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Macro-parametrics and the applications of multi-colinearity and Bayesian to enhance early cost modelling

Dale Shermon, QinetiQ Fellow / Head of Profession - Cost [1] and Dr Catherine Barnaby, Head of Cost Research[1]

[1] *QinetiQ Bristol, Building 240, The Close, Bristol Business Park, Coldharbour Lane, Bristol, BS16 1FJ, United Kingdom*

Abstract

This paper will consider the spectrum of parametric cost models from cost estimating relationships (CER) to micro and finally macro-parametric models. This will lead to a description of the Family of Advanced Cost Estimating Tools (FACET) parametric suite of models and their top-down capability to estimate costs. One of the unique aspects of FACET is the utilisation of multi-colinearity. Typically, in cost research we are taught to discard one of the independent variables which exhibits this characteristic, but QinetiQ used it to enhance the accuracy of parametrics through the comparison of performance and design characteristics, thus improving the confidence in the model input parameters.

FACET is also unique amongst commercial parametric models in the combination of input data uncertainty and CER uncertainty. The mathematical combination of the tolerance in the historical data and the lack of certainty in the future project characteristics results in realistic cost forecasting outputs. Finally, this FACET model has a unique approach to the seamless transition from performance based cost estimating to design based cost estimating depending upon the uncertainty in the inputs characteristics. This paper will explore the cost research conducted by QinetiQ and the implementation of the research into the 80+ QinetiQ FACET models that have been licenced by customer around the world.

Keywords: macro-parametrics, cost model, FACET, multi-colinearity, risk, uncertainty.

Introduction

QinetiQ was formed in July 2001, when the UK Ministry of Defence (MOD) split its Defence Evaluation and Research Agency (DERA) in two. The smaller portion of DERA, was rebranded Dstl (Defence Science & Technology Laboratory) and remains part of the MOD. The larger part of DERA, including most of the non-nuclear testing and evaluation establishments, was renamed QinetiQ and prepared for privatisation. QinetiQ became a public private partnership in 2002.

In 2003, QinetiQ signed a 25-year long term partnering agreement (LTPA) under which we provide the UK MOD with innovative and realistic test and evaluation of military and civil platforms, systems, weapons and components on land, at sea and in the air.

As a people based business, our service offerings account for the majority of sales. In addition our products division provides technology-based solutions on a global basis including offices in Australia and Canada. Through their technical expertise, know-how and rigorous independent thinking, our engineers and scientists are uniquely placed to help customers meet challenges that define the modern world. These challenges include affordability and seeking value for money (VfM).

Cost modelling capability: Knowledge Based Estimating

QinetiQ has a comprehensive, experienced cost modelling capability. To achieve credible and justified cost forecasts we deploy a Knowledge Based Estimating (KBE) philosophy. This is based on the foundation of Data, Tools, People and Process. Within the context of the KBE philosophy Data is defined as any information, both cost and technical, concerning historical projects that will be used as the basis for future estimates, whilst also extending out to information in relation to the technical or programme characteristics of future projects or services. Tools are defined as the software systems that help cost engineers to interpret historical data, such as statistical tools, that can be used to create cost estimating relationships (CER), or other tools that allow the application of such relationships to generate estimates.
People within KBE are recognised as being needed to interpret historical data and predict the concepts for the new projects and services that will satisfy the perceived capability or requirements. Cost engineers need the qualifications to justify their professionalism and skills to elicit the data from finance, project staff and customers. Finally, processes are necessary so that people conduct an estimate in a rational, repeatable way, ensuring that the outputs are traceable to source data and assumptions.

QinetiQ has researched, designed and developed tools which span the Capability Systems Life Cycle (CSLC) starting with the Family of Advanced Cost Estimating Tools (FACET) at the start leading to the Operating and Support Cost Analysis Model (OSCAM) at the end. While FACET deploys a parametric approach, the OSCAM system is based on a system dynamics approach due to the event based nature of the operating and support profile of maintenance.

Macro-parametric cost modelling

When the CSLC begins the need is established and a number of alternative options are considered as viable [1.]. At this point the level of work or product breakdown will not be developed beyond a single node; we need a system. As the life cycle progresses the product breakdown develops in detail, as illustrated in Figure 1.

