is not really a true ‘forecast’ as such detail information may be used in the case of repeat buys or when an existing cost / schedule model is available. Because the lower-level estimating associated with the build-up method uses industrial engineering principles, it is often referred to as engineering build-up.

An engineering build-up estimate is done at the lowest level of detail and consists of labour and materials costs that have overhead, allowances and fee added to them. In addition to labour hours, a detailed parts list is required. Once in hand, the material parts are allocated to the lowest CRBS level, based on how the work will be accomplished. In addition, quantity and schedule have to be considered in order to capture the effects of learning. Typically, cost estimators will work with engineers to develop the detailed estimates.

## Expert Opinion (Delphi)

Expert Opinion is sometimes called the Delphi technique and is used in the absence of anything else. The method uses repeated interviews with Subject Matter Experts (SME) to drive out an opinion on cost and schedule; the results tend to be broad and highly subjective based on particular SME experiences but where no data exists or where the technology is so new and ground breaking as to render existing data unreliable there may be no other way of obtaining an early programme phase estimate.

There are two main methods of predicting cost and schedule:

- Bayesian
- Parametric

## Bayesian

Bayesian Belief Networks (BBNs) are also known as Belief Networks, Causal Probabilistic Networks, Causal Nets, Graphical Probability Networks, Probabilistic Cause-Effect Models, and Probabilistic Influence Diagrams. They have attracted attention as a possible solution for the problems of decision support under uncertainty. Although the underlying theory (Bayesian probability) has been around for a long time, the possibility of building and executing realistic models has only been made possible because of recent algorithms and software tools that are able to implement them. BBNs have been applied successfully to safety case argumentation; military vehicle reliability prediction, cost model development and software defect density prediction. Only one costing tool of this type is currently in MoD use and that is FAMily of Cost Estimating Tools (FACET<sup>14</sup>); this tool is capable of early phase Forecasting of Air, Land, Sea and Space projects through use of historic programme information and Bayesian methods. The skills to develop an in house BBN capability would not normally be found in a costing organisation.

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<sup>14</sup> Developed and marketed by HVR-CSL (now part of Qinetiq).

## Parametric Costing Methods

The parametric method develops a statistical relationship between historical costs, programme physical and performance characteristics. The method is sometimes referred to as a “top-down” approach. A quote from the Parametric Estimating Handbook 4<sup>th</sup> edition...

*“The expectation of a parametric model is that it will estimate costs virtually instantaneously and accurately if the correct information is entered with respect to its parameters. It can do this repeatedly without deviation. Generally, there is an even higher expectation, namely that a parametric model will do these things quicker and better than alternative methods, such as bottoms-up estimating or detailed analogy estimating. This is especially true if the model is intended to support numerous cost trade studies and analyses.”*

While crude analogy estimates can sometimes be produced in minutes, they are not famous for their accuracy. More detailed analogy estimates can be quite accurate, but usually they are time consuming to build. A well conceived and constructed parametric model offers rapid, inexpensive forecasting at any stage of project life, and is generally the more accurate method in the early days of a project. This method is also appropriate when little information about a programme is known, except for a few key characteristics like weight, power or volume.

Developing a sound in house parametric capability requires access to historical data and staff who are competent in the use of regression techniques<sup>15</sup> to determine the CER and test it.

Parametric techniques can be used in a wide variety of situations, ranging from early planning estimates to detailed contract negotiations. It is always essential to have an adequate number of relevant data points, and care must be taken to normalise the dataset so that it is consistent and complete. In software, the development environment, that is the extent to which the requirements are understood and the programmers’ skill and experience, is usually the major cost driver.

Because parametric relationships are often used early in a programme, when the design is not well defined, the forecast can quickly and easily reflect design changes simply by adjusting the input parameter values.

Unlike analogy, parametric estimating relies on data from many programmes and covers a broader range. Confidence in parametric results depends on how valid the relationships are between cost and the physical attributes or performance characteristics. When using this method, the forecaster must always present the related statistics, assumptions, and sources for the data and it is important to make sure that the programme attributes being forecast fall within (or, at least, not far outside) the CER dataset.

Some types of physical attributes used for parametric estimating are weight, power, and for software, lines of code. For example ‘Compensated Gross Tonnage (CGT)’ is often used in early phase forecasting of Naval platforms. Other programme and performance characteristics may include site deployment plans for information technology installations, maintenance plans, test and evaluation schedules, technical

<sup>15</sup> Parametric Handbook 4<sup>th</sup> edition Appendix B deals with this comprehensively



performance measures, and crew size. This list is not exhaustive and will vary depending upon programme type, forecasting requirement and tools available.

Data sources are often found in the technical baseline, Concept of Analysis<sup>16</sup> (CoA), User Requirements Document<sup>17</sup> (URD) or System Requirements Document<sup>18</sup> (SRD). The important thing is that the attributes used in a parametric estimate should be cost drivers of the programme. The key assumption driving the parametric approach is that the same factors that affected cost in the past will continue to affect future<sup>19</sup> costs.

In addition, CERs must be well documented, because serious errors may occur if the CER is improperly used. CERs should be developed using regression techniques, so that statistical inferences may be drawn.

An alternative is to use a commercially available parametric model containing previously developed and tested CERs and then adapt it to meet the particular needs of the programme requiring a forecast; using a commercial tool also means having staff trained and experienced in its usage. These models may be tailored to a particular contractor and economic environment and should be used throughout the development, manufacture (CADM) lifecycle.

The goal of parametric estimating is to create a statistically valid cost estimating relationship (CER) using historical data. The CER may then be used to estimate the cost of the new programme by entering its specific characteristics into the parametric model. CERs established early in a programme's life cycle should be continually revisited to make sure they are current and that their input range still applies to the new programme.

Annex B contains a brief explanation of the more common predictive and statistical tools used by Forecasting and Estimating staffs. The list is not exhaustive.

## Forecasting Schedule

A Forecaster will not be tasked to forecast a complete detailed programme or project schedule as that is the responsibility of the programme or project office. However in creating a cost forecast it is necessary to provide a corresponding time line in order to obtain a realistic cost profile or to adjust a previous forecast to a changed assumption set.

Some of the predictive tools provide costs against an optimised schedule, mainly for hardware/ software development and production phases, and this assists schedule understanding at a high level to which must be added the programme office views on risk.

Schedule Forecasting has no known guides although with sufficient historic data from near neighbour programmes it is possible through regression techniques to obtain Schedule Estimating Relationships (SERs). At best the following paragraphs<sup>20</sup> and information in Annex E will assist the forecaster to develop a sound appropriate approach to schedule tasks. Annex G will provide a good basis for schedule risk analysis and contains examples.

<sup>16</sup> CoA – see [www.aof.mod.uk](http://www.aof.mod.uk)

<sup>17</sup> URD – see [www.aof.mod.uk](http://www.aof.mod.uk)

<sup>18</sup> SRD – see [www.aof.mod.uk](http://www.aof.mod.uk)

<sup>19</sup> See **Technology Considerations**.

<sup>20</sup> Adapted & anglicized (with permission) from US GAO 'Cost Estimating and Assessment Guide'.

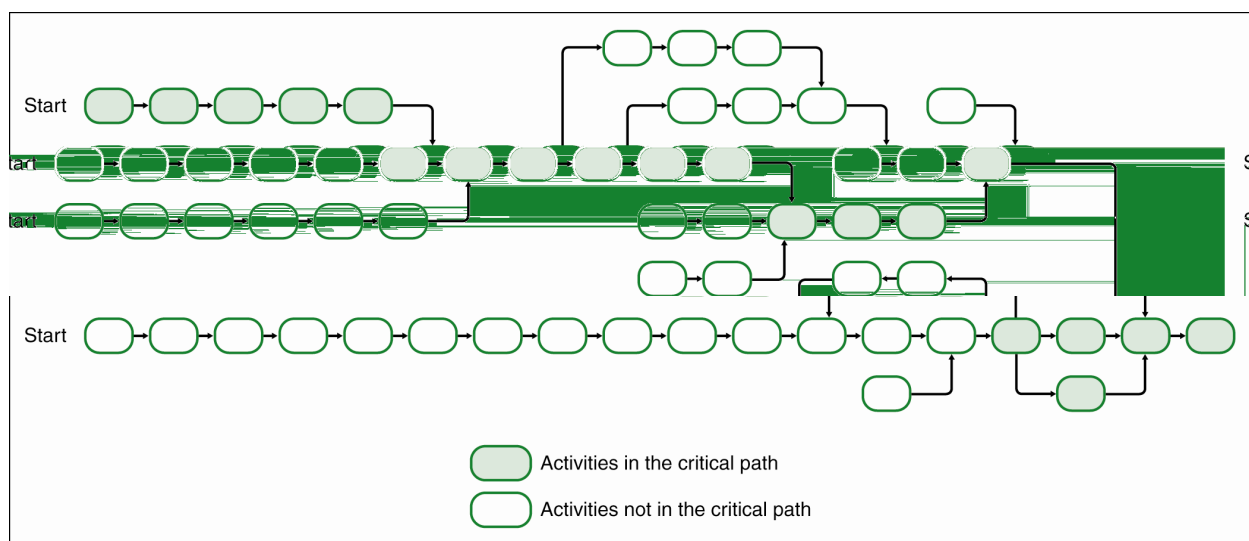
Creating a schedule provides a time sequence and the duration of the programme's activities and will help everyone understand both the dates for major milestones and the activities, often called "critical and near-critical activities," that drive the schedule. A programme schedule also provides assists a time-phased budget baseline. The typical method of analysis of schedules is the Critical Path Method (CPM), which is implemented in standard scheduling software packages.

Because some costs such as labour, supervision, rented equipment/facilities and escalation, will cost more if the programme takes longer (standing army and overhead effects) a schedule can aid analysis of cost impacts when schedules need to be extended or shortened. The schedule shows when major events are expected as well as the completion dates for all activities leading up to them, which can help determine if the schedule is realistic and achievable. When fully laid out, a detailed schedule can be used to identify where problems are or could potentially occur.

Programme success often depends on the quality of its schedule. If it is well integrated, the schedule clearly shows the logical relationships between program activities, activity resource requirements and durations, and any constraints that affect their start or completion.

An integrated schedule is a key to managing programme performance and is necessary for determining what work remains and the expected cost to complete it. As programme complexity increases, so must the schedule's sophistication.

When activities are sequenced, using dependencies between them that reflect the programme's execution plan, the result is a network of activity chains like those shown in the network figure<sup>21</sup> below.



Source: © 2005 MCR LLC, "Schedule Risk Analysis."

**Figure 2: An Activity Network**

A network diagram outlines the activity sequences and their dependencies; it also documents how the programme measures progress toward certain milestones. By linking activities together with appropriate finish-to-start logic, one can determine which activities must finish before others begin (known as predecessor activities) and which activities may not begin until others have been completed (successor activities). Other relationships such

<sup>21</sup> For more detail see GAO Cost Estimating and Assessment Guide

as start-to-start and finish-to-finish are used as well. This information fosters a better understanding of the programme as a whole, identifies disconnects as well as hidden opportunities, and helps improve efficiency and accuracy. Moreover the programme schedule provides a method for controlling the program by comparing actual to planned progress.

Schedules should also be integrated. When integrated horizontally, the schedule links the products and outcomes associated with already sequenced activities. These links are commonly referred to as “hand offs” and serve to verify that activities are arranged in the right order to achieve aggregated products or outcomes. Horizontal integration also demonstrates that the overall schedule is rational, planned in a logical sequence, accounts for interdependencies between work and planning packages, and provides a way to evaluate current status. Being traceable horizontally, however, is not a simple matter of making sure that each activity has a successor. Activities need to have certain predecessor-successor relationships so the schedule gives the correct results when they are updated or when durations change. There are two logic requirements that both have to be provided:

- Finish-to-start or start-to-start predecessors so that if the activity is longer than scheduled it does not just start earlier automatically; and
- Finish-to-start or finish-to-finish successors that will be “pushed” if they take longer or finish later.

This is good critical path method scheduling and is crucial to Monte Carlo simulation when activity durations are changed on purpose thousands of times. Without this logic, simulation techniques will not identify the correct dates and critical paths when durations change.

Schedule mapping or alignment within the layers of the schedule among levels (master, intermediate, detailed) enables traceability and different groups to work to the same master schedule. When schedules are vertically integrated, lower-level schedules are clearly traced to upper-tiered milestones, allowing for total schedule integrity and enabling different teams to work to the same schedule expectations.

The schedule should be analysed on a regular basis for variances and changes to the program’s completion date by experienced scheduling staffs trained in critical path method network analysis. The schedule should be monitored and progress reported regularly so that the current status of the activities, total float, and the resulting critical path can be determined. Variances between the baseline schedule and the current schedule should be examined and assessed for impact and significance. Changes to the program scope should also be incorporated with the appropriate logic.

From the analysis, management can make decisions about how best to handle poor schedule performance. For example, management could decide to move resources to critical path activities to improve status or allocate schedule reserve to immediately address a risk that is turning into an issue.

In addition, the risks from the cost estimate uncertainty analysis should be compared against the management reserve allocation. This practice further ties the cost estimating risk analysis with EVM. It can also help to avoid handing out money whenever a part of the program encounters a problem, thereby ensuring that as more complicated tasks occur later in the program there would still be management reserve left if problems arise. This

method also allows budget to be allocated in a way that matches each control account's expected cost distribution, which is imperative for minimizing cost overruns.

Historically, state-of-the-art technology development programs have taken longer than planned for the same reasons that costs often exceed the estimate: no point estimate for schedule duration is correct and risk is generally high in development programmes. Each estimate of activity duration has a range of possible outcomes, driven by various uncertainties such as a lack of available technical capability, software development, integration problems, and test failures.

The Forecaster needs to be aware that one programme office method of regaining lost time is to curtail the time for late programme activities by, for example, reducing the number of tests/ trials or reducing the integration and test schedules (collect 'live' data once fielded) or by adding more resource to the problem activities. In some cases this may work but for software development and where software integration requirements are complex (safety critical) the reduction in late testing activities adds significant risk to time, cost and performance; throwing more resources at software development simply creates more difficulties in programme execution and again adds significant risk to deliver of acceptable software.

## Forecasting Outputs

Forecasting outputs are dictated by two factors – the customer requirement and the type of forecast prepared, above all the outputs must be presented clearly<sup>22</sup>, be understandable and provide a sound base for decision makers.

Most Forecasting outputs are either:

- a cost model which contains tabular output data and graphs or
- a written report containing assumptions, analysis of the predicted costs and/ or schedule for a range of options or
- a presentation for delivery to the customer's team summarising the assumptions, methods and outputs.

In all cases Forecasting outputs **must** have a:

- documented cost or master data assumptions list (CDAL or MDAL)
- validated cost model and
- cost and schedule outputs accompanied by a set of statistical data that provide confidence information for the customer.

Forecast costs for option comparisons are normally prepared according to the economic appraisal rules set out in JSP507 and reported as constant costs in 'Net Present Values (NPV)' excluding VAT. Preferred option costs for inclusion in the business case will be calculated at full cost including VAT.

At customer request the business case full costs may be converted into resource accounting and budgeting format for direct comparison with programme budget lines although this is usually Finance staff responsibility. The generic Output Forecasting Model (OFM) may be used for this.

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<sup>22</sup> See *Visual Explanations*, Edward R. Tufte, Graphics Press, 1997

## Data

Parametric techniques and Historic Trends Analysis (HTA) require the collection and use of consistent, traceable historical cost and schedule data (including labour hours), associated technical non-cost and organisational information and factors that describe and strongly influence these data. Data should be collected and maintained in a manner that provides a complete audit trail with expenditure dates so that costs can be adjusted for inflation and/ or currency conversion. The Parametric Handbook contains more information on data and data manipulation.

A fundamental requirement for the inclusion of a technical non-cost variable in a CER is that it must be a significant predictor of cost and often it is an iterative process of trial and error to establish the 'best' variables within a CER, it follows that data requirements are often poorly understood.

Typical technical non-cost data:

- physical, quantity, equivalent units
- performance
- engineering characteristics of a system or sub-system
- development and production schedules
- production rates, breaks in production
- significant design changes

For example, weight is a common non-cost variable used in CERs. Annex D illustrates some of the typical data items that may be required. Technical non-cost data come from a variety of sources including the MIS (e.g., Materials Requirements Planning<sup>23</sup> (MRP) or Enterprise Resource Planning<sup>24</sup> (ERP) systems), engineering drawings, engineering specifications, certification documents, interviews with technical personnel, and through direct experience (e.g., weighing an item). Relevant programme data including anomalies such as impacts of industrial unrest, exchange rate fluctuation, raw material shortages and natural disasters are also necessary to fully explain any significant fluctuations in the data.

