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Hybrid cost estimating: the union of macro and micro-parametrics

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Abstract

At the pre-concept and concept phases of a project the nature of the solution is varied and the number of options plentiful. There are many ways to satisfy the capability need. At this point the estimating accuracy is such that the output tolerance is broad.

As the project moves into the concept and assessment phases the feasibility studies begin to produce more information for the purpose of options analysis and estimating, and the number of options starts to reduce. Now the estimating tolerance can start to reduce.

In a hybrid cost estimating framework solution it is possible to migrate from a macro cost model to a micro cost model without the need for retraining or new skills. The framework is able to accommodate a change in the estimating model without amendment.

If necessary it is possible to apply both macro and micro-parametrics together to estimate the cost of project solutions.

Keywords: macro-parametrics, micro-parametrics, cost model.

Introduction

This paper will consider how different types of parametric cost estimating can work together as the life cycle of a project progresses, reflecting the changing quality of the information available and the need for cost forecasts of increasing accuracy. QinetiQ has a consulting business called Advisory Services (AS) which promotes the application of cost engineering and other disciplines related to complex decision making.

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 this 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 [1.].

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).

Macro versus micro parametrics

At the joint ISPA / SCEA conference in Belgium in 2012 there was a Modelling Vision Panel session held. On the developers' panel was Hans Vonk, Herbert Spix, Dale Shermon, Doug Howarth, Dan Galorath and Tony Demarco [2.]. Each panellist was given five minutes to describe their vision of the future and this was the first time I used the terms macro and micro in combination with parametric cost modelling. In preparation for the panel I considered the past decades as follows:

- 1960-70 **Introduction** – the genesis of parametric cost modelling
- 1970-80 **Acquisition** – the licensing of parametric cost models
- 1980-90 **Teaching** – the period of receiving wisdom from the developers
- 1990-2000 **Exploring** – the application of parametrics and what can be achieved
- 2000-10 **Learning** – the eagerness to explore the data and algorithms
- 2010-20 **Creating** – the generation of niche cost models

I then introduced the QinetiQ philosophy of knowledge based estimating (KBE) which is the foundation of any justified and credible estimate [3.]. The pillars of KBE are Data, Tools, People and Process. These pillars were used to explore the future characteristic of cost estimating models. Under Tools I described my vision for; COTS versus bespoke, visualisation, portability and finally macro-parametric versus micro-parametrics.

It was not until the ICEAA conference in San Diego that the concept of macro-parametrics was fully defined [4.]. Using an extension to the ICEAA cost forecasting methodologies figure for the project life cycle, parametrics was sub-divided into two parts; macro-parametrics for early pre-concept analysis and micro-parametrics to follow. The characteristics of each parametric model were defined in a table, reproduced below for convenience.

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

Table 1: Characteristics of parametric models

Different types of cost forecasting methods are appropriate at different times within a project life cycle as the use or application of the costs resulting from the forecast are used in subtly different ways. As discussed in the 2018 ICEAA Phoenix paper [5.] looking at air superiority capability, the pre-concept options analysis is a consideration of a large number of domain options (land versus air versus space versus maritime) considering which platforms can satisfy a capability. The solution may be another manned aircraft, but equally the capability might be an unmanned solution. Other platform options might consider rotary platforms, ground based or maritime solutions. Many options need to be costed to ensure that that nobody is able to argue that the ultimate solution is a 'pet-project' or a pre-selected option. Only platform-level cost modelling using analogous and parametric methods are able to deliver a cost-effective set of reports for this spectrum of options.

As shown in Figure 1, once the platform type has been down-selected then there still remains a large number of design options to be cost estimated. So it might be an aircraft, but what will it look like? Parametrics is still the favored methodology as the design is quickly reviewed, refined and re-engineered in the concept and assessment phases. It is not until the development or demonstration phase that the sub-systems are detailed and considered. In this phase there are still options to be assessed; there will be a radar sub-system, but what is the design; phased array or traditional gimbaled radar?