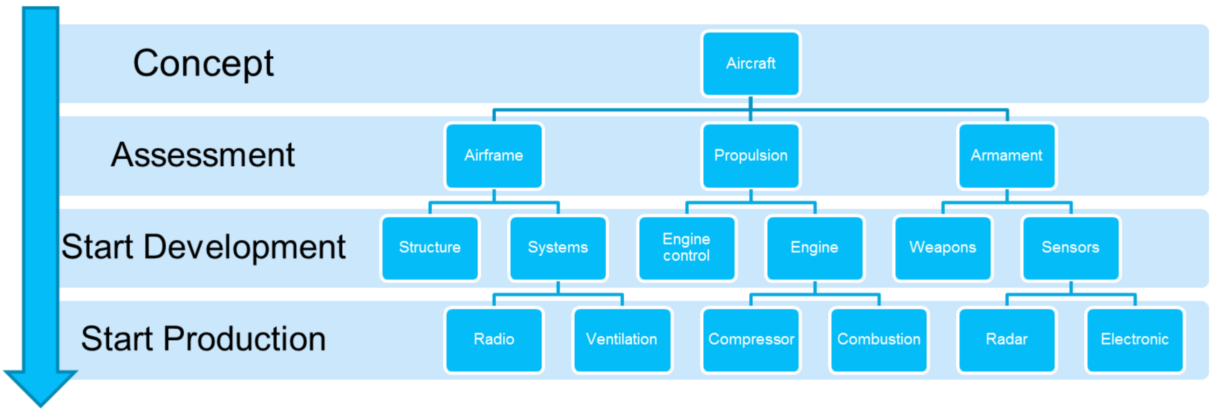

Figure 1: Development of a product breakdown structure through the Capability Systems Life Cycle

Ultimately there will be a Bill of Materials (BOM) that can be used to estimate the cost in detail taking time and resources. At the start the numerous options need to be estimating quickly utilising few resources. Parametric and analogous estimating methodologies are generally acknowledged to be the preferred approach as shown in Figure 2.

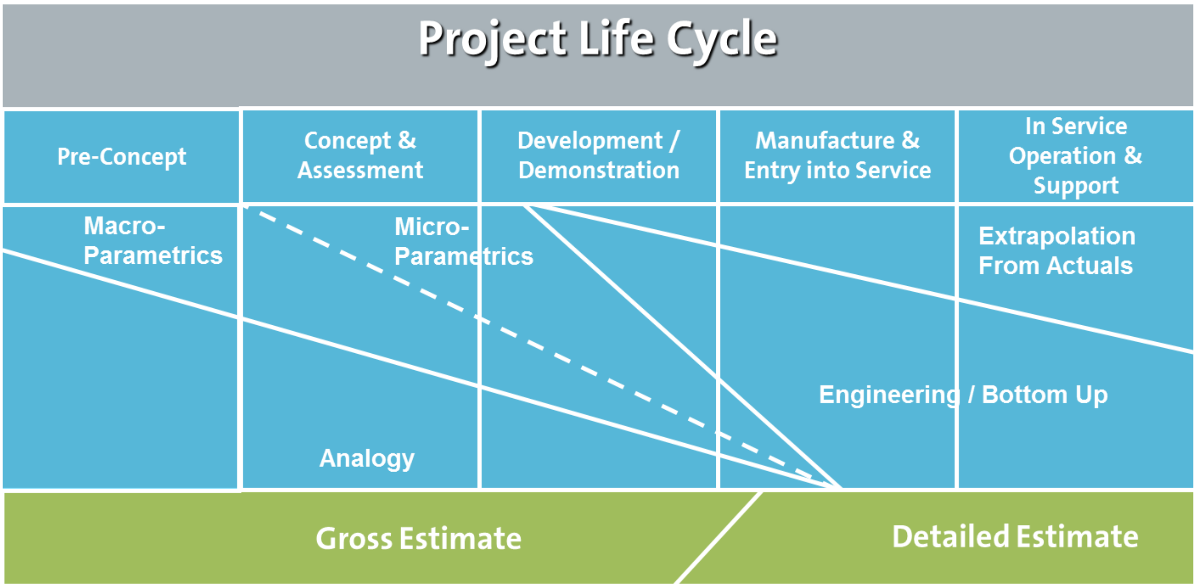

Figure 2: Types of cost forecasting methodologies across the life cycle.