Other data that should be collected relates to the tools and skills of the project team, the working environment, ease of communications, international partner involvement and compression of schedule. Project-to-project variability in these areas can have a significant effect on cost. For instance, working in a secure facility under "need to know" conditions or achieving high levels in various team certification processes can have a major impact on costs.

Data sources which contain a wealth of validated data for public sector procurement previous analysis results may be found on the UK National Audit Office<sup>25</sup> (NAO) website, the US based Rand Corporation<sup>26</sup> and the US GAO<sup>27</sup>.

<sup>23</sup> MRP – Manufacturing Resource Planning

<sup>24</sup> ERP - Enterprise Resource Planning (ERP) refers to the implementation of an administrative software system based on commercial off-the-shelf software throughout an organisation. ERP's objective is to integrate information and business processes—including human resources, finance, manufacturing, and sales—to allow information entered once into the system to be shared throughout an organisation. ERP systems force business process re-engineering allowing for improved operations which can lead to later savings.

<sup>25</sup> [www.nao.gov.uk](http://www.nao.gov.uk)

<sup>26</sup> <http://www.rand.org/publications/electronic/mat.html>

<sup>27</sup> [www.gao.gov](http://www.gao.gov)



Once collected, data must be adjusted to account for the effect of certain non-cost factors, such as production rate, improvement curve, and inflation - this is data normalisation.

Data quality may require the assignment of an agreed “quality indicator” to each of data element so that forecast reviewers may establish the overall data quality used to provide the output.

While there are many formats for collecting data, one commonly used by industry is the Work Breakdown Structure<sup>28</sup> (WBS); this very similar to the MoD CRBS. The WBS provides for uniform definition and collection of cost and certain technical information. The collection point for cost data is generally a company Management Information System (MIS), which in most instances contains the general ledger and other accounting data.

A forecaster should arrange to review Invitation To Tender (ITT) and Request For Quotation (RFQ) documents at a draft stage to ensure that the right data will be returned as part of any tendering exercise and then later reported as part of contractual deliverables as each contract item is completed. This implies early involvement with both programme and commercial staffs.

Forecasting practices should contain procedures for mapping the cost data to the cost elements of the parametric technique(s) which will be used.

## Uncertainty & Risk in Forecasting

First, two definitions are necessary to remove confusion and clarify meanings:

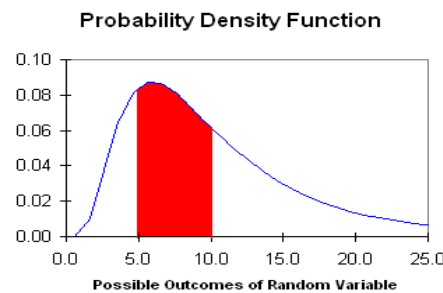
**Uncertainty** – this is a known factor, it may be included within forecasting algorithms and also be present within typical input data. Uncertainty may be expressed as a range of cost (£1,000 – £2,000) or schedule (16 – 24 months) between the limits of which the ‘real’ or ‘eventual’ value may lie; another method is to express uncertainty as three input points (low, most likely and high), this is widely referred to as the “3 point estimating” technique. Both methods permit use of stochastic simulation techniques to derive an output Probability Density Function (pdf). Allocation of probability values to an uncertainty is not possible. If it were possible then the uncertainty would be a ‘Risk’.

**Risk** – an event or occurrence that has an impact on cost, schedule or performance (or any combination thereof) and which can be quantified<sup>29</sup> in terms of impact and probability of occurrence. For example collected field data may be analysed to provide statistical information about occurrences of failure – 1 failure per 10 hours of flight or 1 failure per 50 kilometres. Good practice suggests that any risk having a probability of greater than 80% (approaching certainty of occurrence), should be brought into the base forecast.

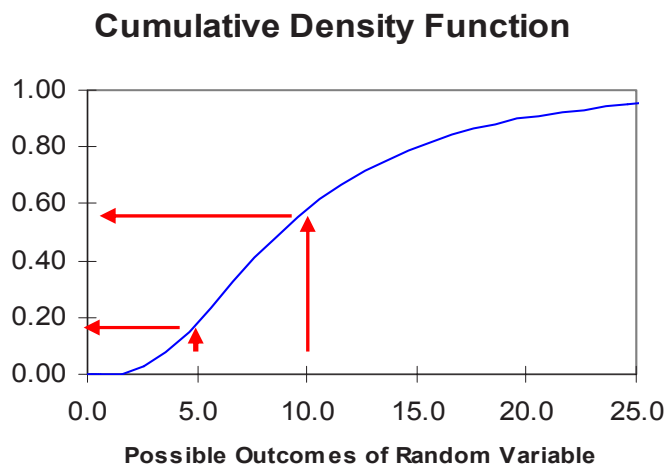
<sup>28</sup> A commonly used standard WBS is MIL-881

<sup>29</sup> *Risk Analysis: A Quantitative Guide*, David Vose, 2000, John Wiley & Sons





The above chart shows an example output from a stochastic simulation, the total area under the curve is 1; the probability that the random variable takes on some value in the range is 0-1 is 100%. The red shaded area is the probability that the random variable has a value between 5.0 and 10.0 in this case that value is 40%. An alternative method is to show stochastic results as a cumulative density function (CDF) or as a 's-curve'. The graph below shows the same random variable results as a CDF, the y axis represents probability with the difference between being 40% for y values of 5 and 10.



This type of s-curve is normally used as a forecasting output to display probability Vs cost or schedule for the option being considered.

A forecast constructed across CADMID phases and with a tailored CRBS will consist of many elements each bounded by uncertainty ranges, perhaps 'point estimates' modified by a distribution<sup>30</sup> (triangular or beta) and combined with quantified risks. Most cost or schedule distributions are not 'normal' and are skewed with a right tail as shown below.



Triangular distribution



non-Normal distribution

<sup>30</sup> Cost and schedule distributions are never 'normal' in the statistical sense and will only appear so as a result of a large number of Monte Carlo simulations when the Central Limit theory applies.

All of these will have some time phasing considerations as well. The cost model must be able to correctly combine all of these into a single cost or schedule coherent stochastic process to correctly calculate the output.

If forecasts are derived using statistical methods their outputs **must not** be simply aggregated they must be combined statistically.

For example if an Option cost forecast contains elements of vehicles, aircraft, ground stations, training simulators and maintainers and each is forecast correctly using different tools or within different Forecasting sections, their outputs **must not** be aggregated in MS Excel to obtain an Option cost total as it will provide the wrong total and be without proper confidence limits.

Current MoD project costs are required to be stated at the 10<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentiles with the figures being obtained from a stochastic simulation. All individual cost elements must be properly combined into the modelling of cost and schedule by use of statistical techniques. Just because all figures may be stated to be 'the 50<sup>th</sup> percentile' **it is statistically incorrect and is unacceptable practice** to simply add them up, this is not a matter of simple addition! Commercial models and MS Excel may be used to perform this combination.

## Optimism Bias

The UK Treasury in 2002, as a direct result of government wide projects failing to meet the requirements of time, cost and quality, engaged Mott MacDonald (MM) to carry out a study<sup>31</sup> to identify the reasons why. Their report concluded that project managers and their advisers are invariably over optimistic in all three major areas (time, cost & quality).

MM found that the levels of optimism (or understatement of cost/ schedule) could be greatly reduced by better attention to 12 main criteria and they allocated weightings<sup>32</sup> to reflect their relative impact. These criteria and associated weightings were built into an Optimism Bias calculator; two versions exist, one for IG and the other for MG.

The premise the tool works on is that a perfectly constructed and fully staffed business case should not be penalised. This has been accepted and the tool incorporates this methodology and MoD acquisition processes now require OB to be calculated and discussed for IG and MG business cases.

It should be noted that a minimum penalty of 10% is applied to both Schedule and Costs irrespective of the robustness of the business case. The tool is available from CAAS-CF for use on IPT business cases.

## Cost Modelling & Tools of the Trade

The stock tool for most cost Forecasting and estimating work tends to be Micro Soft Excel and a listing of all the cutneiseA 0.0mC -eC.k tool3 Tm99 Td(Exc)-

## The Aggregation model

An aggregation model will be normally constructed using Excel. Each cost element is an input value which the model processes upwards to a total value that includes effects of quantity and timing. In other words the model relies upon cost input data from other sources either as direct inputs or obtained from feeder models; the aggregation model **does not create or predict values for particular input CRBS elements**.

Most so called 'cost models' in use by MoD for project and programme costing by Finance, budget staffs and delivered by third party cost consultants fall into the aggregation category and are not generally statistically based predictive models (see later Predictive Model paragraph. Whilst this statement is not meant to detract from the value of an aggregation model within the business it does highlight two serious drawbacks:

- Unless constructed as a statistical model the aggregation of lower level elements will result in an incorrect answer.
- If changes to quantity and or timing are required it cannot be a simple pro rata within the aggregation model input data. To adjust inputs correctly requires a return to the original assumptions and feeder predictive modelling tool(s); changes to timing or schedule will also present similar challenges as development/ production schedules are interwoven with cost impacts that are dependent upon many factors and, these will not be replicated within the aggregation model.

If either or both of the above bullet points apply then changes **must** be referred to a competent Forecasting area for rework to the changed assumption set to preserve the integrity of the forecast - and this takes time.

## The Predictive Model

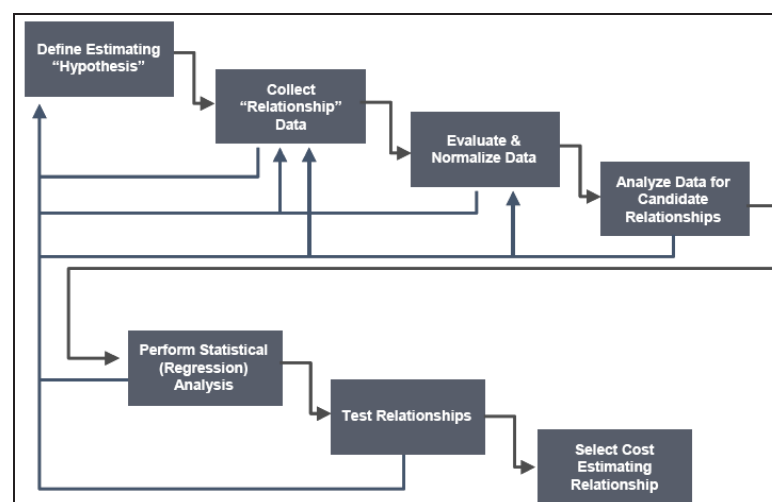
There are relatively few bespoke predictive models, those that do exist are ‘niche’ with restricted capability covering a small number of CRBS line items. A cost analyst will build a predictive model using commercially available predictive tools (Price, Seer, FACET etc), existing CERs or by deriving new CERs from collected data. Most likely the forecast will use a combination of tools to provide complete coverage of the CRBS elements. The precise predictive tool selected will depend upon project phase and availability of data; for example, FACET would be used at concept phases whilst Seer or Price would be used in later Assessment, Demonstration or manufacture phases where greater detail is available.

A predictive model relies on programmatic inputs for quantity, schedule, physical and performance parameters; the exact input requirements depend upon the method(s) selected; cost and schedule are statistically calculated and thus any changes to input parameters can be quickly achieved and will be reflected in the output.

Since most commercially available models do not cover (for defence purposes) a complete range of cost breakdown element outputs, a number of different predictive model outputs may need to be brought together within Microsoft Excel to produce an overall model and final format bearing in mind the impact of “Uncertainty & Risk”.

## Cost & Schedule Estimating Relationship (CER & SER)

A CER/ SER will be produced by a competent cost analyst using regression techniques and known valid data. A CER/ SER usually relates to only a single element (radar, engine etc.) although whole platform CER/ SER may be created for very early concept phase work. Relationships may be used to predict cost for future systems within the confidence bounds created by the historic data on which they are based. For example if a CER is based on platform weight and power from data in the range of 100-200KGs and 50-400KW respectively, then to predict the cost of a new system weighing 1500KGs with 900KW is unsafe because the new performance characteristics are far outside the nearest data point. A typical flow diagram<sup>33</sup> below shows the necessary steps in developing a CER or SER.

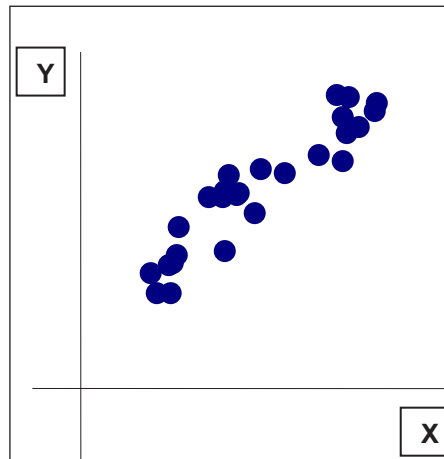


<sup>33</sup> Source – NASA Cost Estimating Handbook Edition 4

Figure 3 Development Steps

## Overview of CER/ SER Regression Analysis

To perform a regression analysis, the first step is to determine if a relationship exists between cost (dependent variable) and its various drivers (independent variables). This relationship is determined by developing a scatter chart of the data. If the data are linear, they can be fit by a linear regression. In the example chart below there is clearly a positively correlated relationship between the dependent and independent variables.



Positive correlation means that as 'x' increases in value, there is a corresponding increase in the 'y' value. Cost and schedule models must consider the impact of correlation between the model sub-elements.

If the relationship is not linear and transformation of the data (using logarithmic scales) does not produce a linear fit, nonlinear regression may be used. The independent variables should have a high correlation with cost and should be logical.

The ultimate goal is to create a fit with the least variation between the data and the regression line. This process helps minimize the statistical error or uncertainty brought on by the regression equation.

The purpose of the regression is to predict with known accuracy the next real-world occurrence of the dependent variable (or the cost), based on knowledge of the independent variable (or some physical, operational, or program variable). Once the regression is developed, the statistics associated with the relationship must be examined to see if the CER is a strong enough predictor to be used in the estimate. Most statistics can be easily generated with Microsoft Excel's regression analysis function. Among important regression statistics are R-squared, statistical significance, the F statistic, and the t statistic; these statistics are calculated within MS Excel and other packages automatically.

### R-squared

The R-squared ( $R^2$ ) value is the ratio of explained to total variation; it is therefore a measure of the strength of association between the selected independent and dependent variables; cost is usually the dependent variable.  $R^2$  values range between 0 and 1, where 0 indicates that there is no relationship between dependent and its independent variable, and 1 means that there is a perfect relationship between them. Thus, a higher  $R^2$  is better. For example, a CER with an  $R^2$  of 0.91 or 91% explains 91 percent of the variation in costs, indicating that it is a very good cost driver.



## **Statistical Significance**

Statistical significance is the most important factor for deciding whether a statistical relationship is valid. Statistical significance is determined by both the regression as a whole and each regression variable.

An independent variable can be considered statistically significant if there is small probability that its corresponding coefficient is equal to zero, because a coefficient of zero would indicate that the independent variable has no relationship to cost. Thus, it is desirable that the probability that the coefficient is equal to zero is as small as possible. Just how small is identified by a predetermined value called the 'significance level'. For example, a significance level of .05 would mean there was a 5 percent probability that a variable was not statistically significant.

### **F Statistic**

The F statistic is used to judge whether a CER/ SER as a whole is statistically significant by testing to see whether any of the variables' coefficients are equal to zero. The F statistic is defined as the ratio of the equation's mean squares of the regression to its mean squared error, also called the residual. The higher the F statistic value is, the better the regression, but it is the level of significance that is important.

### **t Statistic**

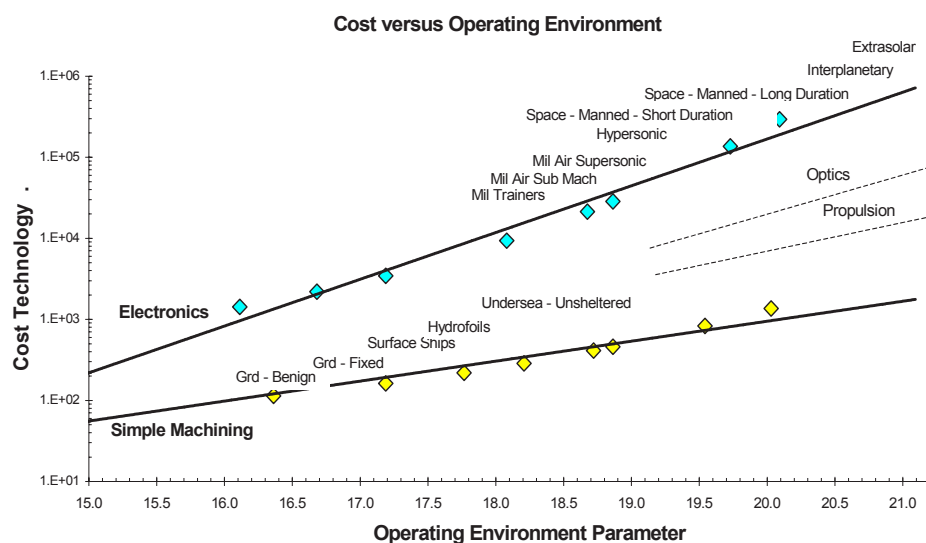
The t statistic is used to judge whether individual coefficients in the equation are statistically significant. It is defined as the ratio of the coefficient's estimated value to its standard deviation. As with the F statistic, the higher the t statistic value is, the better, but it is the level of significance that is important.

