Chapter 5 – MODELS

5.1 GENERAL

This chapter presents the results of the matrix survey, mentioned in Chapter 1, on models. The focus here is to summarise the use of models by the nations (both commercially available and in-house) and present the results in a general overview. The models used and any requirements on the use of a specific model across all of the PAPS phases will be presented. Annex A contains all the participating nations' completed matrices.

In everyday cost analysis language, the terms models and tools are often used interchangeably. This is, for instance, exemplified in the questions put forward in the matrix that the nations in the Task Group where requested to answer. It might be of interest for some other types of studies to make a distinction between the two, but for the scope of this work it has been decided that no such distinction is needed. In the Programme of Work for the SAS-054 Task Group the term (cost) model is defined as:

> *"A Cost Model: is a set of mathematical and/or statistical relationships arranged in a systematic sequence to formulate a cost methodology in which outputs, namely cost estimates, are derived from inputs. These inputs comprise a series of equations, ground rules, assumptions, relationships, constants, and variables, which describe and define the situation or condition being studied. Cost models can vary from a simple one- formula model to an extremely complex model that involves hundreds or even thousands of calculations. A cost model is therefore an abstraction of reality, which can be the whole or part of a life cycle cost."*

Using this definition, both a graphic description of the relationships that represent the abstraction or simplification of reality as well as a series of connected, specially developed computer programmes, can be a model.[1] The bulk of the models discussed in this chapter are of the latter kind, but range from very complex types of models to simple spreadsheet models. For the purpose of consistency the term model is therefore used throughout the chapter.

5.2 OVERVIEW OF MODELS

This section is a comparison on the different models that are currently in use by the nations taking part in the study. The first conclusion that can be drawn from the matrices is that no specific model for a certain phase is mandatory for any nation. Many nations do, on the other hand, have some recommendation on what type of model that should be used.

5.2.1 The Different Types of Models Identified

To begin with, among the models used by the nations, four different types of models have been categorised. These are: models for optimisation, simulation, estimation and for decision support. Each is briefly described below.

5.2.1.1 Estimation Models

This represents a broad spectrum of models that are used at the core of the life cycle costing process. As shown later in the chapter, the estimation type of model is often used, in all the PAPS phases.

[1] In some occasions it might be helpful to define a so called LCC model framework including the use of several models operating together to complete the LCC framework (see Sub-section 2.7.6).

Estimation models are all types of models dealing directly with the estimation and calculation of cost. The estimation of cost can, in turn, be supported by some other type of method, but in the case of the estimation model the main objective is to come to some sort of conclusion as to the level of cost for a system or sub-system.

Since this is a wide model category there are many examples of the estimation type models being used, both in terms of commercially available and those developed in-house. One common feature often found is that all the models employ a defined cost breakdown structure. These models are often tailored to a specific programme and, for those developed in-house are often implemented in a spreadsheet environment.

5.2.1.2 Decision Support Models

In this category, many types of operational research models with the purpose of choosing or ranking between different alternatives can be found. The models are typically based on soft management science approaches such as analytical hierarchical process or on multi-criteria decision analysis techniques.

5.2.1.3 Simulation Models

This category contains all the models based on one of the simulation methodologies outlined in Chapter 4. This therefore includes models using system dynamics and discrete event simulation. In addition, models using Monte Carlo simulation have also been included.

5.2.1.4 Optimisation Models

This category contains all the models that are based on some type of optimisation method, be it mathematical programming, heuristics, or other types of optimisation approaches. These models are most frequently used as support methods for the life cycle cost estimation process. For example, they are frequently employed to determine stock levels, maintenance regimes and supply chain impacts.

5.2.2 The Models Used by the Nations – General Overview

A first look at the different types of models shows that all nations use some form of in-house developed model for LCC analysis. The majority also use some type of commercial model. However, some nations do not use any type of commercial model; instead they rely entirely on in-house developed models and/or other types of methods such as expert analysis.