This ICEAA diagram has been developed to extend the project life cycle backwards to early decisions and the parametric methodology has been split into two sub-elements. QinetiQ has identified two types of parametric cost model as defined in Table 1.

Table 1: Characteristics of parametric models

Classification	**Model focus**	**Mathematics**	**Cost drivers**
Marco-parametrics	Platform / system	Multiple specific model	Few platform specific parameters
Micro-parametrics	Technology / Line Replaceable Unit	Single universal model	Many universal parameters

The development of a parametric cost model is a process (see Figure 3) of cost and technical data gathering, followed by normalisation of imperial units, currency, base year and so forth. The cost research then seeks statistically significant cost estimating relationships (CERs) between the dependent and independent variables. The dependent variable is generally cost and the independent variables are the design or performance parameters that are termed cost drivers.[3.]

This technique has been used by QinetiQ to develop a macro-parametric cost model called Family of Advanced Cost Estimating Tools (FACET) [4.]. FACET has a whole life cost (WLC) capability combined with other unique features that make it ideally suitable for the creation of cost forecasts at an early stage in the life cycle. During this period of the project life there is the opportunity for projects to influence the Whole Life Cost at minimum expense to the overall project. The methodology adopted for the FACET models gives accurate unbiased costs for a wide range of weapon systems at the earliest (pre-concept and concept) stages of projects.

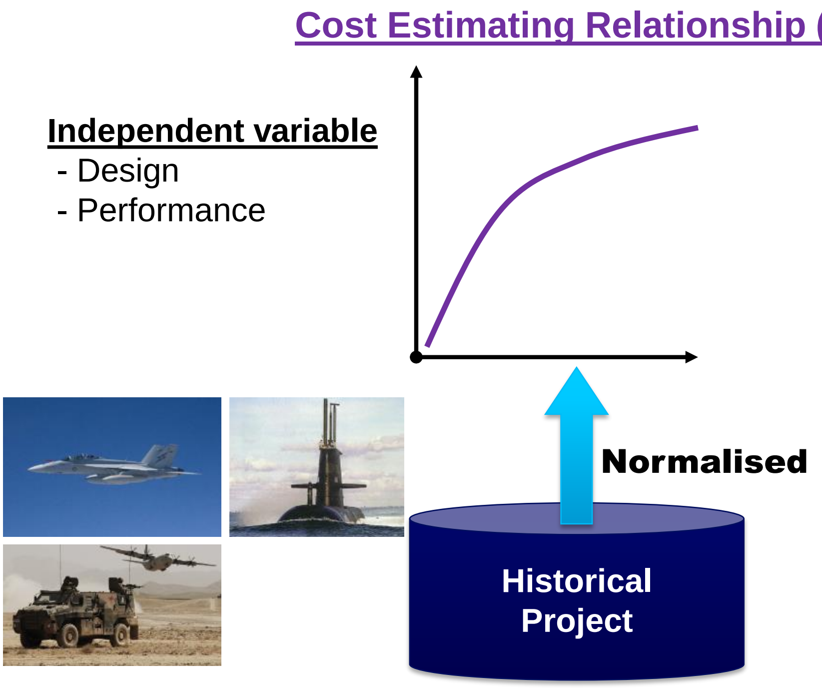

Figure 3: The technique for the creation of a parametric cost model

The database of historical information is common to all parametric cost models. Typically the database will include national and international project, but there has only been a limited number of defense project through history. What varies from micro and macro-parametrics is the different approach to the cost research as shown in Figure 4.

Frank Freiman, the acknowledged "founding father" of parametric looked at this database and saw different technologies. His research led to one universal model with numerous independent variables (as many as 70+) to represent the future platform cost estimate to the parametric model. The cost research at QinetiQ considered the database as numerous platform or system types. This research led to numerous (currently 80+) parametric models each with few (about 12) platform specific independent cost drivers to be populated.