## Technology Considerations (Historic Trends)

The UK MoD Approvals processes require that major programmes (Category A & B) are set against a 'Historic Trend Analysis (HTA)' conducted to support their IG business case. Forecasters require historic data to provide time sequenced cost and schedule trends. The following paragraphs and Annex E illustrate how changes over time may be used to place current forecasts against a historic trend and assess whether the current forecast is realistic.

Whenever a future programme forecast is required, account must be taken of changes to technology between the time of the forecast and later new system procurement. Often new systems forecasts will look 30 years or more into the future.

Consider the graph below produced by the Aerospace Corporation<sup>34</sup>, this shows growth in cost against operating environment for electronic assemblies and also simple machined components, it is clear that no matter what the technology may be, the more demanding an environment the greater the cost. Detailed investigation will reveal that higher value environments place greater demands on technology to deliver reliable systems within physical constraints; this drives cost and often introduces risks especially where the technology is not mature.



As technology matures and grows, the overall weight for a given functionality declines and this is particularly prevalent in electronic systems.

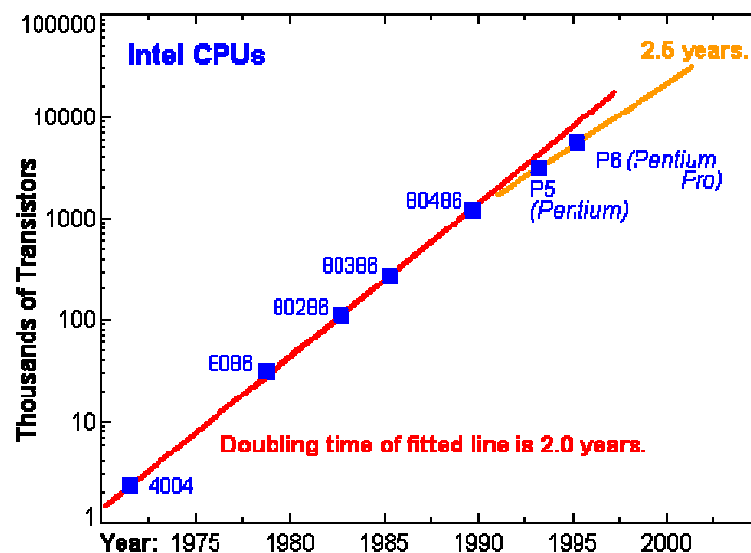
An example of changing technology impact on system weight would be a typical ground communications High Frequency vacuum tube radio system (without ancillary equipment) manufactured by the Collins Radio Company<sup>35</sup> in the early 1950s, it comprised a receiver and transmitter each weighing approximately 38 Kilograms, giving a two box system weight of 76 Kilograms. By the early 1960s an equivalent system was available as a single box of 38 Kilograms hybrid vacuum tube plus discrete semiconductor technology and by 2000 as a single box weighing just 16 Kilograms using very large scale integration (VLSI) and partially discrete semiconductor technology yet offering significant performance enhancement through

<sup>34</sup> Aerospace Corporation, FFRDC, Los Angeles, California 2006.

<sup>35</sup> Now Rockwell Collins

use of software based digital processing techniques. By 2008 a slightly reduced performance VLSI and application specific technology (ASIC) system (still exceeding 1950s performance) is now on the market weighing under 3 Kilograms! Changing technology has caused these system level weight reductions although this trend may not be fully observable at platform level. Weight based parametric hardware cost techniques will be adjusted by complexity factors to obtain development and production costs and will require additional modelling to account for the 'software development' necessary to provide the necessary system functionality.

The scale of technology advancement is contained in Moore's Law<sup>36</sup>. This observation made in 1965 by Gordon Moore, co-founder of Intel, was that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented and this has marked the rate of the semiconductor industry advance since the late 1960s. While the density of transistors has been doubling every 18 months since 1997, in the electronic memory storage industry, density has been doubling every 12 months. The graph for Intel processors is shown below.

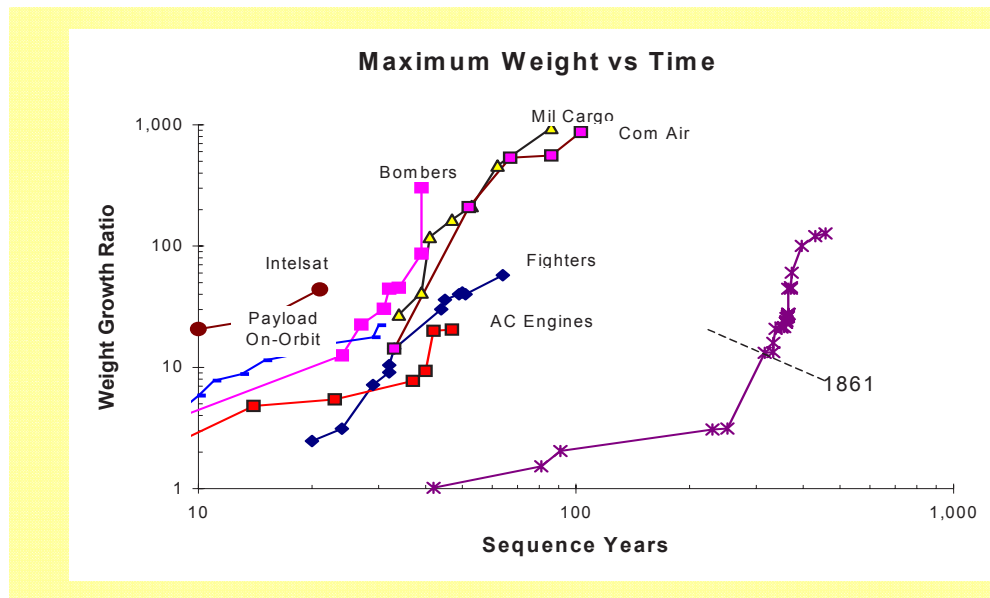


Moore predicted that this trend would continue for the foreseeable future. In subsequent years, the pace slowed down, but data density has still doubled approximately every 18 months; this is the current definition of Moore's Law, which Moore himself has blessed. Most experts, including Moore himself, expect Moore's Law to hold for at least another two decades.

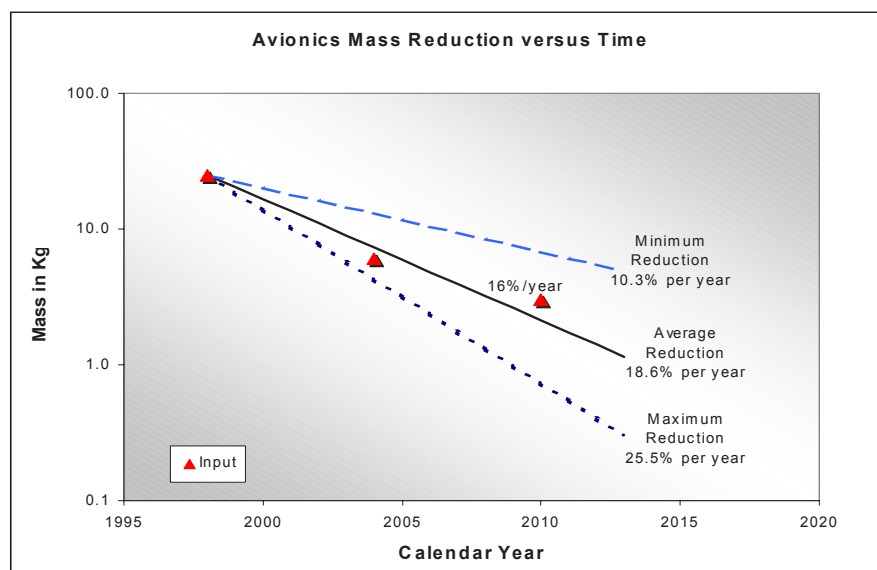
<sup>36</sup> Gordon Moore, co-founder of [Intel](http://www.intel.com), 1965. See the [May/June 2000 Issue](#) of *Technology Review*.

## Growth

If we collect, for example, weight data relating to particular technologies (platforms) there is a demonstrated significant growth in weight (and cost) with each successive generation. The graph<sup>37</sup> below clearly illustrates this growth phenomenon, the right hand lower graph also shows that the rate of growth increases rapidly from 1861 onwards. Aircraft tend to have 80% of weight growth during development and thereafter a rule of thumb of approximately 1% per year may be applied throughout operational life.

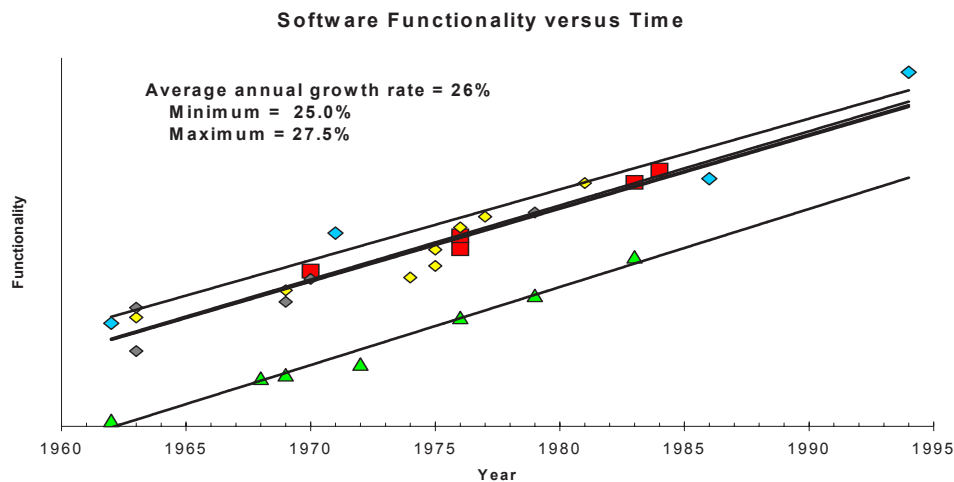


Systems fitted within the platform may have negative weight growth, the avionics graph below shows how avionics weight has decreased with time. True comparisons of system data are difficult because as weight decreases, embedded functionality increases so it becomes more difficult to compare similar programmes over time on a precise 'like for like' basis.



<sup>37</sup> Source Aerospace Corporation, FFRDC, Los Angeles, 2006.

Similarly it is hard to find a civil or military programme that does not depend upon software for correct functionality. The graph below outlines a consistent growth trend in software functionality with time.



The message here is that the forecasting of future programmes must include such growth for two reasons;

- first, increased weight margins will mean increased capacity for functionality or reduced performance and
- second, a heavier platform will inevitably cost more due to material costs and potentially higher labour costs resulting from use of advanced materials (e.g. composites) as a weight reduction measure leading to more complex precision assembly requirements.

## Software Dependent Programmes

A Software Dependent Programme (SDP) is one that relies upon software application(s) to deliver the required operational capability, this may be a simple indication of door open/ closed for an alarm system or a safety critical flight management system that enables a high performance military aircraft to fly.

Software does not quite fit the UK CADMID cycle because it has only two phases – Development and In Service support, the manufacturing phase cost, usually replication of the application on CD or other media is cheap enough to ignore.

A Standish Group International 2000 report showed that 31 percent of software programs were cancelled, more than 50 percent overran original cost estimates by almost 90 percent, and schedule delays averaged almost 240 percent.<sup>38</sup> Moreover, the Standish Group reported that the number of software development projects that are completed successfully on time and on budget, with all features and functions as originally specified, rose by only 12% from 16% in 1994 to 28% in 2000<sup>39</sup>.

<sup>38</sup>Daniel D. Galorath, Software Projects on Time and Within Budget—Galorath: The Power of Parametrics, Powerpoint presentation, Galorath Inc., El Segundo, California

<sup>39</sup>Jim Johnson and others, "Collaboration: Development and Management—Collaborating on Project Success," *Software Magazine*, Sponsored Supplement, February–March 2001, p. 2.

A second European Report<sup>40</sup> in 2007 identified 105 problematic public sector IT procurements, quoting

*“Central civil government spends annually some £2.3 billion on information technology, equivalent to 16% of total procurement expenditure, yet this Committee has reported on a succession of IT programmes and projects characterised by delay, overspends, poor performance and abandonment”* (House of Commons PAC, 2005).

This suggests that forecasting software represents more of a challenge than forecasting a hardware system.

Software Forecasting requires three principal items other than programmatic information:

- Programme size metrics
- Programme language
- Application type.

### **Programme size**

Estimating software size is not easy and depends on having a detailed knowledge about a programme's functions in terms of scope, complexity, and interactions. Not only is it hard to generate a size estimate for an application that has not yet been developed, but the software process also often experiences requirements growth and scope creep that can significantly affect size and the resulting cost and schedule estimates. For example, software programmes that are more complex<sup>41</sup>, perform many functions, have safety of life requirements, and require high reliability will typically be bigger than simpler programmes.

Methods for measuring size data include feature point analysis, function point analysis, object point analysis, source lines of code, and use case. Since source lines of code have been used widely for years as a software sizing metric, many organisations have databases of historical source lines of code counts for various completed programmes.

### **Programme Language**

Software is written in a variety of languages, these range from the very low level machine code to high level languages that may be read with care direct from a printed page. All of these languages impact size, generally a low level language will result in higher code count due to a large number of simpler instructions and longer development times whereas a higher level language has a smaller size but requires additional testing routines due to program complexity. Automatic code generators are available and these speed up parts of the software development. Some languages are 'niche' and have only a small number of competent programmers thus choice of language may impact labour costs as well.

### **Application**

Significantly large software development efforts frequently experience cost and schedule growth. This is due to the complexities inherent in managing configuration, communications, design assumptions, and so on typically hinder software development productivity. In addition, there is a ripple effect that increased software

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<sup>40</sup> ESSU Report No3 December 2007 Cost Overruns, Delays and Terminations

<sup>41</sup> See 'Ultra Large Systems' by Dr Linda North SEI, Carnegie-Mellon



schedule has on other collateral support efforts such as programme management and systems engineering.

## Code Definitions

- **Reused** software is code that is used verbatim without modification, the effort associated with reused code depends on whether significant integration, reverse engineering, and additional design, validation, and testing are required. If the effort to incorporate reused software is too great, it may be cheaper to write the code from scratch. As a result, the size of the software needs to reflect the amount of effort expected with incorporating re-used code from another source. This may be accomplished by calculating equivalent source lines of code (ESLOC) which adjusts the software size count to reflect the fact that some effort is required.
- **adapted** software is code that needs to be redesigned, it may need to be converted and may need some new code added,
- **auto-generated** software provides the developer with code that can be used in a new programme, however additional effort is usually associated with incorporating into a new programme.

Once the software has been developed, tested, and installed in its intended location, it must be maintained, just like hardware. Often called the operational phase for software, maintenance costs must be accounted for in Through Life Costing. Software maintenance has a distinct terminology:

- **Corrective** maintenance - fixing any defects not discovered in testing. The quality of the developed software will also affect corrective maintenance. If the software was rigorously tested, then less corrective maintenance will be needed. Software that is well documented provides maintainers with a better understanding of how the software was designed will be easier to debug and streamline modifications.
- **Adaptive** maintenance - modifying the software to work with any changes to its physical environment, technology upgrades driven by hardware evolution.
- **Perfective** maintenance - adding new functionality, user enhancement requests. Perfective maintenance often makes up the bulk of the software maintenance effort. When adding functionality, the effort is similar to a mini development effort and the cost drivers are the same as in development. If development requirements were deferred until the maintenance phase or the requirements were vague and not well understood, then additional perfective maintenance will be necessary.

## Software Forecasting with Parametrics

Software development cost estimating tools - or parametric tools - can be used to estimate the cost to develop and maintain software. When a parametric tool is used, it is essential to ensure that the estimators are trained and experienced in applying it and interpreting the results. Highly recommended reading is 'Chapter 12 Software Estimating' in the GAO Cost Estimating and Assessment Guide.

Parametric tools should be used throughout the development lifecycle of the software. They are especially beneficial in the early stages of the software life cycle, when requirement specifications and design are still vague. For example, these tools provide flexibility by accepting multiple sizing metrics, so that forecasters can apply different sizing methods and examine the results. Additionally, parametric-based estimates can be used to understand tradeoffs by analysing the relative effects of different development scenarios, determine risk areas that can be managed, and provide the information necessary for monitoring and control of the programme. Developers who use tools in development can discover potential problems early enough to mitigate their impact.