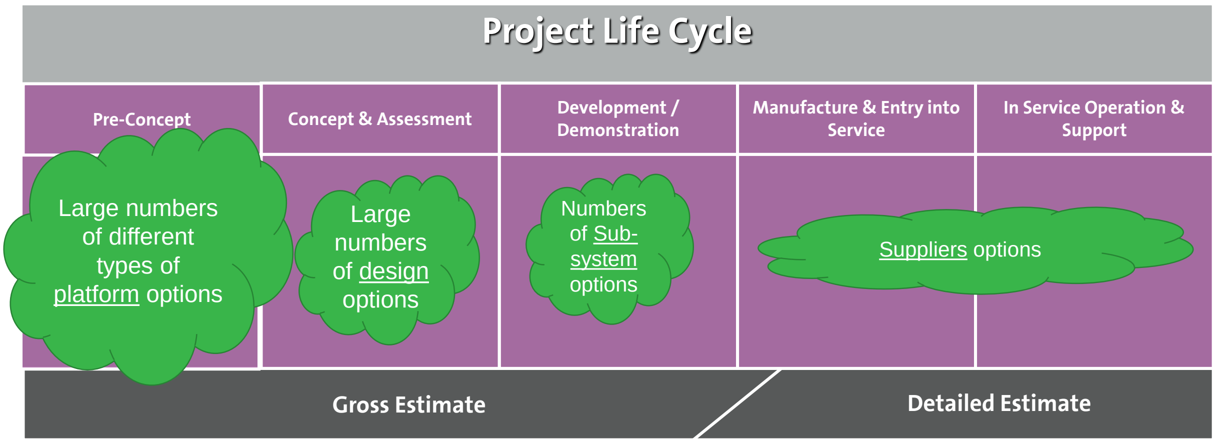

Figure 1: Option process - the development of the types of options considered through the project life cycle

Finally, the tender assessment process will set a "Should Cost" target for potential suppliers and the tendering process will begin. The final cost modelling will be commercially committing and will favour bottom-up, detailed work package resource estimating.

Besides the application of the output from the cost modelling, the input data to the cost modelling is important, when assessing the cost methodology to be used. The quantity and quality of technical data available has an influence on the cost methodology utilised. As shown in Figure 2 the product breakdown structure (PBS) of a product or service is developed during the project life cycle. It would be a complete waste of resources and time to develop a PBS for every option during the pre-concept phase to the last nut and bolt, only for most options to be deemed not value-for-money and hence dismissed at this early stage.

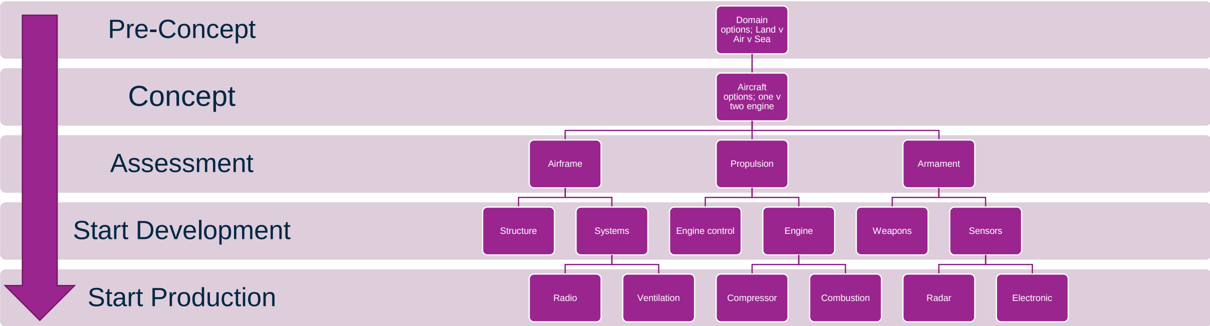

Figure 2: Product breakdown - the development of the capability configuration and breakdown with the project life cycle

Hybrid cost estimating

The International Society of Parametric Analysis (ISPA) Parametric Estimating Handbook (Introduction, page 5) [6.] identified that the 'savings to proposal preparation' – using parametric techniques – 'is between 40% and 80% as compared to the normal bottom-up approach'. It is this acceleration in time and resources that makes parametrics attractive when there is little information available and large numbers of options. The compromise is the accuracy or estimating tolerance as discussed in this section.

The tolerance of an estimate is measured in the same way as the tolerance of a machined or fabricated product, with an indication of the upper (positive) and lower (negative) range of expected outcomes. The estimating tolerances defined by the American Association of Cost Engineering (AACE) [7.] are shown in Table 2 updated with typical accuracy ranges [8.].