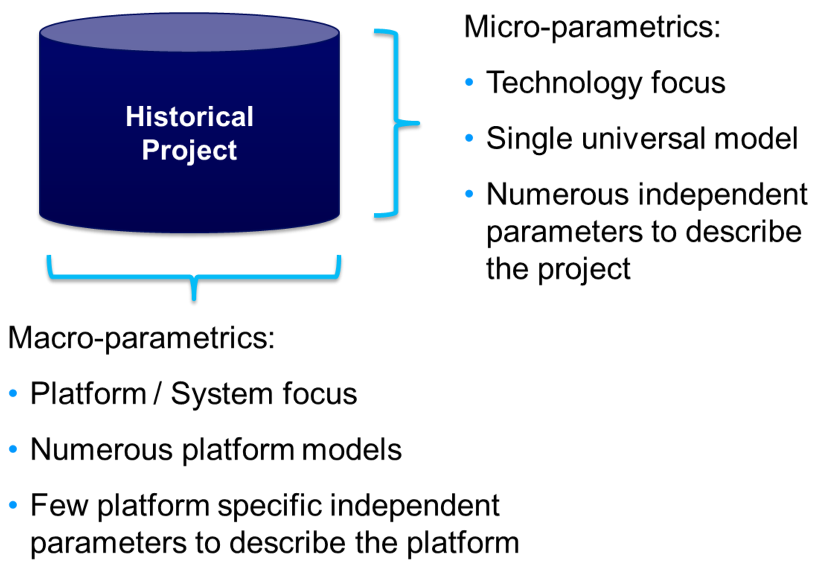

Figure 4: One database: two cost research methods

In classical parametric cost research it is expected that multi-colinearity will be explored. Any signs of correlation between the independent variables, like in Figure 5, would result in one of the independent parameters being excluded from the CER. By inference if you have one parameter, you are considering the other variable due to its correlation.

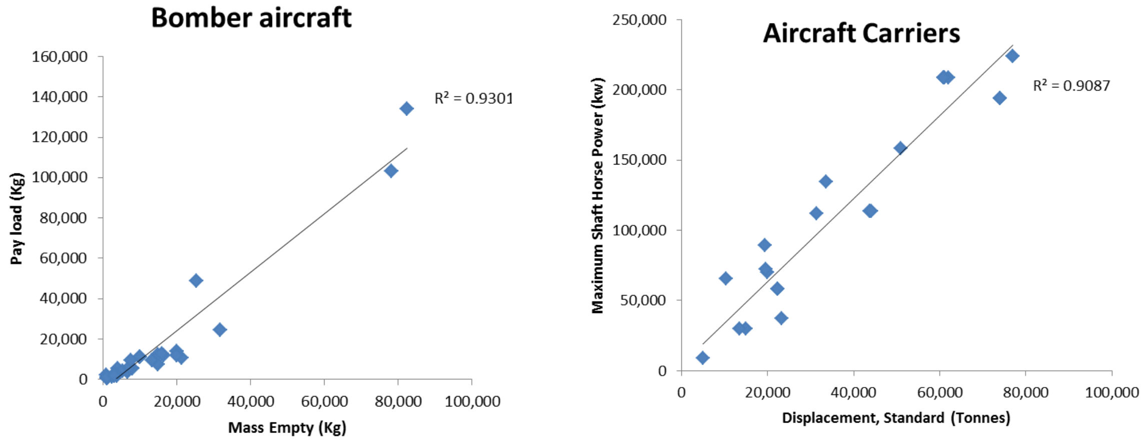

Figure 5: Design and performance characteristics exhibiting correlation

In the FACET system we utilise the multi-colinearlty for cross checking. At the early stages of a project, when very little information is available, macro-parametrics are most appropriate, but you are heavily dependent on engineers describing the potential solution to the aerospace need.

As shown in Figure 6, the FACET system has input for both performance and design. The performance requirements are translated through sizing rules to create a nominal design. This is compared mathematically with the user design inputs.