Many different types of models are used by the nations. There are for instance hundreds of models, the bulk of which are in house developed, but for this study, nearly 40 different models have been identified in the matrices. Nearly half of them are commercially available models and the other half have been developed in-house. There are differences between the in-house developed models, but one common feature is that many are developed in a spreadsheet environment and often tailored for each specific programme or project. The in-house developed models are, generally, only used by the nation that has developed the model.

Of the four categories of models identified the most prominent is that of estimation. This statement is still valid in considering the use of commercial or in-house models.

Based on the sample size of 40 models, Figure 5-1 shows the number of nations that are using a certain type of model in each PAPS phase. It also gives an indication of which types of models that are used most frequently among the nations. Note that the matrix indicates the number of nations and not the number of models.

Models		Mission need	Pre-feasibility	Feasibility	Project Definition	Design & Developm.	Production	In-service	Disengage-ment
Optimization	In-house		○						
	Commercial				○	◒	◒	◒	◒
Simulation	In-house			○	◒	◒	◒	◒	◒
	Commercial	○		○	○	○	◒	◒	◒
Calculation / Estimating	In-house	●	●	●	●	●	●	●	●
	Commercial	◒	●	●	●	●	●	◒	◒
Decision Support	In-house	◒	○						
	Commercial	◒							○

Legend

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

Figure 5-1: Analysis of Nations' Matrices.

For life cycle cost analysis all the nations have in-house models that are based on a defined CBS (cost breakdown structure). Data for these models can be estimated by empiric methods and or by parametric formulae (sometimes both methods are used for completeness). For more complex cost relationships some nations use other model outputs as an input to the overall CBS model. One example of this is to use a model for optimisation of spares to calculate the cost of stock inventory (both in terms of initial investment and annual cost of spares). This provides a cost-effective support cost baseline.

During the early PAPS phases most of the cost models are used to support operational analysis studies therefore implying the need for high-level analysis and the use of in-house developed models is common.

In the later PAPS phases most models are used to support investment appraisal, logistic modelling and through life management planning. The quantity and range of applications of the models are greater from the project definition phase than for the earlier phases, this is valid both for in-house developed and commercial models.

Only a few nations use optimisation or simulation models. These are mainly used from the project definition phase and onward for optimisation of logistics resources and simulation of the support system. Optimisation and simulation methods are used to analyse system availability and endurance to support operational and tactical planning of technical system in a cost-effective way.

5.2.3 Models Used in Each Phase

This sub-section summarises on what types of models are being used in each PAPS phase by the nations. There is a strong similarity between the phases, but for the purpose of completeness each PAPS phase is described below.

5.2.3.1 Mission Need Evaluation Phase

In this phase most of the nations use models for estimation. Only a few nations have stated that other types of models are used. The most frequently used of the other type of model are those for decision support. There are only three nations that state the use of commercially available models for estimation, whereas the in-house developed models are used in greater numbers among many more nations.

One reason that nations mainly use in-house developed models in this phase could be that the level of detail and availability of data is poor in this phase. This forces the cost estimator to resolve to construct their own model. The analyses made in this early phase are often not made by experienced cost estimators and the reason for this is since the estimates by default are very rough, the perceived benefit of the experienced estimators might be negative. **However, it is recommended that a cost estimate is made by suitably experienced personnel**.

5.2.3.2 Pre-Feasibility Phase

The same pattern as in the previous phase can be observed. There is still a large collection of models used for estimation purposes and among those; the in-house developed ones are employed in greater numbers. This is probably even more so than is shown by the responses given by the nations, since five nations report the use of spreadsheet models. There are probably several of these spreadsheet models in use in each of these nations. There are, however, a few more commercially available ones being mentioned here and more than one nation is using them. One nation reports the use of more than one model for estimation purposes, therefore there seems to be an evolving acceptance of the commercially available models. The use of models for decision support has dropped to just one nation using an in-house model.

The strong preference for in-house developed models is probably, as already stated, a result of poor data availability. In this phase however, more experienced cost estimators are involved in the process, reflecting the growing use of commercial models.