Primary Characteristic		**Secondary Characteristic**		
Estimate Class	Degree of Project Definition Expressed as % of complete definition	End Usage Typical purpose of estimate	Methodology Typical estimating method	Expected accuracy range Typical variation in low and high ranges
Class 5	0% to 2%	Concept, screening or feasibility	Capability factored, parametric models, judgement or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Concept study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorisation or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid / tender	Detailed unit cost with forced detailed take-off	L: - 5% to -15% H: +10% to +20%
Class 1	50% to 100%	Check estimate or bid / tender	Detailed unit cost with detailed take-off	L: -3% to -10% H +3% to +15%

Table 2: Estimating tolerances - the AACE cost estimate classification system

This table can be drawn as a graphical cone or funnel of estimating accuracy as shown in Figure 3. It should be recognised that in practice this funnel would not be a straight line as drawn here, but the cost estimate (the 0% line) will also alter (increase and decrease) as the degree of project definition is matured. As more is known about the nature of the project the baseline scope of work and the subsequent cost estimate will alter.

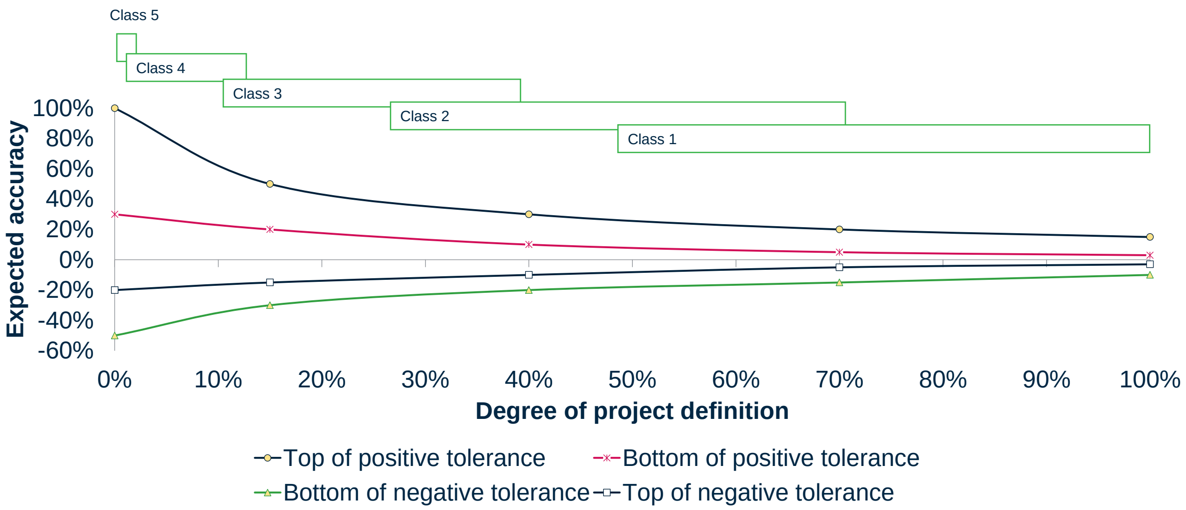

Figure 3: Funnel of accuracy - the progressive estimating tolerance as the project progresses

However, is this practical? To explore the AACE classification system this paper will utilise the TruePlanning framework [9.] which has both macro-parametric capability (in terms of the Family of Advanced Cost Estimating Tools (FACET) algorithms from QinetiQ - see Figure 4) and micro-parametric capability (in terms of its hardware, software and IT algorithms).

Figure 4: FACET cost objects - the icons representing some of the 60+ macro-parametric cost objects.

This concept of a funnel of accuracy will be explored using two case studies estimated using this hybrid of cost models accommodated within this single user interface.

Case study – training aircraft

The first case study will use the BAe Systems Hawk training aircraft [10.] as an exemplar. The TruePlanning system has a number of Military Handbook (Mil-Hdbk)-compliant work breakdown structure (WBS) 881C templates [11.]. The Hawk advanced training aircraft is a sophisticated and mature training platform which is fully known in terms of specification, fleet quantities and price.

The macro-parametric cost model is a single model (cost object) requiring the population of just 23 input parameters, see annex A. It will estimate the development, production and operating & support phases of the project with costs phased in detail across five activities.

The micro-parametric cost model by contrast is a template with 93 cost objects of assemblies, hardware and software items used to describe the platform. A single hardware cost object can require 48 input parameters plus others parameters if an operating & support estimate is required. However, this level of data input is rewarded with a rich detail of 54 costed activities.

For this case study the detailed Mil-Hdbk-881c template (as provided by PRICE Systems) was accepted as calibrated and correct. A quick review of the amortised unit production price ($11m as spent) correlated to the published, public domain aircraft price. So the macro-parametric cost model input parameters were entered with exactly the same technical data, for example the weight of structure was 4,302kg and weight of electronics 178kg so the basic mass empty (BME) in the macro model was entered as 4,480kg and so forth.