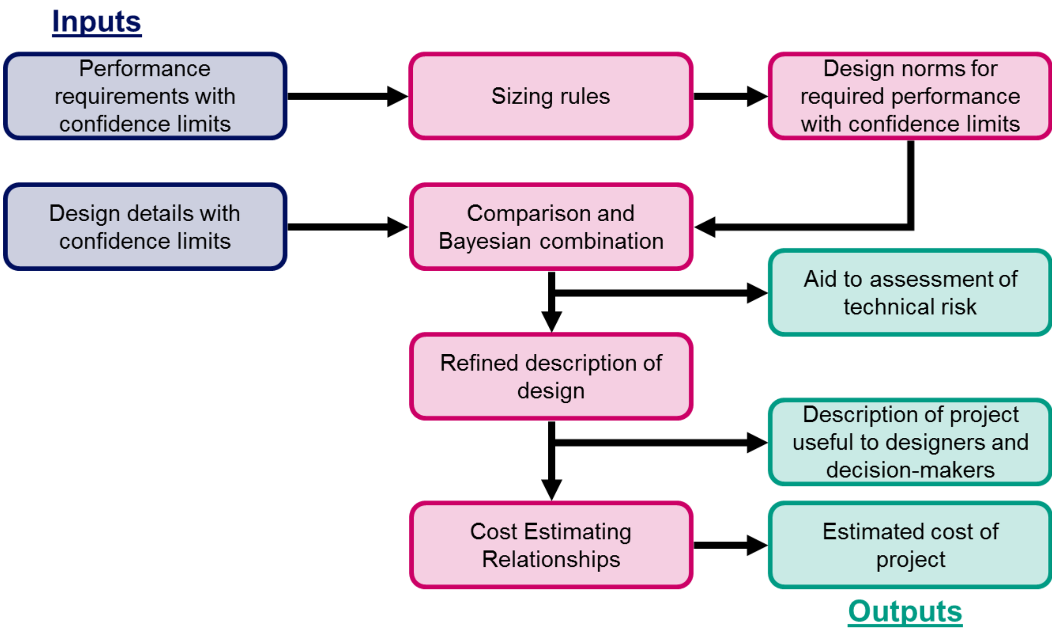

Figure 6: FACET estimating process with the application of Bayesian

If the inputted design details have a wide tolerance band, as is the case at the start of a project, the underlying algorithm within the FACET toolset will interpret this as a user who is uncertain of the design of their finished system. FACET will hence discriminate against the user entered design parameters, and generate an output that is aligned to the nominal design derived from the entered performance parameters. FACET effectively forecasts, for the required level of performance, what the user should be expecting in terms of a design. FACET alerts the user that this has happened, and advises the user as to the design parameters that they should be expecting to meet their performance requirements. As the project life cycle progresses and the tolerance on the design parameters progressively reduces to certainty the design then has bias towards the design inputs. The FACET model will signal initial observations regarding this comparison and highlight any technical risks if the performance derived design and design inputs are seriously misaligned.

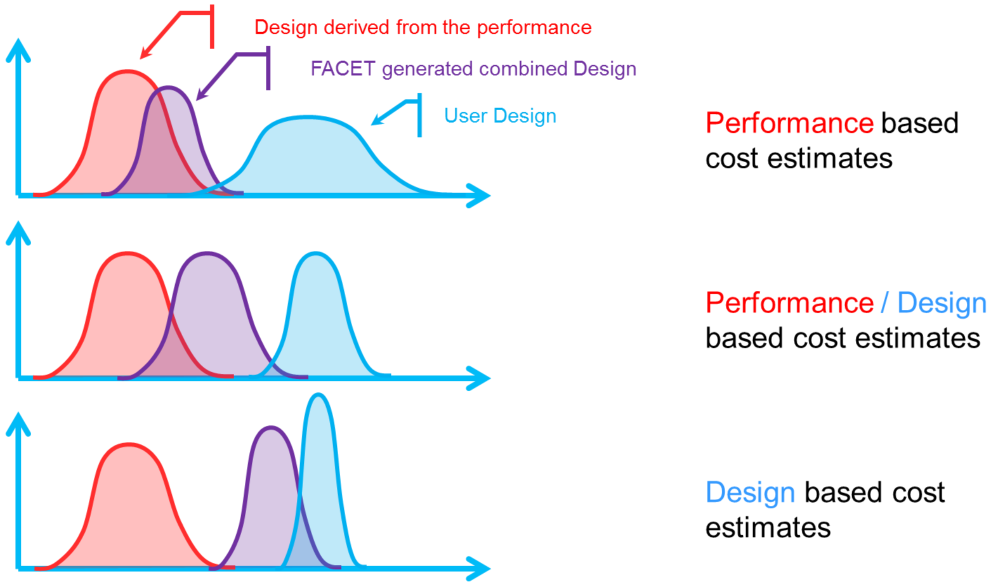

Figure 7: The combination of performance and design inputs based upon the certainty of the design

Once the model has generated a combined design this is used as the basis of the whole life cost estimate, as shown in Figure 8.