5.2.3.3 Feasibility Phase

Again, the same pattern and trend as in the previous phase can be observed. The bulk of models used by the nations are still for estimation purposes and the bulk of these are in-house developed ones. In the use of commercially available models there seems to be a preference for parametric estimating models. The reported use of models has ended.

The reasons for the continued trend for in-house developed estimation models are believed to be the same as in the previous phase.

5.2.3.4 Project Definition Phase

The overall picture is the same in this phase with the bulk of models used for estimation purposes. In this phase more nations use a couple of more commercially available models. And more nations use a few different models for their estimation purposes. Of the models that the nations have reported roughly a third are commercially available ones. This is a slight misrepresentation of the fact that, as mentioned before, in the nations that report the use of spreadsheet modelling, this most probably means that more than one model is in use within each nation. Of the commercially available models for estimation, models dealing with parametric estimation seem to be preferred.

A slight trend for a growing use of models for optimisation and simulation can be seen in this phase. These models are most probably used in support for estimation models and the growing use is most likely a consequence of more data being available.

5.2.3.5 Design and Development Phase

As was mentioned under Section 5.2 the overall picture is the same in all the phases, with a strong preference in all nations for models doing estimation. In this phase, the trend mentioned for the project definition phase, with a wider spread use of models for optimisation or simulation is still in place. These optimisation models are either used to optimise stocks of spares and use this as input in the

calculation of a larger investment programme, or they are used to estimate cost of optimised inventory of spares.

The fact that a growing portion of all models reported are commercial indicates a growing reliance on commercial models and this might be due to the fact that data is more readily available at this and the following stages.

5.2.3.6 Production Phase

As before, models for estimation are still the ones being used the most among the nations, but the trend towards a more widespread use of optimisation models or simulation models or a combination of them, continues, and is even slightly emphasised – though it can hardly be said to be widespread. There are almost as many commercial models as in-house models reported in this phase. Again, this appearance might be false, since the use of Excel-based models might indicate that more than one such model is used in each of the nations that have reported their use.

5.2.3.7 In-Service Phase

The picture is almost identical as in the production phase, but only three nations are still using commercial ones. As in the three previous phases, a growing number of nations are using optimisation models or simulation models. The distribution between the use of in-house developed models for estimation and commercial ones is about the same as in the production phase.

5.2.3.8 Disengagement Phase

Regarding models for estimation, there is a slight drop in numbers in both in-house and commercial models, but the number of nations employing them is the same. The number of models used for simulation is the same as in the four previous phases, but only one nation still uses a specific model (commercial) for optimisation. In this phase, one other nation again reports the use of a decision support model.

5.3 RECOMMENDATIONS

From the material, it is clear that what has here been labelled models for estimation are the preferred models for life cycle cost analysis. There is also a clear pattern that to supplement models for estimation, more models for decision support are used in the earliest phases and more models for optimisation and simulation are used later on.

To ensure Best Practice, the use of more than one model is recommended. For the purpose of verifying results, more than one method of estimation should be used and this means that if data permits, two or more models for estimation can be used. If data is available, the use of models for simulation and/or optimisation to supplement models for estimation is recommended. The use of multiple models should always be evaluated on from a cost-benefit point of view. In the earliest phases, scarcity of data often means that the recommended model to use is a decision support model.

When it comes to multi-national programmes, there is a need for all participating nations to understand and trust the models used. The participating nations will need to agree on at least one common model or framework (see Sub-section 2.7.6). There is also a need to be clear on which data to use and how to collect this data. One way of handling these needs is to use one or more commercial models, maybe supplemented with national models, for multi-national programmes.

There is no single model, of all the models presented by the nations that cover all aspects, so in Section 5.4 there will be a description of some of the more prominent attributes a good model should have.

These attributes can also be used as a checklist when creating or constructing an in-house model or when evaluating a commercially available model.

5.4 DESIRED MODEL ATTRIBUTES

The characteristics[2] of a high quality cost estimates are:

- Accuracy;
- Comprehensiveness;
- Ability to Replicate and Audit;
- Traceability;
- Credibility; and
- Timeliness.