Assuming that the pre-concept phase, adopting the macro-parametric estimating techniques, results in 0% to 2% of the completed definition, then the AACE would classify this estimate as a Class 5 estimate (see Table 2). Similarly, if the concept and assessment phases, adopting the micro-parametric techniques, result in 1% to 15% of the completed definition, this would be a Class 4 estimate.

When reviewing the outcome of the advanced fighter aircraft case study the tolerances achieved were generally better than expected, as seen in Table 3. This generally means that the tolerances achieved were tighter than the AACE recommendations.

Project phase & estimating technique	Estimate class	Degree of project completion	Expected tolerance	Development	UPC	Development and Production
Pre-concept macro-parametrics	5	0% to 2%	L: -20% to -50% H:+30% to +100%	-23% ● +29% ●	-8% ● +9% ●	-8% ● +9% ●
Concept / Assessment Micro-parametric	4	1% to 15%	L: -15% to -30% H:+20% to +50%			+2% ● -2% ●

Table 3: advanced training aircraft results assessment - key: ● better than expected, ● as expected, ● worse than expected

The development cost generated by the micro-parametric cost model is $210m (as spent) which equates to the 70% and 75% confidence band in the macro model. In production terms, the amortised unit cost in the more detailed micro model is $11.1m (as spent) which equates to the 70% to 75% confidence band in the macro model.

The results of the two models, for the same advanced training aircraft, for development and production together, are as shown in Figure 5.

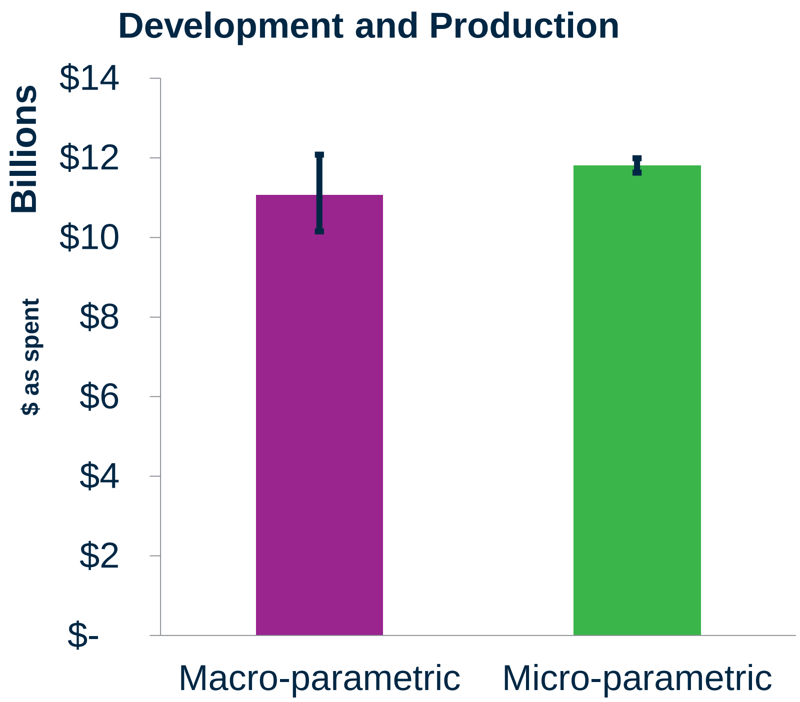

Figure 5: Comparison - the result of modelling an advanced training aircraft with two parametric models

This chart shows that the macro-parametric model has a larger tolerance, as indicated by the error bars, than the micro-parametric model. As both models inhabit the same framework they both have the ability to generate S-curves and the 10% / 50% / 90% confidence levels have been plotted on the graph in Figure 5.

It is reassuring to see that the micro-parametric cost model output falls within the tolerance band of the macro-parametric model.

In chronological order the macro model would be developed at first and the micro model later as the details of the solution evolved. The micro model is a detailed representation of one possible technical solution considered by the macro modelling capability. There could be other technical solutions, covered by the macro model, which could be cheaper, but potentially less capable. The Hawk is acknowledged to be a sophisticated platform relative to other training solutions and therefore the micro-parametric model output inhabits the top of the macro-parametric model tolerance.

Case study - UCAV

The second case study was produced to determine if this pattern was repeatable and uses a sample unmanned combat air vehicle (UCAV) as an exemplar. This estimate was originally produced in 2006 for a concept which was 5,600Kg and about 3m SLOC in terms of software.

Again, the macro-parametric cost model is a single model (cost object) requiring the population of just 16 input parameters (see annex B) to enable it to estimate the development, production and operating & support phases of the project with details of four activities as there are no crew costs in this estimate.