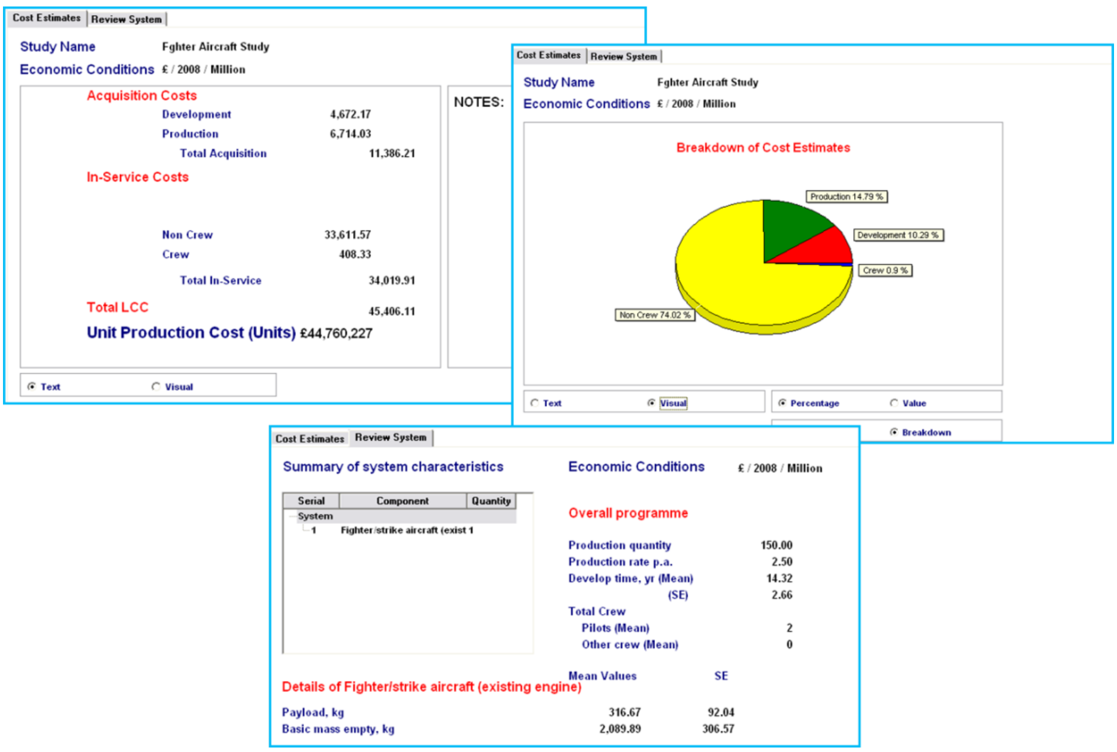

Figure 8: A selection of standard FACET output reports

Uncertainty and uncertainty

The other unique feature of FACET is its uncertainty capability. Following the cost research on the line of best fit it is possible to statistically determine the uncertainty or prediction error for the line. The FACET parametric cost model considers the combination of this algorithm uncertainty and the uncertainty in the inputs parameters.