Each of the above should demonstrate these quality characteristics in the following ways:

- **Accuracy** – Cost estimating relationships (CERs) will be the result of regression analysis with good curve fits and minimal error bands, making them valid predictors of cost. Estimates should be unbiased, not 'low balled' or overly conservative, but based on an assessment of the most likely costs. Underlying data will have been correctly normalised for technical baseline and for inflation using appropriate guidance. The time phasing of the estimate should also be logical and accurate.
- **Comprehensiveness** – Estimates should use a cost breakdown structure that is at a level of detail appropriate to ensure that cost elements are neither, omitted or double-counted. All the cost driving ground rules and assumptions must be detailed in the documentation of the cost estimate.
- **Replicability and Auditability** – The estimate should be presented in a cost breakdown structure and work breakdown structure that is fully traceable to the system specification. The estimate documentation should include source data, significance and goodness of fit statistics for CERs, clearly detailed calculations and results and explanations for why a particular method or reference was chosen. An independent reviewer must be able to follow the estimating process, repeat the calculations and arrive at the same answer.
- **Traceability** – Data should be traceable back to the source documentation.

Without these characteristics the estimate will not be **credible**, which is the most important quality of a good estimate and the benefits just discussed will be much harder to realise. Finally, an estimate must be **timely**. The best estimate in the world does no good if it is too late to provide decision makers the insight needed.

A cost model must therefore be able to demonstrate that it meets the characteristics listed above and is fully documented in order to justify the life cycle cost estimate produced.

[2] These characteristics are given in the Society of Cost Estimating and Analysis training programme – CostProf © – Programmed Review of Fundamentals. They are replicated here by kind permission of the SCEA Office.

5.5 COST MODEL VALIDATION – A PRACTICAL PROCEDURE

5.5.1 Preamble

The following sub-sections set out a practical procedure for validation[3] which can be carried out irrespective of the amount of detailed data on specific projects available. However, the confidence which can be placed on the validation is obviously dependent on the number of projects for which outturn costs can be provided and the reliability of those outturn costs.

5.5.2 The Procedure

The procedure described here would be applicable to the form of model comprising only cost estimating relationships derived by statistical analysis of the costs of the past projects and relating costs to objective quantitative design and/or performance characteristics of the product. It can be used also for methods involving non-physical 'complexity factors' or equivalents providing that those factors are all derived via relationships linking to objective quantitative design and/or performance characteristics in unambiguous and repeatable fashion. In that case, those relationships must be declared prior to any trials and adhered to without change throughout such trials. However, it is important to note that there is a numerically important class of model that relies upon the subjective judgement of the user to set values for 'complexity factors' or equivalents. For such models, validation is neither possible by the means described here nor by any other method.

5.5.3 Review of Basic Data

Obtain a list of projects upon whose costs the model being validated is based, including names of projects.

The important thing at this stage is to establish that the projects on which the model is based all belong to a well defined class or generic type. A list is sufficient for this purpose.

5.5.4 Test Regression

Predicted costs are then used as the explanatory variable in a test regression to derive: actual cost = f(predicted cost). The test statistics (n: number of observations, r: correlation coefficient , σ: standard error) of such a regression provide a summary of the performance of the model.

5.5.5 Calibration Tests

The model is tested against data not used in its construction, using **outturn** values of design and performance characteristics as input.

5.5.6 Prediction Tests

A more rigorous test than calibration is the prediction test. In this test, outturn cost data not used in the construction of the model is compared to the estimates made by the model based on contemporary accounts of the performance and/or other characteristics required of the project at an earlier stage of its evolution (typically when development of the project in question was commenced).