Among other things, these software inputs extend beyond the hardware parametric tool inputs and generally include the size of the software, personnel capabilities, personnel experience, organisation CMMI<sup>42</sup> level, development environment, amount of code reuse, programming language, and labour rates.

## So You want to be a Forecaster

You will have read in **‘What skills are required in a Forecasting Team’** about the wide range of skills and broad background that most forecasters acquire over a number of years. Some of the educational background and necessary on the job experience must be supplemented by specific training in Forecasting and estimating techniques, tools and methods. Such courses are vital to developing an ability to understand and create both schedule and cost forecasts for any or all project lifecycle phases.

There is a range of specific individual estimating courses available in UK MoD though none lead to formal examination based certification or accreditation in cost estimating/Forecasting.

A Forecasting post provides excellent ground in analysis of project cost and schedule and ensures a sound understanding through involvement in defence acquisition processes in far greater detail than a post in a single project because a forecaster will work on many project approvals and business cases each year whereas a project team concentrates upon their immediate approval and then only once (Initial and Main Gate).

A Forecaster will become productive (if not fully competent) after a period of approximately 2 years, competence at ‘practitioner’ level is likely to be achieved with appropriate training and experience after around 5 years with ‘subject matter expert’ or ‘expert’ competence rating after 10 or more years in a Forecasting post(s).

Widely accepted training for cost analysts is offered by the Society of Cost Estimators and Analysts (SCEA training leads to accreditation as a Certified Cost Estimator & Analyst<sup>43</sup> (CCEA) and for the parametric specialisation the Certified Parametric Practitioner<sup>44</sup> (CPP) accreditation is offered by the International Society of parametric analysts (ISPA). The tested approach is supplemented by on the job training and experience. So a newcomer to Forecasting will need to build up experience as well as receive training before entering the accreditation examination.

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<sup>42</sup> Capability Maturity Model Index (CMMI) SEI, Carnegie Mellon University, Pittsburgh

<sup>43</sup> See Society of Cost Estimators and Analysts (SCEA) [www.sceaonline.net](http://www.sceaonline.net) website for details.

<sup>44</sup> See International Society of Parametric Analysts (ISPA) [www.ispa-cost.org](http://www.ispa-cost.org) website for details.

Membership of both organisations is recommended and a global community from over 50 countries of analysts, drawn from like skilled people in Industry and Government, greatly enhances knowledge transfer.

## SCEA CCEA

The basic training offered by SCEA covers the syllabus below and leads to examination and award, if successful, of a CCEA certificate valid for 5 years and which will require re-certification after 5 years.

There are new developments<sup>45</sup> entitled CEBok (**C**ost **E**stimating **B**ody of **K**nowledge) and the new material will be suitably annotated during training delivery, there will be a new CCEA examination introduced in 2009.

The new exam has two parts:

- Part I qualifies an individual as a Professional Cost Estimator/Analyst (PCEA)
- Parts I and II combined qualify an individual as a Certified Cost Estimator/Analyst (CCEA).

The syllabus covers topics familiar to both the estimating and Forecasting fraternity, forecasters also need to understand everything listed in the syllabus but will probably not use the really detailed elements of learner theory or manufacturing processes in any cost or schedule forecast.

- **I. Cost Estimating Basics**
  1. Cost Estimating Techniques
  2. Parametric Estimating
- **II. Cost Analysis Techniques**
  1. Data collection & normalization
  2. Index Numbers & Escalation
- **III. Analytical Methods**
  1. Basic data analysis principles
  2. Learning curve
  3. Regression Analysis
  4. Cost risk analysis
  5. Probability & Statistics
- **IV. Specialized Costing**
  11. Manufacturing cost Estimating
  12. Software cost estimating
- **V. Management Applications**
  11. Economic analysis
  12. Contract pricing
  13. Earned Value Management systems (EVMS)
  14. Cost management

## ISPA CPP

ISPA offers training and examination based CPP certification in the use of parametric techniques, this is again subject to re-certification after 5 years and details are on the

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<sup>45</sup> For more see [http://www.sceaonline.org/certification/NEW\\_CCEA\\_Program\\_brochure.pdf](http://www.sceaonline.org/certification/NEW_CCEA_Program_brochure.pdf)

ISPA website. The examination and syllabus are based upon the “Parametric Estimating Handbook” sponsored by the US department of Defense (DoD) and is available as a free download from the IPSA website.

Parts of the syllabus are common with the SCEA CCA training but are covered in much greater detail and this is understandable considering the very much reduced focus on parametrics. An outline of the coverage is below.

- Parametric analysis overview
  1. Best practices
  2. Cost Estimating Relationships
  3. Complex models
- Data collection and analysis
  1. Data types
  2. Data sources
  3. Routine normalisation
  4. Significant normalisation
- Cost Estimating Relationships
  1. CER development
  2. Curve fitting and OLS Regression
  3. Testing significance of CERs
  4. Evaluating CERs
- Company developed complex Models
- Complex Hardware models
- Complex software models
- Government compliance
- Other parametric applications
- International use of parametrics

These topics are underpinned by a number of detailed supporting annexes and illustrations.

## Annex A 12 Steps of Forecasting<sup>46</sup>

### 1. Define Forecast's purpose

- the 'why';
- the level of detail required;
- who will receive the forecast
- overall scope.

### 2. Develop Forecasting plan

- Determine the cost Forecasting team for the task.
- Outline the cost Forecasting approach.
- Agree the forecast timeline.
- Determine who will do the independent cost estimate.
- Develop the team's master schedule.

### 3. Define programme characteristics

- programme's purpose;
- system and performance characteristics;
- technology implications;
- all system configurations;
- programme acquisition schedule;
- acquisition strategy;
- relationship to other existing/ future systems;
- support (manpower, training, etc.)
- security needs;
- risk areas;
- system quantities for development, test, and production;
- deployment and maintenance plans;
- predecessor or similar legacy systems.

### 4. Determine Forecasting structure

- Define & tailor CRBS
- Describe each element in a CRBS dictionary; for example an out-sourced major automated information system may have only a small cost element structure.
- Choose the best primary Forecasting method for CRBS elements.
- Identify potential cross-checks for likely cost and schedule drivers.
- Develop a cost Forecasting checklist.

### 5. Identify ground rules and assumptions.

Clearly define inclusions and exclusions in the MDAL:

- Identify global and programme specific assumptions;
- the forecast base year, including time-phasing and life cycle;
- programme schedule information by phase;
- programme acquisition strategy;
- any schedule or budget constraints;
- inflation/ escalation assumptions;
- Government Furnished Equipment/ Data/ Information;

<sup>46</sup> Unabridged original version in GAO Cost Estimating and Assessment Guide

- Likely prime contractor and major subcontractors;
- use of existing facilities or new modification or development;
- technology refresh cycles;
- technology assumptions and new technology to be developed;
- commonality with legacy systems and assumed heritage savings; effects of new ways of doing business.

## **6. Obtain data**

- Create a data collection plan with emphasis on collecting current and relevant technical, programmatic, cost, and risk data.
- Investigate possible data sources.
- Collect data and normalise them for cost accounting, inflation, learning, and quantity adjustments
- Analyse data for cost drivers, trends, and outliers; compare results against rules of thumb and historical data.
- Interview data sources and document all pertinent information, including an assessment of data reliability and accuracy.
- Store data for future estimates.

## **7. Develop forecast and compare it to an independent cost estimate.**

Note that initial forecasts will contain a 'point forecast' which is a single value and a 'distribution based forecast' which is the result of combining uncertainty and risk into the model using statistical techniques – usually reported as a mean value with confidence levels. The point and distribution values will not be identical.

- Develop the cost model by Forecasting each CRBS element, using the best methodology from the data collected.
- Include all estimating assumptions in the cost model.
- Express costs in constant year and present value (PV).
- Time-phase the results by spreading costs in the years they are expected to occur, based on the programme schedule.
- Validate and Verify (VnV) the model.
- Compare forecast against the independent cost estimate and examine where and why there are differences.
- Perform cross-checks on cost drivers to see if results are similar.
- Update the model as more data become available or as changes occur; compare results against previous estimates.

## **8. Conduct sensitivity analysis**

- Test the sensitivity of cost elements to changes in estimating input values and key assumptions.
- Identify effects of changing the programme schedule or quantities on the overall estimate.
- Determine which assumptions are key cost drivers and which cost elements are affected most by changes.

## **9. Conduct uncertainty and risk analysis**

- Determine the level of cost, schedule, and technical risk associated with each CRBS element and discuss with technical experts.
- Analyse each risk for its severity and probability of occurrence.



- Develop minimum, most likely, and maximum ranges for each element of risk.
- Use an acceptable statistical analysis methodology (e.g., Monte Carlo simulation) to develop a confidence interval around the point estimate.
- Determine type of risk distributions and reason for their use.
- Identify the confidence level in the forecast.
- If appropriate identify the 'optimism bias' and determine the risk-adjusted cost forecast.

#### **10. Document the estimate**

- Document all model development steps creating the forecast so that an unfamiliar cost analyst may reproduce the same result.
- Document the purpose of the forecast, who prepared it, and who approved it on what date.
- Ensure CDAL/ MDAL is agreed, including Forecasting methods, data sources and normalisation methods.
- Present the time-phased life-cycle cost of the programme.
- Describe the results of the risk, uncertainty, sensitivity analyses and any optimism bias comparison.
- Document how the forecast compares to the funding profile.
- Track how this forecast compares to previous forecasts, if applicable.

#### **11. Present Forecast for approval**

- Develop a briefing that presents the documented whole life cost forecast for approval, including:
  - Explained technical and programmatic baseline and uncertainties;
  - comparison to a second source forecast or an ICE with explanations of any differences;
  - comparison of the forecast (whole life cost) to the budget;
  - enough detail to easily defend the forecast by showing how it is accurate as possible, complete, and high in quality.
- Focus the briefing, in a logical manner, on the largest cost elements and drivers of cost.
- Make the content crisp and complete so that those who are unfamiliar with it can easily comprehend the competence that underlies the estimate results.
- Make backup slides available for more probing questions.
- Act on and document feedback from management.

#### **12. Update the forecast to reflect actual costs and changes**

- Update the forecast to
  - reflect any changes in technical or programme assumptions or
  - update the forecast as the programme passes through new phases or milestones.
- Replace forecast model component(s) as more detail becomes available
- add EVM data and Independent Estimate at Completion (EAC) from any EVM system.
- Report progress on meeting cost and schedule forecasts.



- Conduct 'learning from experience' or 'post project evaluation' and document lessons learned for elements whose actual costs or schedules differ from the forecast.
- Document all changes to the programme and how they affect the cost forecast.

## Annex B Forecasting Tools

Hardware Toolset	Pre-concept	Concept	Assessment	Demonstration	Manufacture	In-Service	Disposal
Rule of Thumb <sup>4</sup>	✓	✓	✓	✓	✓	✓	✓
CER <sup>4</sup>	✓	✓	✓	✓	✓	✓	✓
FACET <sup>4</sup>	✓	✓	✓	✓	✓		
NAFCOM <sup>3, 4, 8</sup>	✓	✓	✓	✓	✓		
PRICE TrueConcepts <sup>4</sup>	✓	✓					
PRICE H/ TrueH <sup>4</sup>	✓	✓	✓	✓	✓		
PRICE HL <sup>4</sup>						✓	
Price TP <sup>7</sup>	✓	✓	✓	✓	✓	✓	✓
Propriicer <sup>7</sup>		✓	✓	✓	✓	✓	✓
SEER H <sup>3, 4</sup>	✓	✓	✓	✓	✓		
SEALECT <sup>3</sup>						✓	
OSCAM (Air, Land, Sea) <sup>4</sup>						✓	
Disposal model (Excel)							✓
Software Toolset	Pre-concept	Concept	Assessment	Demonstration	Manufacture	In-Service	Disposal
Rule of Thumb <sup>4</sup>	✓	✓	✓	✓		✓	
CER <sup>4</sup>	✓	✓	✓	✓		✓	
PRICE True S <sup>3</sup>	✓	✓	✓	✓		✓	
PRICE True IT <sup>3</sup>	✓	✓	✓	✓		✓	
SEER SEM <sup>3</sup>	✓	✓	✓	✓		✓	
Cocomo <sup>3</sup>	✓	✓	✓	✓		✓	
VERA <sup>3, 4, 8</sup>	✓	✓	✓	✓		✓	
R <sup>2</sup> Estimator <sup>2,3,8</sup>	✓	✓	✓	✓		✓	
SSCM <sup>3</sup>						✓	
Detail Estimates				✓		✓	✓
Risk Toolset	Pre-concept	Concept	Assessment	Demonstration	Manufacture	In-Service	Disposal
Palisade @Risk	✓	✓	✓	✓	✓	✓	✓
Predict <sup>5</sup> (schedule only)	✓	✓	✓	✓	✓	✓	✓
Crystal Ball <sup>3</sup>	✓	✓	✓	✓	✓	✓	✓
ARRISCA	✓	✓	✓	✓	✓	✓	✓
Trend Toolset	Pre-concept	Concept	Assessment	Demonstration	Manufacture	In-Service	Disposal
Price KM <sup>3</sup>	✓	✓	✓	✓	✓	✓	✓
CONTEXT	✓	✓	✓	✓	✓		
MS Excel <sup>7</sup>	✓	✓	✓	✓	✓	✓	✓

### Notes

- The ticks indicate software listed has a capability to forecast costs within the particular UK MoD project phase. The absence of a tick does not necessarily mean that the model / tool has no capability, the analyst should seek further advice if their preferred selection is not listed for the phase required. Obviously the models may be used in any project phase to forecast costs of upgrades that have their own but different phases.
- None of the above models provide phase outputs fully comparable to the unique UK CADMID phases.
- This item is not available as a networked model/ tool at present.
- This item should not be used as a primary tool for all IG or MG cost elements, the analyst should seek advice if no other model/ tool is available for the particular Forecasting task or task sub-element.
- Predict should be used **only** for schedule risk/ variability calculations. The tool provides no active linking to Excel based cost models and cannot therefore provide sensitivity analyses that are correct.
- There are no developed schedule estimating tools (commercial or bespoke). Some hardware and software models do provide schedule durations for contractor work content (Seer, Price, Facet).
- Excel, Price TP (the framework, **not** the catalogues) and Propriicer are “cost aggregators” using inputs taken from other estimating methods.
- Must not be used as a primary tool, analysts must seek advice before using these tools.

Extracted from 2007-09-14-U-SET-SF-F0001.doc

## Annex C Resources

### Recommended Reading

Source book of Defence equipment costs Philip G Pugh 2007 ISBN 978-0-9556258-0-0

Parametric Estimating Handbook Issue 4

NASA Cost Estimating Handbook

GAO Cost Estimating and Assessment Guide July 2008

Technological Forecasting for Decision Makers J. P. Martino 1993

Systems Cost Engineering Program Affordability Management & Control D Shermon 2009

Cost Estimating Rodney D. Stewart

HM Treasury Green Book (Appraisal and Evaluation in Central Government)

Smart Approvals Guide

JSP 507

Mott MacDonald Report (2002) Optimism bias in government procurement

Technology Forecasting Study – Report for UK MoD by Aerospace Corporation 2006

Ultra Large Systems Dr Linda North SEI, Carnegie-Mellon

### Recommended web sites for Forecasting and estimating information

[www.ispa-cost.org](http://www.ispa-cost.org)

The above web site contains downloadable 'Parametric Handbook', training materials and Certified Parametric practitioner (CPP) accreditation information as well many links to other costing areas.

[www.sceaonline.net](http://www.sceaonline.net)

The above web site contains training materials and Certified Cost Analyst (CCA) accreditation information as well many links to other costing areas.

[www.ceh.nasa.gov](http://www.ceh.nasa.gov)

This site contains a comprehensive and very detailed estimating handbook that covers basics, space and ground station estimating processes.

General forecasting enquiries may be directed to:

[descomrclcaas-cf-ProgMgr@mod.uk](mailto:descomrclcaas-cf-ProgMgr@mod.uk)

## Annex D Key System Data Checklist

Analysts need weapon system or information system specific characteristics before they can develop a forecast, a sample list is below. The physical and performance data for a system will be dictated by the system and the selected Forecasting methodology.