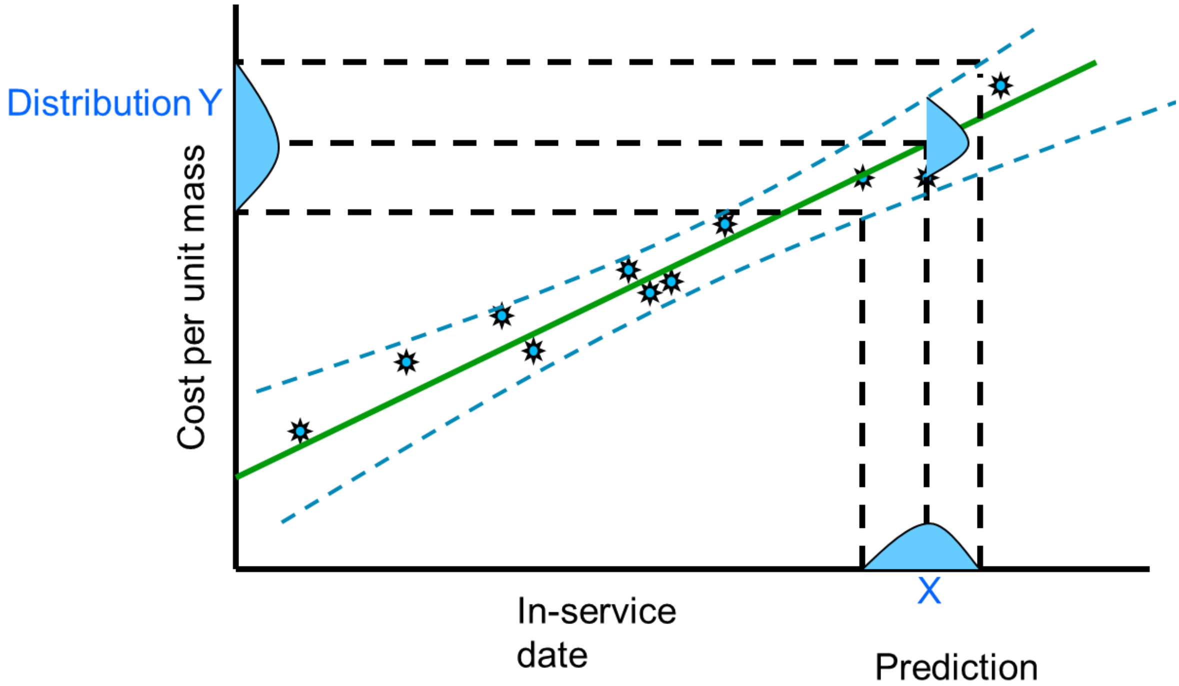

Figure 9: Mathematical combination of the uncertainty in the algorithm and the input parameters

The FACET parametric model provides statistical outputs (see Figure 10) to enable the correct interpretation of the results together with the S-curve of uncertainty.

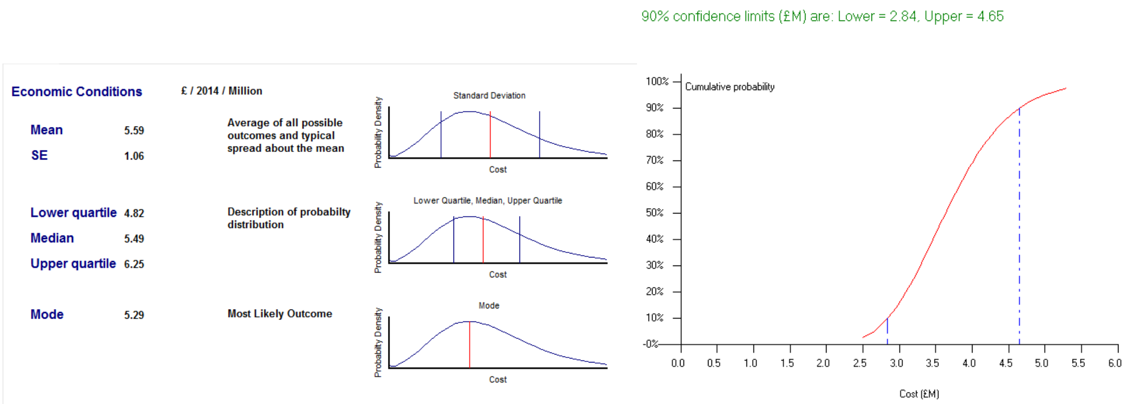

Figure 10: Comprehensive output statistics from FACET including the S-curve of uncertainty

Conclusion

This paper has examined some of the challenges of cost forecasting complex projects. Business processes demand that projects have costs generated for them early when there is little information available. This paper developed the theories that:

- Marco-parametric estimating is useful early in an aerospace project and for independent cost estimating (ICE).
- Don’t ignore correlated independent variables due to multi-colinearity; they can be used as a cross check of the parametric inputs.
- FACET is a macro-parametric cost model which seamlessly migrates from performance-based to design-based cost forecasting.
- It is possible to combine the uncertainty in the algorithm and the uncertainty of the inputs parameters, but beware that the outputs will correctly have a large tolerance.

References

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