As with calibration tests, the mean and population standard deviation of the cost estimating errors are calculated. It is to be expected that errors incurred during use in the prediction mode using performance

[3] Reference is made here to the procedure for validating cost estimating models used in cost forecasting. The full statistical and practical procedure reference PV/11/098 is available from HVR Consulting Services Ltd.

requirements will be larger than in the calibration mode when working from details of the design of the equipment in question. However, it may be difficult to find sufficient data to carry out an adequate prediction test since people constructing cost models tend to base their models on all the projects on which they have outturn data. They are naturally reluctant to set data aside for use in prediction tests when they could be incorporated in the model to its benefit.

5.5.7 Mixed Tests

In some cases, the actual projects on which the model is based may not be known and in this case the person carrying out the validation must depend on his own database. In this situation, he simply compares the outturn costs of as many projects as possible of the specified type with the costs estimated using the model and calculates the mean and population standard deviation of the estimating error. It is important, however, that the database used by the person carrying out the validation is agreed prior to the trial.

5.5.8 Frequency/Probability Distributions

For some models, there may be sufficient data to make possible the construction of graphs showing the probability of forecasting errors exceeding a given percentage of the actual outturn along the lines of Figure 5-2 (or as histograms of the frequency with which forecasting errors occur). Such graphs are exceedingly useful, in that they reveal both the accuracy of estimates and any bias.

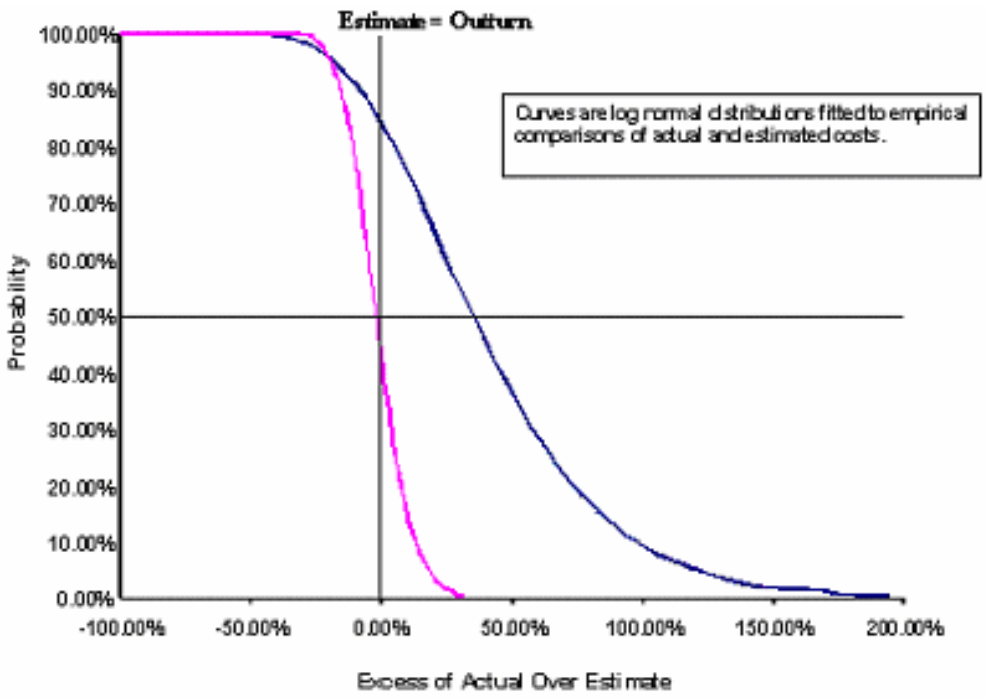

Figure 5-2: Comparison of Two Models.

However, a very large data set is required for meaningful results to be obtained.

5.5.9 Judging the Comparative Validity of Models

The procedure described above can enable those responsible for validating models, first to establish qualitatively that each model covers a well defined class of equipment and then calculate a number of measures of its comparative validity. The word ‘comparative’ needs to be emphasised. The procedure is

best used to judge whether one model is more likely than another to be useful, having regard to the fact that its application to future projects will invariably involve some extrapolation beyond the data set on which it was based. However, it is necessary to take complete account of the prediction errors set out in the statistical methods upon which the cost model is based.