### General System Characteristics

System	Characteristic	Type
<b>Aircraft</b>	Airframe unit weight by material type	
	Combat ceiling and speed	
	Internal fuel capacity	
	Length	
	Load factor	
	Maximum altitude	
	Maximum speed (knots at sea level)	
	Systems & Sensors	Defensive, offensive, quantities
	Mission and profile	
	Weight	Airframe unit weight , combat, empty, maximum gross, payload, structure
<b>Automated information systems</b>	Wetted area	
	Wing	Wingspan, wing area, wing loading
	Architecture	
	COTS software used	
	Customization of COTS software	
	Expansion factors	
	Memory size	
	Processor type	
	Proficiency of programmers	
	Organisational proficiency	CMMI
<b>Missiles</b>	Programming language used	
	Software sizing metric	New, re-used, modified code
	Diameter	
	Length	
	Payload (instruments/ warhead)	
	Propulsion type	
	Range	
	Sensors	
	Weight	
	Width	
<b>Space</b>	Attitude	
	Design life and reliability	
	Launch vehicle	
	Mission and duration	
	Orbit type	
	Pointing accuracy	
	Satellite type	
	Thrust	
	Weight and volume	
	Acoustic signature	
<b>Ships</b>	Full displacement	
	Full load weight	
	Length overall	
	Lift capacity	
	Light ship weight	
	Margin	
	Maximum beam	

System	Characteristic	Type
	Number of crew	
	Payload	
	Propulsion type	
	Shaft horsepower	
	Weapon systems & Sensors	Defensive, offensive, quantities
<b>Tanks and trucks</b>	Engine	
	Height	
	Horsepower	
	Length	
	Weight	
	Width	
	Tracked/ Wheeled	
	Payload	

Source: DOD and GAO.

Each element may be further sub-divided if sufficient information is available to make a comprehensive list of 'physical' items and performance attributes to be included in the forecast; other areas for consideration are flight certification, ordnance board clearances and other test/ integration routines not included above.

## Annex E Technology Maturity Considerations

Each programme or project office must conduct a ‘technology readiness level (TRL)’ assessment using a standard methodology described in the AoF. Forecasters may use this assessment to aid Forecasting work, for pre-concept Forecasting no TRL will be available and advice may need to be sought from the Defence Scientific & Technology Laboratory (DSTL) or Research Manager staffs.

The likely changes in technology over time must be assessed and accounted for in the forecast. Normal practice is for programmes or projects to assign a maturity level to their proposed technology. TRLs will impact the confidence levels within a cost and schedule forecast.

Other aspects of this type of analysis include a review of the technology and processes required to achieve effective production<sup>47</sup>; often an analysis goal seeks to reduce costs to both Customer and contractor without impacting quality or performance and this is part of the ‘Cost Management Through Life (CMTL)’ initiative where overall project life costs require continuous consideration.

Technology maturity normalizes data for where a programme is in its life cycle; it also considers learning and rate effects. The first unit of something would be expected to cost more than the 1,000th unit, just as a system procured at one unit per year would be expected to cost more per unit than the same system procured at 1,000 units per year. Technology normalisation is the process of adjusting cost data for productivity improvements resulting from technological advancements that occur over time.

In effect, technology normalisation is the recognition that technology continually improves, so a forecaster must make a subjective attempt to measure the effect of this improvement on historical programme costs. For instance, an item developed 10 years ago may have been considered ‘state of the art’ and the costs would be higher than normal. Today, that same item may be available off the shelf and at considerably less cost.

Therefore, technology normalisation is the ability to forecast technology by predicting the timing and degree of change of technological parameters associated with the design, production, and use of devices. Adjustment of cost data to reflect where the item is in its life cycle, however, is very subjective, because it requires identifying the relative state of technology at different points in time and this must be documented as part of the Forecasting process.

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<sup>47</sup> Consortium for Advanced Manufacturing – International (CAM-I) Cost Management Systems (CMS), <http://www.cam-i.org>

## Annex F Schedule Forecasting Hints

The schedule should reflect all activities (e.g., steps, events, outcomes, etc.) as defined in the programme's work breakdown structure (WBS) to include activities to be performed by both the government and its contractors. The schedule's activities should also be traceable to the programme statement of work to ensure all effort is included.

The schedule should line up all activities in the order that they are to be carried out. In particular, activities that must finish prior to the start of other activities (i.e., predecessor activities) as well as activities that cannot begin until other activities are completed (i.e., successor activities) should be identified. By doing so, dependencies among activities that lead to the accomplishment of events or milestones can be established and used as a basis for guiding work and measuring progress.

More risky or more complex programs should have resource-loaded schedules—that is, schedules with resources of staff, facilities and materials needed to complete the activities that use them. Resource loading can assist in two ways:

- Scarce resources can be defined and their limits noted, so that when they are added to the activities and “resource-levelled,” the resources in scarce supply will not be over-scheduled in any time period; and
- All resources can be defined and have costs placed on them so that the programme cost estimate can be developed within the scheduling package.

The next step is estimating how long each activity will take—who will do the work, whether the resources are available and their productivity, and whether any external factors might affect the duration (e.g., funding or time constraints). It is crucial at this point in schedule development to make realistic assumptions and specify realistic durations for the activities. In determining the duration of each activity, the same rationale, data, and assumptions used for cost estimating should be used for schedule estimating. Further, these durations should be as short as possible and they should have specific start and end dates. Excessively long periods needed to execute an activity should prompt further decomposition of the activity so that shorter execution durations will result.

To develop and maintain an integrated network schedule all activities must be:

- a) defined (using the WBS) at some level of detail;
- b) sequenced and related using network logic. The schedule should be horizontally and vertically integrated;
- c) resource-loaded with labour, material, and overhead;
- d) estimated for duration, usually with reference to the resources to be applied and their productivity along with any external factors affecting duration;
- e) identified on the programme master schedule and critical path;
- f) calculated with float time—the amount of time a task can slip before affecting the critical path;
- g) simulated (Monte Carlo) with a schedule risk analysis for larger, more complex, important, or risky programs;
- h) calculated to show schedule reserve, often this is initially accomplished by reference to a management-supplied finish date; and



- i) analysed as part of the overall schedule continuously for variances and changes to the critical path and completion date.

Often the programme will be asked by the customer, management, or other stakeholder to shorten the schedule. There may be strategies that can help with this effort. Some activities can be shortened by adding more people to do the work, although others will take a fixed amount of time no matter what resources are available. Other strategies often require “fast track” or “concurrent” scheduling which schedules successor activities or phases to finish before their logical predecessors have completed. In this case, activities or phases that would, without the pressure for a shorter schedule, be scheduled in sequence are overlapped instead. This approach must be used with caution since shortening activity durations or overlapping activities may not be prudent or even possible given the logic of the program.

Further, schedules need to consider programme calendars and special calendars that may be more appropriate for shared resources (e.g., test facilities that may work 24/7). Calendars will recognise specific holidays and other vacations. If training is required, it should be provided in the schedule. Also, sometimes it is unwise to assume 100 percent productivity and therefore many organisations routinely provide sick leave in their estimates. Procurement time for ordering and receiving material and equipment must be allocated so it is available when needed—some material / equipment take a period of time to make and are often called “long lead time items.” Schedules need to recognise these items as being both critical and having a long lead-time, so they are often ordered before design is complete.

It is useful to rely on historical data for scheduling information as much as possible when developing activity durations so that they are as realistic as possible. Often there are parts of the program for which no analogous estimates exist, so program participants will estimate durations using expert judgment. Furthermore, it is a best practice for schedule duration rationale to tie directly to the cost estimate documentation. The figure below shows the typical output of the activity duration estimate.

**Activity Durations as a Gantt Chart**

ID	Name	Start	2002, Qtr 2			2002, Qtr 3			2002, Qtr 4			2003, Qtr 1		
			Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	Event 1	4/29/02												
2	Accomplishment 1.1	4/29/02												
3	Criterion 1.1.1	4/29/02												
4	Task 1.1.1.1	4/29/02												
5	Criterion 1.1.2	5/12/02												
6	Task 1.1.2.1	5/12/02												
7	Accomplishment 1.2	5/5/02												
8	Criterion 1.2.1	5/5/02												
9	Task 1.2.1.1	5/5/02												
10	Event 2	5/3/02												
11	Accomplishment 2.1	5/3/02												
12	Criterion 2.1.1	7/26/02												
13	Task 2.1.1.1	7/26/02												
14	Criterion 2.1.2	5/3/02												

Source: DOD.

Even if staffs work overtime, schedule overruns may still occur, since overworked staffs are less efficient. Understanding how programme risks may affect durations is often

accomplished by using 3-point estimate techniques (optimistic, most likely and pessimistic) durations and using these values to check the reasonableness of the durations used. A standard way to use these values to improve the accuracy of the schedule durations is to average them. The resulting single-point or “deterministic” durations are usually more accurate than simply the most likely durations without considering other possible scenarios.

After the activity durations have been estimated, scheduling software can be used to determine the program’s overall schedule and critical path, which represents the chain of dependent activities with the longest total duration.<sup>48</sup> Along the critical path if any activity slips, the entire program will be delayed. Therefore, management must focus not only on problems in activities along the critical path (activities with zero total float) but also on near-critical activities (activities with low total float), because these activities typically have the least amount of time to slip before they delay the total programme.

Management should also identify whether the problems are associated with items being tracked on the programme’s risk management list. This helps management develop workarounds, shift resources from non-critical path activities to cover critical path problems, and implement risk management actions to address problem areas. In addition, the critical path in the overall schedule is invaluable in helping to determine where management reserve and unfunded contingencies may exist.

The schedule should identify the time that a predecessor activity can slip before the delay affects successor activities, which is known as “float time.” As a general rule, activities along the critical path typically have the least amount of float time. Float is calculated by taking the time difference between early finish and late finish dates and is an indicator of schedule flexibility. As the programme proceeds, float will change and can be positive or negative. Positive float indicates the amount of time the schedule can fluctuate before impacting the end date. Negative float, on the other hand, indicates critical path effort and may require management action such as overtime, second or third shifts, or re-sequencing of work to mitigate. As a result, float needs to be assessed continuously.

A schedule risk analysis should be performed using statistical techniques to predict the level of confidence in meeting a programme’s completion date. This analysis focuses not only on critical path activities, but also on activities near the critical path, since they can potentially affect program status. A schedule risk analysis examines the effect of various risks such as unrealistic durations, poor or inadequate logic, overuse of constraints, several parallel paths, multiple merge points, material lead times, external factors (e.g., weather, funding, etc.) to identify those activities that most affect the finish date. This helps management focus on important risk mitigation efforts.

To determine the full impact of risks on the schedule, a schedule risk analysis should be conducted to determine the level of uncertainty. A schedule risk analysis can help to answer three questions that are difficult for deterministic critical path method scheduling to address:

- How likely is it that the programme will finish on or before the scheduled completion or baseline date?
- How much schedule reserve time is needed to provide a date that satisfies stakeholder desires for certainty?

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<sup>48</sup>Since the activity durations are estimates and may differ from those in the schedule, the actual critical path may differ from that computed by the scheduling software. This is one reason that a schedule risk analysis provides information on the schedule “criticality,” the probability that schedule activities will be on the final critical path.

- Which activities or risks are the main drivers of schedule risk and the need for schedule reserve? This last type of information helps management mitigate schedule risk to improve the chances of finishing on time.

Risk inherent in a schedule makes it prudent to add in schedule reserve for contingencies—a buffer for the schedule baseline. Typically, schedule reserve is calculated by conducting a schedule risk analysis, choosing a percentile that represents the organisation's tolerance for overrun risk, and selecting the date that provides that degree of certainty. As a general rule, the reserve should be applied to high risk activities, which are typically found along the critical path.

Schedule reserve is a management tool for dealing with risk and should be identified separately in the schedule baseline. It is usually defined as an activity at the end of the schedule that has no specific scope assigned (since it is not known which risks may come to fruition). Best practices call for schedule reserve to be allocated based on the results of the schedule risk analysis (Annex G) so that high risk activities have first priority for schedule reserve.

Thus, schedule analysis is necessary for monitoring the adequacy of schedule reserve and determining if the program can finish on time. It is also important for identifying problems early on when there is still time to act.

Programmes with greater risk, such as development programs, usually require higher amounts of management reserve than programs with less risk, such as programs in production. The two issues associated are how much management reserve should be provided to the program and how will it be controlled? Regarding the first issue, research has found that programmes typically set their contract value so they can set aside 5 to 10 percent as management reserve. This amount may not be sufficient for some programmes and may be more than others need. The best way to calibrate the amount of management reserve needed is to conduct a risk analysis for schedule (to determine the schedule reserve needed) and for cost (to determine the management reserve for cost).

The second issue is very important because if budgets are not spread according to the amount of anticipated risk, then control accounts that are over budgeted will tend to consume all the budget rather than return it to management reserve—"budget allocated equals budget spent" in EVM terms. If reserve is not set aside for risks farther downstream, it tends to get consumed by early development activities, leaving inadequacies for later complex activities like integration and testing. Whilst a forecaster is not normally concerned with EVM, part of the Forecasting task is to identify the links to later programme phases and the need to ensure data capture takes place. Captured data especially from EVM will permit assessment of risk mitigation thus providing a route to improved Forecasting.

## Annex G- Schedule Risk Analysis<sup>49</sup>

Schedule risk analysis uses statistical techniques to predict the level of confidence in meeting a programme's completion date. This analysis focuses not only on critical path but also on near-critical and other activities, since any activity may potentially affect the program's completion date. Like a cost risk and uncertainty analysis, a schedule risk analysis requires the collection of programme risk data such as:

- Risks that may jeopardise schedule success. These are usually found in the risk register and prepared well before the schedule risk analysis is conducted.
- Probability distributions, usually specified by a point estimate of activity durations,
- Probability of a risk register risk's occurring and its probability distribution of impact if it were to occur,
- Probability that a branch of activities might occur (e.g., a test failure could lead to several recovery tasks), and
- Correlations between activity durations.

Schedule risk analysis relies on Monte Carlo simulation to randomly vary the following:

- Activity durations according to their probability distributions, or
- Risks according to their probability of occurring and the distribution of their impact on affected activity if they were to occur, and
- Existence of a risk's or a probabilistic branch's occurring.

The objective of the simulation is to develop a probability distribution of possible completion dates that reflect the programme and its quantified risks. From the cumulative probability distribution, the organisation can match a date to its degree of risk tolerance. For instance, an organization might want to adopt a program completion date that provides a 70-percent probability that it will finish on or before that date, leaving a 30-percent probability that it will overrun, given the schedule and the risks. The organization can thus adopt a plan that is consistent with its desired level of confidence in the overall integrated schedule. This analysis can give valuable insight into what-if drills and quantify the impact of programme changes.

To develop a schedule risk analysis, activity duration probability distributions have to be established. Furthermore, risk in all activities must be evaluated and included in the analysis. Some people focus only on the critical path, but because we cannot know the durations of the activities with certainty, we cannot know the true critical path. Subsequently, it would be a mistake to focus only on the deterministic critical path when some off-critical path activity may become critical if a risk were to occur. Typically, three-point estimates (i.e., best, most likely, and worst case estimates) are used to develop the probability distributions for the duration of workflow activities. After the distributions are developed, the Monte Carlo simulation is run and the resulting cumulative distribution curve, the S-curve, displays the probability associated with the range of program completion dates.

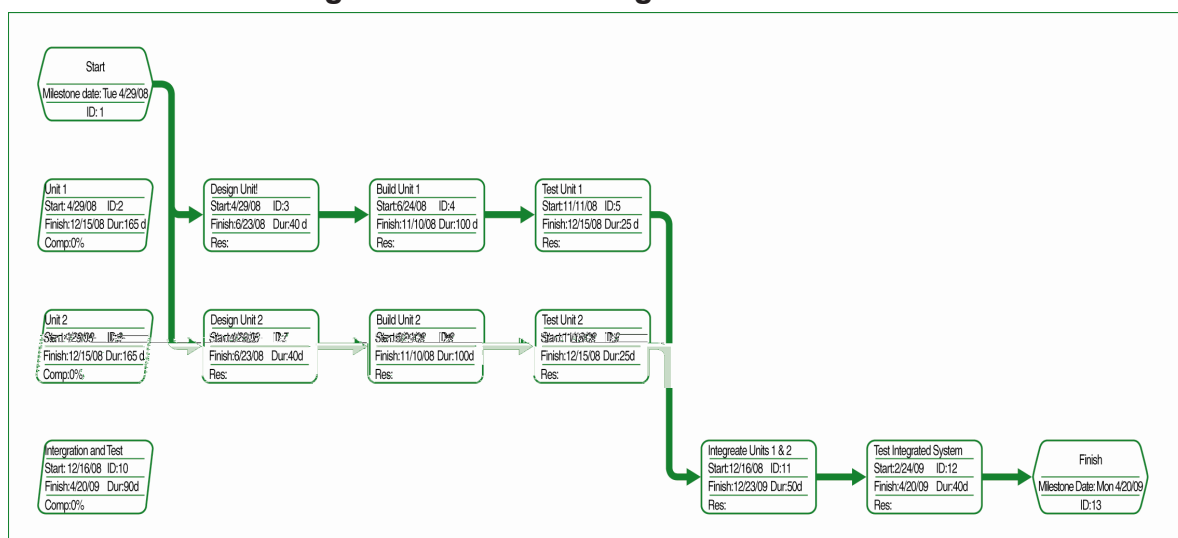
<sup>49</sup> Adapted from Appendix XII of the GAO Cost Estimating and Assessment Guide

If the analysis is to be credible, the programme must have a good schedule network that clearly identifies the critical path and that is based on a minimum number of date constraints. The risk analysis should also identify which tasks during the simulation most often ended up on the critical path, so that near-critical path activities can also be closely monitored. It is important to represent all work in the schedule since any activity can become critical under some circumstances. Complete schedule logic that addresses the logical relationships between predecessor and successor activities is also important. The analyst needs to be confident that the schedule will automatically calculate the correct dates and critical paths when the activity durations change as they do thousands of times during a simulation. Because of debugging, and because the collection of schedule risk data can take some time and resources, it is often a good idea to work with a summary schedule rather than the most detailed schedule.

One of the most important reasons for performing a schedule risk analysis is that the overall program schedule duration may well be greater than the sum of the path durations for lower-level activities. This is in part because of:

- **Schedule uncertainty.** This can cause activities to shorten (an opportunity) or lengthen (a threat). For instance, if a conservative assumption about labour productivity was used in calculating the duration of an activity and during the simulation a better labour productivity is chosen, then the activity will shorten. However, most program schedule risk phenomena exhibit more probability of overrunning (threats) than under-running (opportunities), which can cause activities to lengthen.
- **Schedule structure.** A schedule's structure has many parallel paths joined at a merge or join point, which can cause the schedule to lengthen. Merge points include programme reviews (e.g., Preliminary Design Review (PDR), Critical Design Review (CDR), etc.) or the beginning of an integration and test phase. The timing of these merge points is determined by the latest merging path. Thus, if a late required element is delayed, the merge event will also be delayed. Since any merging path can be risky, any merging path can determine the timing of the merge event. This added risk at merge points is called the "merge bias." See Figure 1 below for an example of the schedule structure that illustrates the network or pure-logic diagram of a simple schedule.

**Figure 1: Network Diagram of Schedule**



Source: Copyright 2007 Hulett and Associates, LLC.



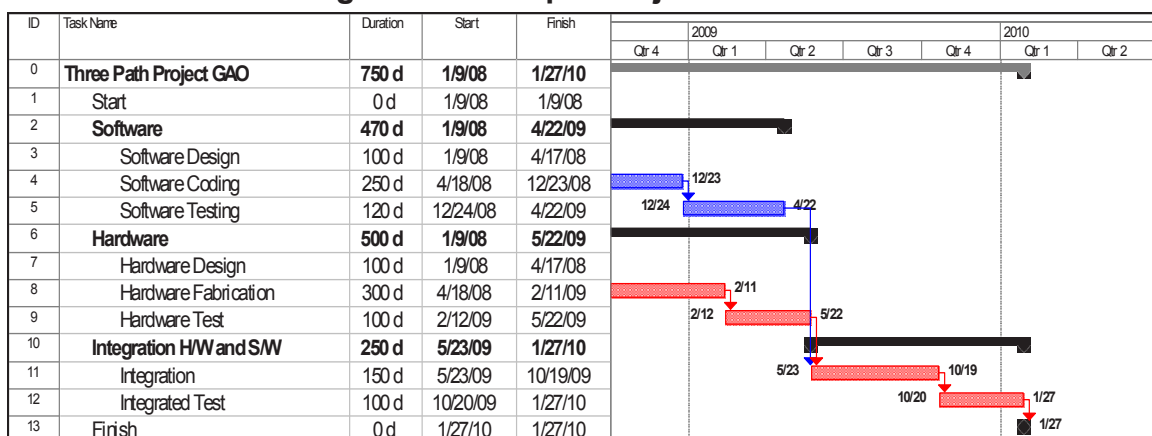
Since each activity has an uncertain duration, it follows that the entire duration of the overall program schedule will also be uncertain. Therefore, unless a statistical simulation is run, calculating the completion date based on schedule logic and the most likely duration distributions will tend to underestimate the overall program critical path duration.

Schedule underestimation is more pronounced when the schedule durations or logic have optimistic bias, for instance when the customer or management has specified an unreasonably short duration or early completion date. The schedule can be configured, and assumptions made about activity durations to make a schedule match these imposed constraint durations. When this is the case, durations are often “best case” scenarios or based on unreasonable assumptions about the resources availability or productivity. Furthermore, the schedule may overlap activities or phases (e.g., detailed engineering, fabrication and testing) that would otherwise be more prudently scheduled in a series in order to compress the time. In addition, external contributions may be assumed with optimistic bias when there is little confidence that their suppliers will be able to comply. As a result, fitting the schedule to predetermined dates is dangerous.

The preferred approach to scheduling is to build the schedule by starting with the WBS to define the detailed activities using program objectives to guide major events. When determining the durations for the activities, resource availability and productivity need to be reasonably assumed, external factors and need to be realistically considered, and organizational risk associated with other programmes and the priority of this programme need to be considered. Once all these aspects have been modelled in the schedule, the scheduling system software can calculate the completion date. Following these best practice approaches to developing a schedule will provide a reasonable first step in determining the schedule duration. If the duration is too long, or the dates are too late, then more resources or less scope may be required. Unless more resources are provided it is inappropriate to shorten the schedule to fit a pre-conceived date given the original scope of work.

Accordingly, because activity durations are uncertain, the probability distribution of the programme’s total duration must be determined statistically, by combining the individual probability distributions of all paths according to their risks and the logical structure of the schedule. Schedule activity duration uncertainty can be represented several ways. We will use the example schedule below to illustrate.

**Figure 2: Example Project Schedule**



Source: © 2007 Hulett & Associates, LLC

In this example schedule, the project begins on January 8, 2008 and is expected to complete about two years later on January 27, 2010. There are three major efforts involving software, hardware, and integration. According to the schedule logic and durations, hardware fabrication, testing, and the integration of hardware and software drive the critical path.

The first way to capture schedule activity duration uncertainty is to collect various estimates from individuals and, perhaps, from a review of past programme actual performance. Estimates derived from interviews or in workshops should be formulated by a consensus of knowledgeable technical experts and coordinated with the same people who manage the programme's risk mitigation watch list. Figure 3 shows a traditional approach with the three-point estimate applied directly to the activity durations.

**Figure 3: Estimated Durations for Remaining WBS areas in the Schedule**

ID	Task name	Rept ID	Mn Rdur	ML Rdur	Max Rdur	Rept ID
0	<b>Three path GAO project</b>	<b>2</b>	<b>0 d</b>	<b>0 d</b>	<b>0 d</b>	<b>0</b>
1	Start	0	0 d	0 d	0 d	0
2	<b>Software</b>	<b>0</b>	<b>0 d</b>	<b>0 d</b>	<b>0 d</b>	<b>0</b>
3	Software design	0	85 d	100 d	150 d	2
4	Software coding	0	212.5 d	250 d	375 d	2
5	Software testing	0	90 d	120 d	240 d	2
6	<b>Hardware</b>	<b>0</b>	<b>0 d</b>	<b>0 d</b>	<b>0 d</b>	<b>0</b>
7	Hardware design	0	85 d	100 d	130 d	2
8	Hardware fabrication	0	255 d	300 d	390 d	2
9	Hardware test	0	75 d	100 d	200 d	2
10	<b>Integration H/W and S/W</b>	<b>0</b>	<b>0 d</b>	<b>0 d</b>	<b>0 d</b>	<b>0</b>
11	Integration	0	120 d	150 d	210 d	2
12	Integrated test	0	75 d	100 d	200 d	2
13	Finish	0	0 d	x d	0 d	0

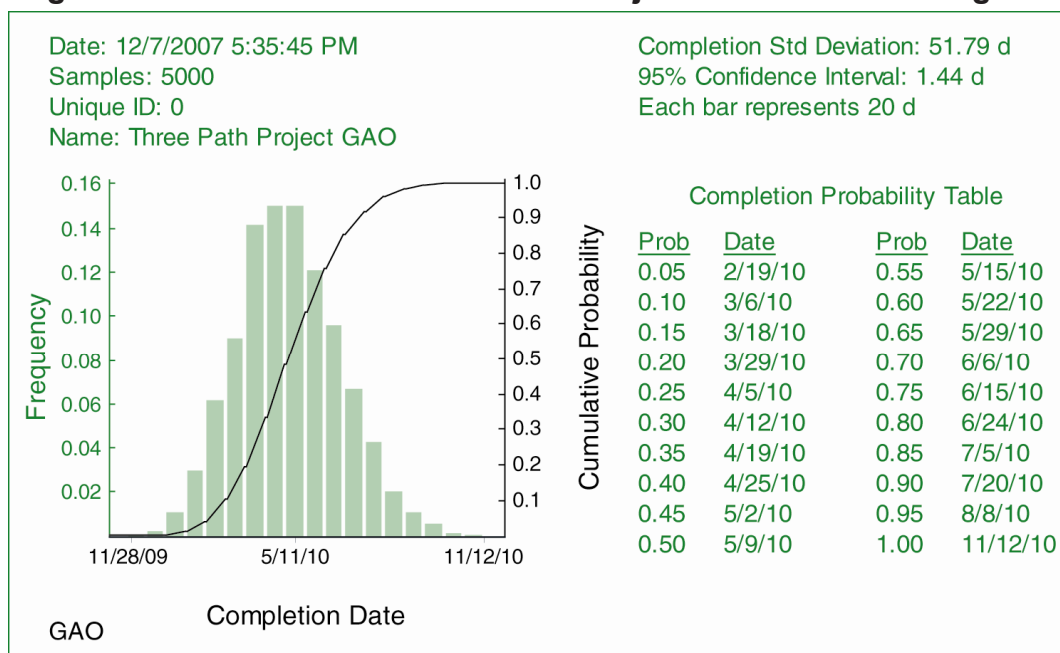
Source: Copyright 2007 Hulett and Associates, LLC.

In this example, three-point estimates of remaining durations are shown. In a real programme schedule risk analysis these would be developed from in-depth interviews of people who are expert in each of the WBS areas of the programme. To model the risks in the simulation, the risks are represented as triangular distributions specified by the three-point estimates of the activity durations. These probability distributions combine the effects of all risks that affect the activities.

Once the distributions have been established, the Monte Carlo simulation uses random numbers to select specific durations from each activity probability distribution and calculates a new critical path and dates including major milestone and programme completion. The Monte Carlo simulation continues this random selection thousands of times, creating a new programme duration estimate and critical path each time. The resulting frequency distribution displays the range of programme completion dates along with the probabilities that these dates will occur, as seen in the figure below.



**Figure 4: Cumulative Distribution of Project Schedule Including Risk**



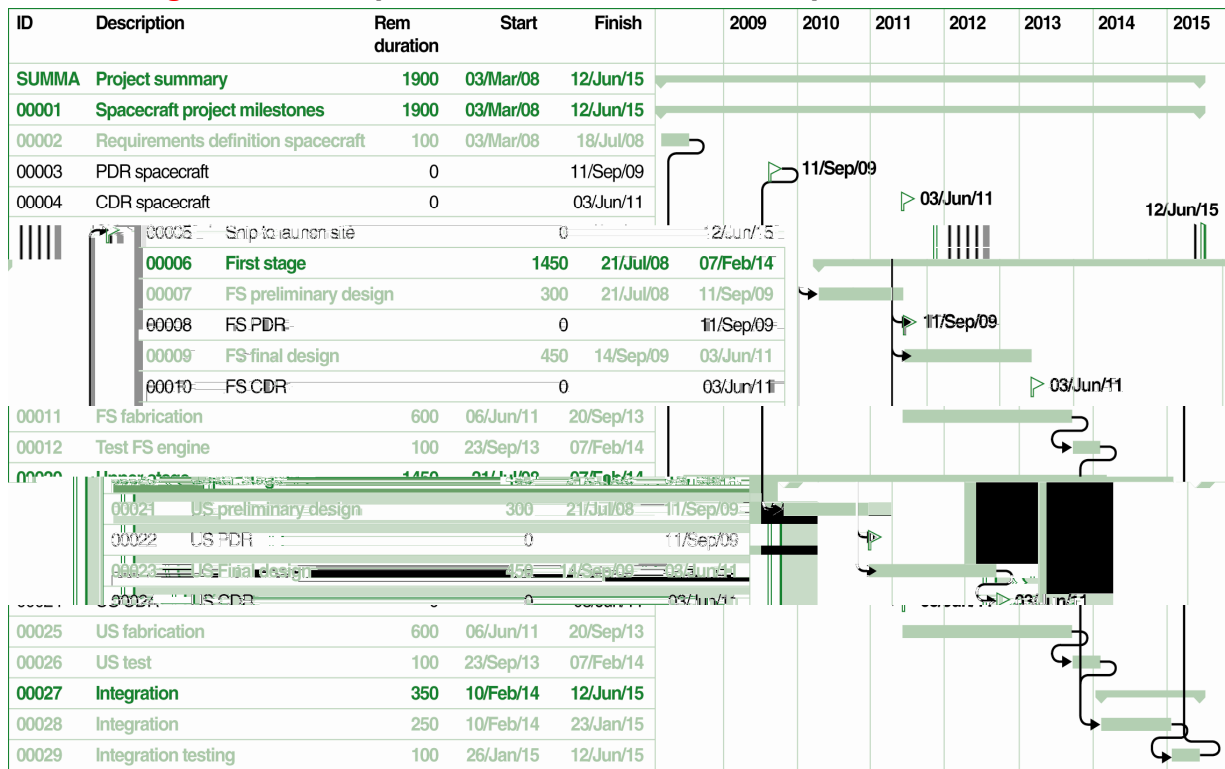
Source: Copyright 2007 Hulett and Associates, LLC.

Figure 4 shows that the most likely completion date is about May 11, 2010 and not January 27, 2010 which is the date computed by the deterministic schedule. The cumulative distribution also shows that, in this case study, the schedule completion date of January 27, 2010 is less than 5 percent likely to occur, given the schedule and the risk ranges used for the durations. An organisation that wants to cover 80 percent of its known unknowns would have to add a time reserve of about 5 months to June 24, 2010.

While it would be prudent to establish a 5-month reserve for this project, each organisation should determine its tolerance level for schedule risk.

A second way to determine schedule activity duration uncertainty involves analysing the probability that risks from the risk register may occur. Using this approach, a probability distribution of the risk impact—expressed in days or as a factor—on the duration is estimated and the risks are assigned to specific activities in the schedule. In this way, activity duration risk is estimated indirectly by the risk and its assignment. This “risk driver” approach focuses on risks and their contribution to time contingency as well as on risk mitigation. The example spacecraft schedule overleaf shows how this approach can be used.

**Figure 5: Example of Identified Risks on a Spacecraft Schedule**



Source: Copyright 2007 Hulett and Associates, LLC.

In this example spacecraft schedule, the work begins on March 3, 2008 and is expected to finish more than seven years later on June 12, 2015. Because of the long timeframe and the risk associated with developing the spacecraft technology, the risk driver method can be used to examine how various risks from the risk register may affect this spacecraft schedule.

**Figure 6: Example of Risk Register for a Spacecraft Schedule**

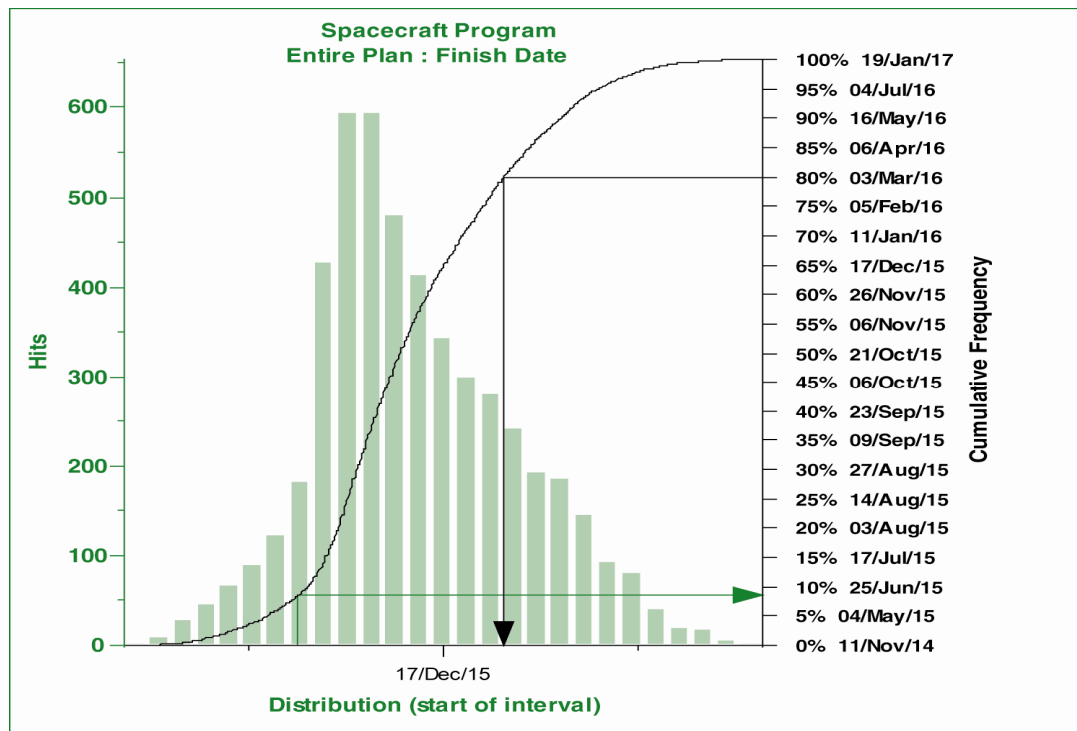
Description	Optimistic	Most likely	Pessimistic	Likelihood
1 Requirements have not been decided	95.00%	105.00%	120.00%	30.00%
2 Several alternative designs considered	95.00%	100.00%	115.00%	60.00%
3 New designs not yet proven	96.00%	103.00%	112.00%	40.00%
4 Fabrication requires new materials	96.00%	105.00%	115.00%	50.00%
5 Lost know-how since last full spacecraft	95.00%	100.00%	105.00%	30.00%
6 Funding from congress is problematic	90.00%	105.00%	115.00%	70.00%
7 Schedule for testing is aggressive	100.00%	120.00%	130.00%	100.00%

Source: Copyright 2007 Hulett and Associates, LLC.

In Figure 6, one can quickly determine that the biggest risk affecting the spacecraft schedule has to do with testing because the schedule is very aggressive. Moreover, funding delays, alternative designs, and the fact that some of the designs are unproven also have a high likelihood of impacting the schedule. Using the risk driver method, these risks

are shown as factors that will be used to multiply the durations of the activities to which they are assigned, if they occur in the iteration. Once the risks are assigned to the activities a simulation is run. The results may be similar to those shown below (**fig. 7**):

**Figure 7: Spacecraft Schedule Results from a Monte Carlo Simulation**



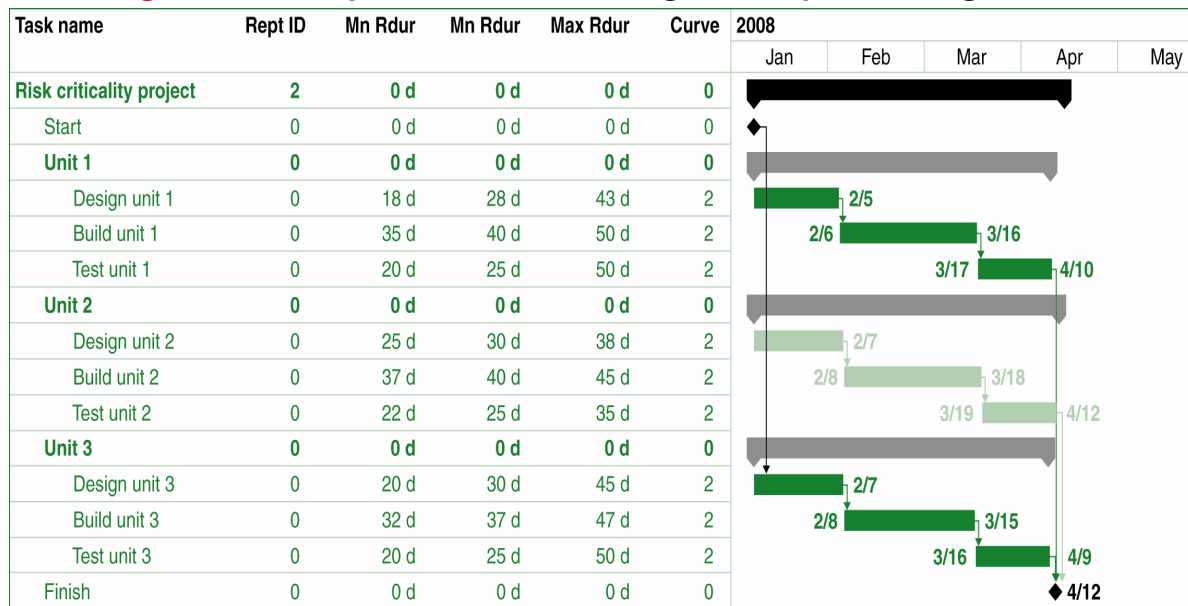
Source: Copyright 2007 Hulett and Associates, LLC.

In this example, the schedule date of June 12, 2015 is estimated to be 9 percent likely based on the current plan. If the organisation chooses the 80<sup>th</sup> percentile the date would be March 3, 2016 representing a 9-month time contingency. Notice that the risks have caused a 14-month spread, a respectable range of uncertainty, between the 5 percent and 95 percent confidence dates.

Regardless of which method is used to examine schedule activity duration uncertainty, it is important to identify those risks that contribute most to the programme schedule risk. Below are several approaches to identifying which activities need close examination for effective risk mitigation.

The first is a comparison of a schedule with a well-managed critical path (i.e., Unit 2) and two other paths that have risk, but positive total float. The non-critical path efforts (i.e., Unit 1 and Unit 3) therefore did not attract the programme manager's risk management attention.

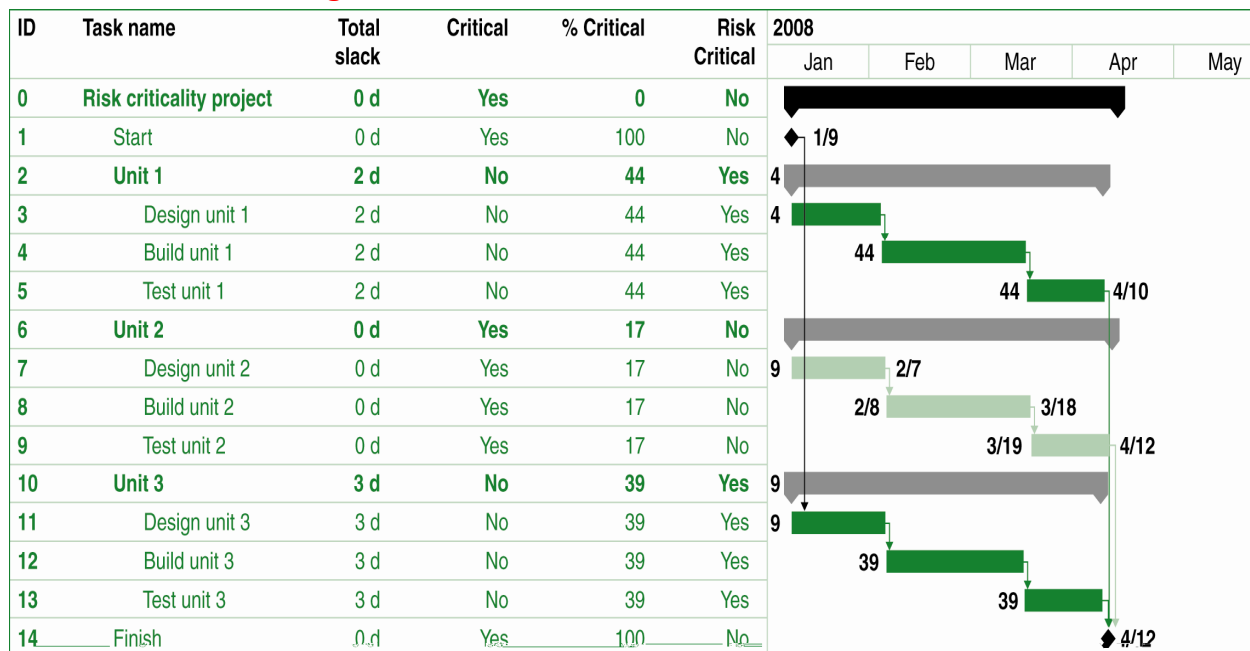
**Figure 8: Example schedule showing critical path through Unit 2**



Source: Copyright 2007 Hulett and Associates, LLC.

The measure of merit, the risk criticality, shows that the risky non-critical paths are more likely to delay the project than the so-called critical path. Figure 9 below shows the results of each unit's probability of landing on the critical path based on the Monte Carlo Simulation.

**Figure 9: Results of Monte Carlo Simulation**



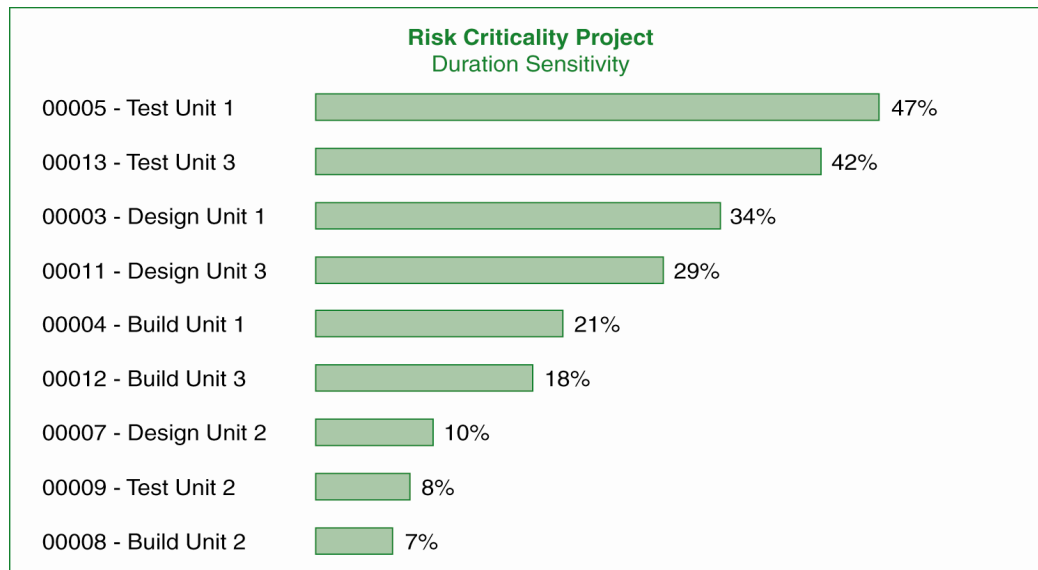
Source: Copyright 2007 Hulett and Associates, LLC.

After running the simulation which takes into account the minimum, most likely, and maximum durations, one can see that although Unit 2 is on the schedule's deterministic

critical path, Unit 1 is 44 percent likely to ultimately delay the project and Unit 3 is 39 percent likely to do the same. In other words, the critical path method “critical path” is the least likely path to delay the project, in this simple case.

Other measures of risk importance can be reviewed. For instance, sensitivity measures reflecting the correlation of the activities or the risks with the final schedule duration can be produced by most schedule risk software. Below is a standard schedule sensitivity index for the spacecraft project that was discussed above.

**Figure 10: Sensitivity Index for Spacecraft Schedule**

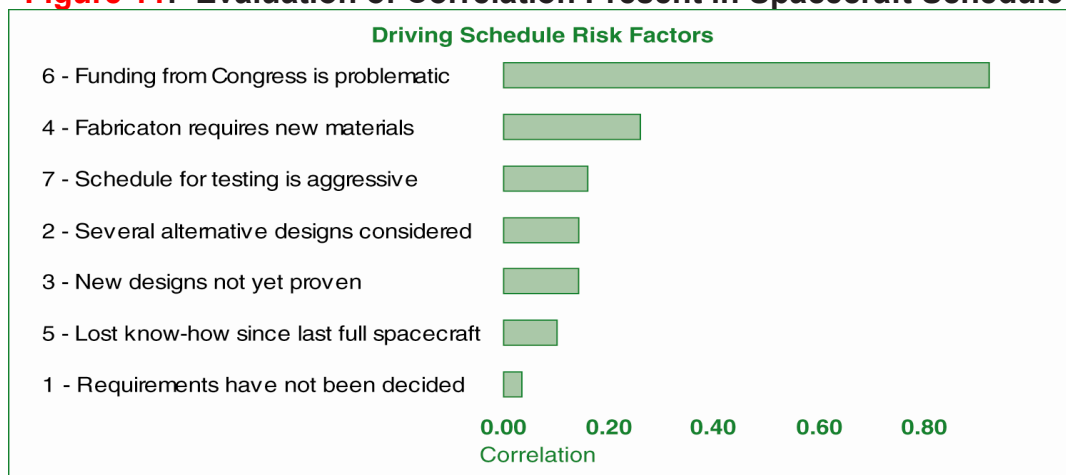


Source: Copyright 2007 Hulett and Associates, LLC.

In this example, the testing and design of Units 1 and 3 affect the schedule duration more than the design, testing, and building of Unit 2, even though Unit 2 represents the critical path in the deterministic schedule. Therefore, without taking into account the risk associated with each Unit’s duration, the programme manager would not know that keeping a strong eye on Units 1 and 3 would be imperative towards keeping the programme on schedule.

Below is a different view of final duration sensitivity resulting from the risk register risks themselves using the risk driver approach discussed earlier. In this case, when a risk is assigned to several activities its sensitivity measure reflects the entire correlation, not just the correlation of one activity to the project duration (**fig. 11**).

**Figure 11: Evaluation of Correlation Present in Spacecraft Schedule**

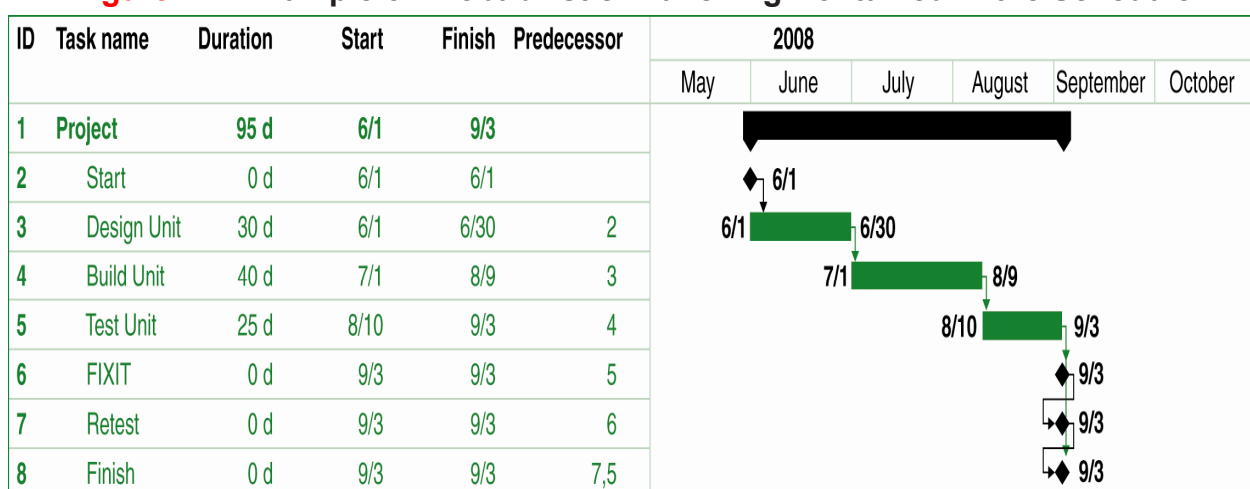


Source: Copyright 2007 Hulett and Associates, LLC.

In this example, funding is the biggest risk driver in the programme schedule followed by new materials that may be needed for fabrication. While not much can be done about the funding issue since this is an external risk, contingency plans can be made for several scenarios where funding may not come through as planned.

In addition to standard schedule risk and sensitivity analysis, government programmes typically have events that can occur and if they do some new activities must be conducted. This is called “probabilistic branching.” A common such event is the completion of a test of an integrated product (e.g., software programme, satellite, etc.). The schedule often assumes that tests are successful, whereas experience indicates that tests may fail and only if they fail will the activities of root cause analysis, plan the recovery, execute the recovery, and re-test be required. This is a branch that only happens with some probability. An example is shown below in **figure 12**.

**Figure 12: Example of Probabilistic Branching Contained in the Schedule**

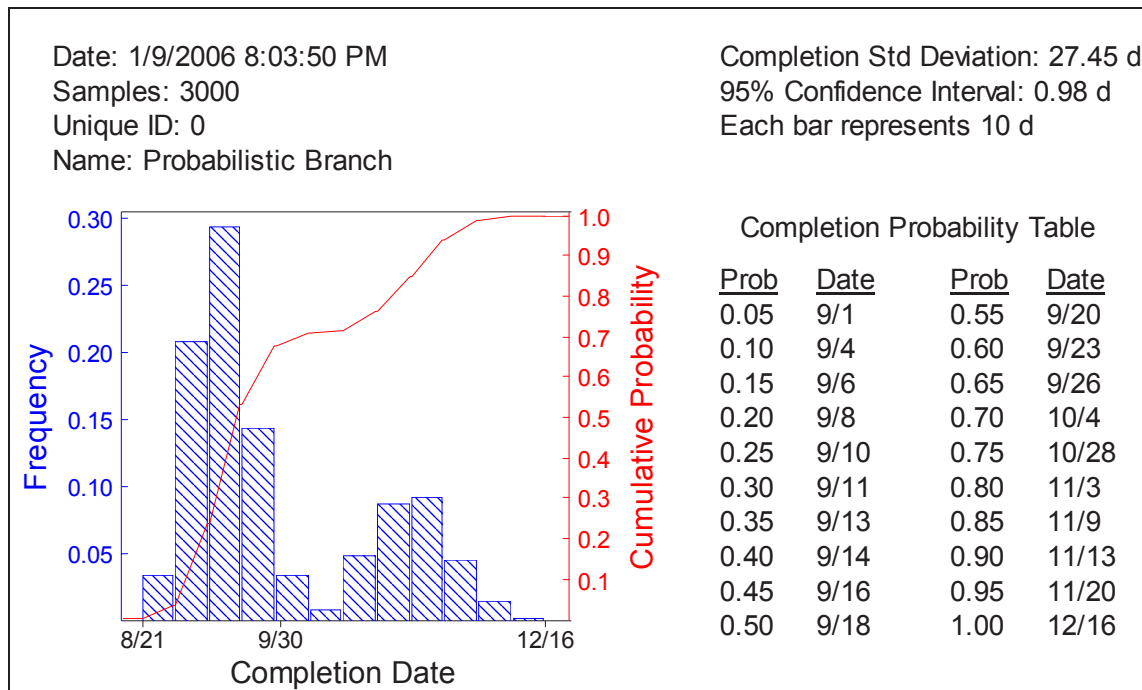


Source: Copyright 2007 Hulett and Associates, LLC.

If the Test Unit activity fails, FIXIT and Retest occur, otherwise they are given duration of 0 days. This is a discontinuous event that leads to the two new activities. If the test is

estimated to fail with some probability, e.g., 30 percent, the resulting probability distribution of dates for the entire project is depicted in Figure 13 below.

**Figure 13: Probability distribution results for Probabilistic Branching in Testing Unit**



Source: © 2007 Hulett & Associates, LLC

Notice the bi-modal distribution with the test success iterations on the left and the test failure iterations on the right. If the organisation demands an 80<sup>th</sup> percentile schedule, it would be November 3, although if it is satisfied by anything under 70<sup>th</sup> percentile the possibility of failure would not be important.

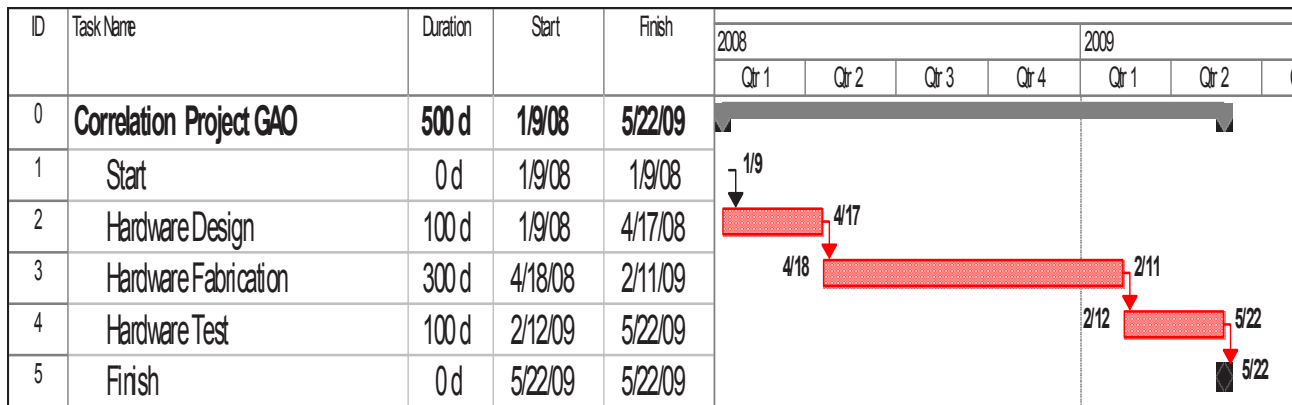
Other capabilities are available once the schedule is viewed as a probabilistic statement of how the program might unfold. One that is notable is the correlation between activity durations. Correlation is when two activity durations are both influenced by the same external force and can be expected to vary in the same direction within their own probability distributions in any consistent scenario. While durations might vary in opposite directions if they are negatively correlated, this is less common in program management than positive correlation. Correlation might be positive and fairly strong if, for instance, the same assumption about the maturity of a technology is made to estimate the duration of design, fabrication, and testing activities. If the technology maturity is not known with certainty, it would be consistent to assume that design, fabrication, and testing activities would all be longer, or shorter, than scheduled, together. It is the “together” part of the consistent scenario that represents correlation.

Without specifying correlation between these activity durations in simulation, some iterations or scenarios would have some activities long and others short in their respective ranges. This would be inconsistent with the idea that they all react to the maturity of the same technology. Specifying correlations between design, fabrication and testing will ensure each iteration represents a scenario in which their durations are consistently long or



short in their ranges. Because schedules tend to add durations (given their logical structure), if the durations are long together or short together there is a chance for very long or very short projects. How much longer or shorter depends, but without correlation, the risk analysis may underestimate the final effect. Figure 14 below demonstrates this using a simple single-path hardware development / fabrication / test programme.

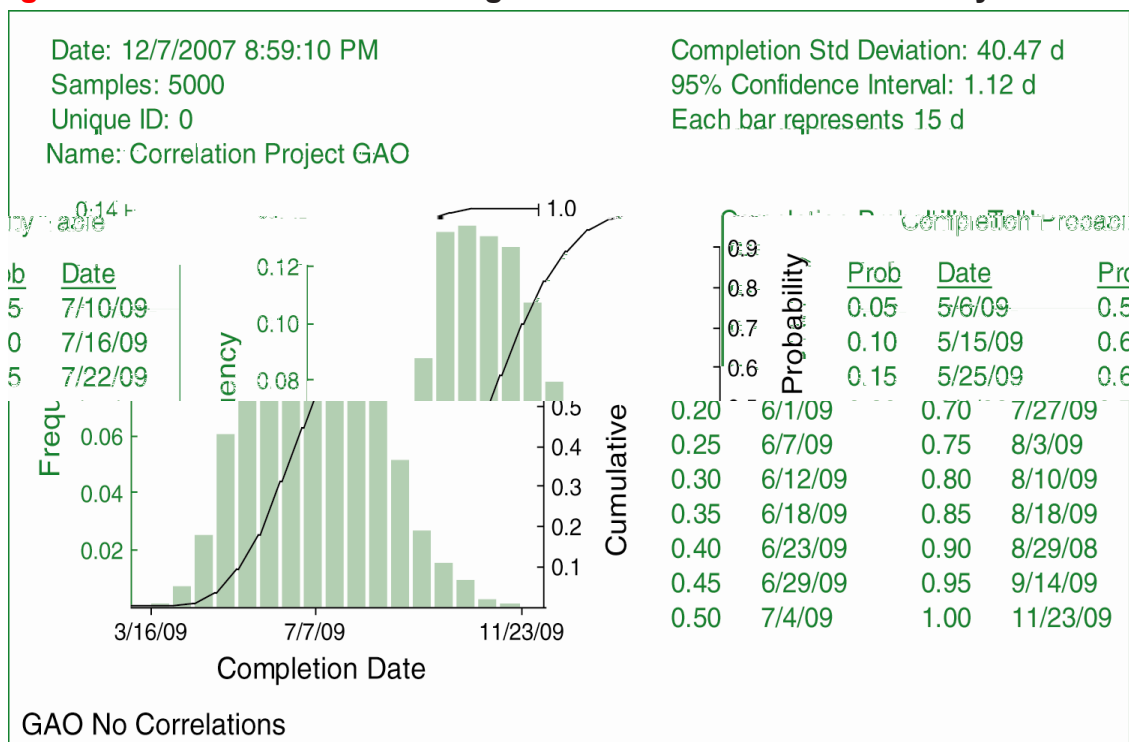
**Figure 14: Example Project Schedule to Highlight Correlation Effects**



Source: © 2007 Hulett & Associates, LLC

Assuming no correlation between the activities' durations the result is shown below. In this uncorrelated case the 80 percent probability date is August 10, 2009 and the standard deviation of completion date, a measure of dispersion, is 40.47 days.

**Figure 15: Risk Results assuming no Correlation between Activity Durations**

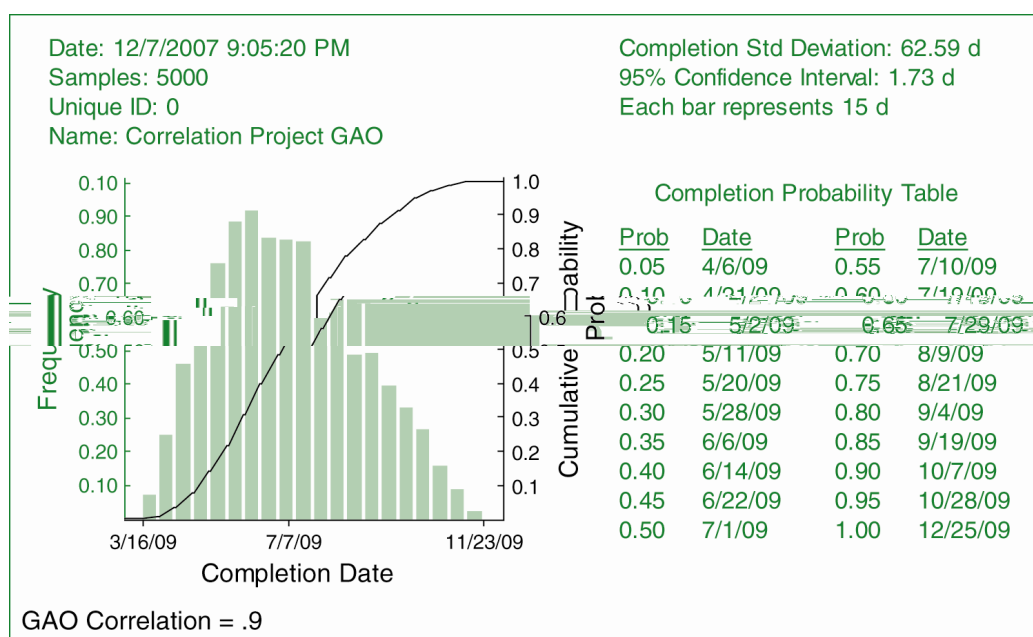


Source: Copyright 2007 Hulett and Associates, LLC.

However, if the influence of the technology maturity is strong and the programme team believes that there is a 90 percent correlation between design, fabrication, and test of the

hardware system this will dramatically affect the simulation results. While the 90 percent correlation is high (correlation is measured between -1.0 and +1.0), there are often no actual data on correlation so expert judgment is often used to set the correlation coefficients in many cases. Assuming this degree of correlation we get the following result:

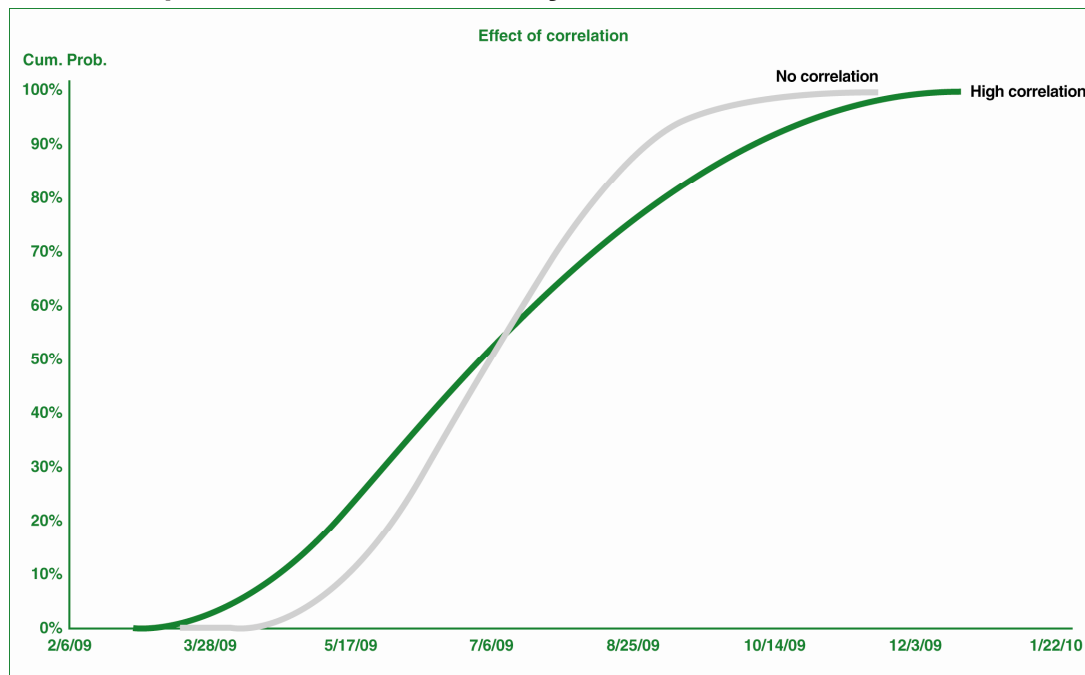
**Figure 16: Risk Results assuming 90 Percent Correlation between Design, Fabrication, and Test of the Hardware System Activity Durations**



Source: Copyright 2007 Hulett and Associates, LLC.

Notice that in this case the 80 percent probability date is September 4, 2009, nearly a month longer, and the standard deviation is 62.59 days, over 55 percent larger than when the design, fabrication, and testing activities were assumed to be independent. The expected date is July 7, 2009 and in this simple one-path schedule is not affected much by correlation. The two results, with and without correlation, are compared in **figure 17** overleaf:

**Figure 17: Comparison of Schedule Analysis Results With and Without Correlation**



Other rules of thumb that can mitigate schedule risk include:

- Longer activities should be broken down to show critical handoffs—for example, if a task is 4 months long but a critical hand-off is expected halfway through, the task should be broken down into separate 2-month tasks that logically link the handoff between tasks. Otherwise, long lags must be used—which are rigid and tend to skew the risk results;
- While on detailed program schedules, there should be a predominance of finish-to-start logical relationships in summary schedules that are typically used in risk analysis there may be more start-to-start and finish-to-finish relationships between phases. This practice requires care in completing the logic with the following rule:
  - Each activity needs a finish-to-start or start-to-start predecessor that drives it AND a finish-to-start or finish-to-finish successor that it drives—in other words, dangling activities must be avoided. In this way, risks in predecessors and successors will be transmitted correctly down the paths to the later programme milestones.
- while on detailed programme schedules, it is recommended that work packages should be no longer than 2 months so that work can be planned within two reporting periods, for schedule risk a more summary schedule with basic activities representing phases is often used;
- while on detailed programme schedules, lags should represent only the passing of time and should never be used to replace a task, in summary schedules used for schedule risk the lags may have to be longer;

- resources should be scheduled to reflect their scarcity, such as availability of staff or equipment;
- constraints should be minimized because they impose a movement restriction on tasks and can cause false dates in a schedule; and
- total “float” that is more than 5 percent of the total programme schedule may indicate that the network schedule is not yet mature.

Questions that should be answered during a schedule risk assessment include

1. Does the schedule reflect all work to be completed?
2. Are the programme critical dates used to plan the schedule?
3. Are the activities sequenced logically?
4. Are activity interdependencies identified and logical?
5. If there are constraints, lags, and lead times, are they required and are documentation available to justify the amounts?
  - Constraints and lags should be used sparingly. There may be legitimate reasons for using constraints, but each constraint should be investigated. For instance, start-not-earlier-than constraints might reflect the availability of funding or a weather limitation and may be logical.
  - Finish-not-later-than (FNLT) constraints are usually artificial and reflect some policy rather than a program reality. If the program does not meet these dates, imposing a FNLT constraint in a computer model of the program schedule has the possibility of making the schedule look good in the computer while the programme is in trouble in the field.
  - Constraints that push out the programme activities beyond the dates that predecessors require in order to add float or flexibility are arbitrary and not recommended. The schedule risk analysis should determine the amount of time contingency needed.
6. How realistic are the schedule activity duration estimates?
7. How were resource estimates developed for each activity and will the resources be available when needed?
8. How accurate is the critical path and was it developed with scheduling software?
9. How reasonable are float estimates? Activities’ floats should be realistic. High total float values often indicate that logic is incorrect or missing and that there are dangling activities.
10. Can the schedule determine current status and provide reasonable completion date forecasts?
11. What level of confidence is associated with the program schedule completion date? Does it reflect a schedule risk analysis and the organization’s or stakeholders’ risk tolerance?

## NOTES

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## NOTES

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