The micro-parametric cost model, by contrast, has 29 cost objects of assemblies, hardware and software items. A hardware model still requires 48 input parameters plus others if an operating & support estimate is required. Again, this level of detail results in the forecast cost of 57 activities for each cost object.

When reviewing the outcome of the UCAV case study the cost tolerances achieved were generally as expected, as seen in Table 4.

Project phase & estimating technique	Estimate class	Degree of project completion	Expected tolerance	Development	UPC	Development and Production
Pre-concept macro-parametrics	5	0% to 2%	L: -20% to -50% H:+30% to +100%	-52% ● +82% ●	-29% ● +32% ●	-34% ● +51% ●
Concept / Assessment Micro-parametric	4	1% to 15%	L: -15% to -30% H:+20% to +50%			+8% ● -8% ●

Table 4: UCAV results assessment - key: - ● better than expected, ● as expected, ● worse than expected

The development cost generated by the micro-parametric cost model is £591m (March 2018 ec) which equates to 40% and 45% confidence band in the macro model. In production terms, the amortised unit cost in the more detailed micro model is £13.3m (March 2018 ec) which equates to the 70% to 75% confidence band in the macro model.

The results of the two models, for the same UCAV, for development and production together, are as shown in Figure 6.

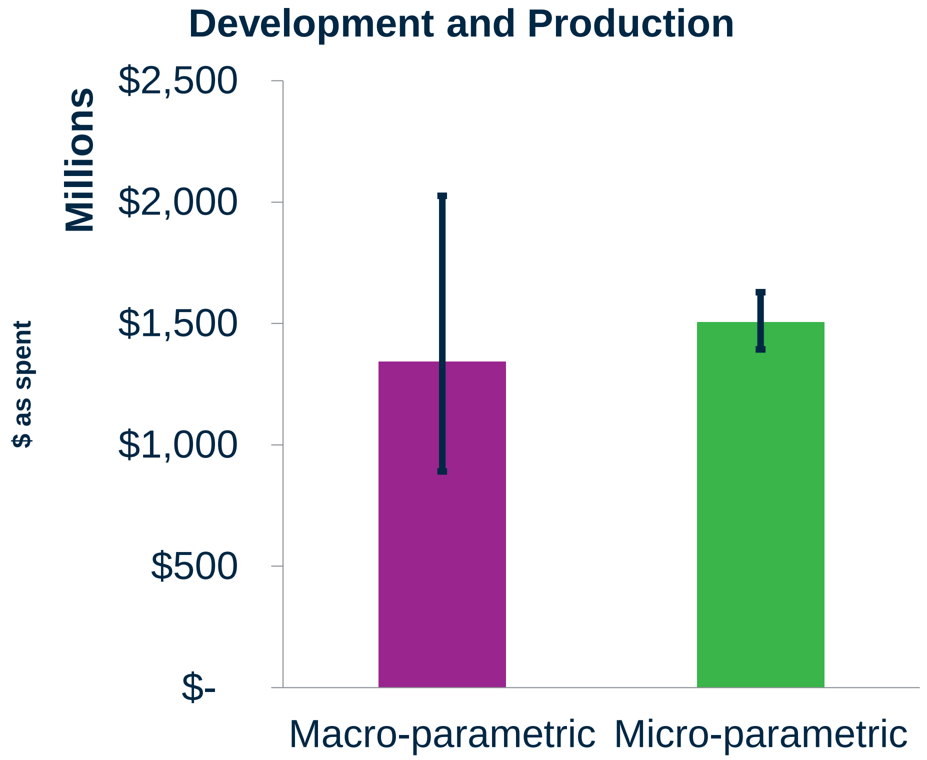

Figure 6: Comparison - the result of modelling an unmanned aircraft with two parametric models

As before, in the Hawk case study, it can be seen that the macro-parametric model has a larger tolerance, as indicated by the error bars, than the micro-parametric model when plotting the 10% / 50% / 90% confidence levels from the respective model s-curves on this graph.

It is again reassuring to see that the micro-parametric cost model output falls within the tolerance band of the macro-parametric model.

The macro model would be developed first and the micro model second as the details of the solution evolved over time. The micro model is a detailed representation of one possible technical solution considered by the macro modelling capability. There could be other technical solutions with varying capabilities, covered by the macro model, which could fall within the tolerance of the macro model results.

Lessons learnt

What are the limitations of this study that need to be acknowledged? The following is an initial list:

- Only one micro level solution was considered, when there could be a number of technical solutions;
- No consideration of project-specific risks;

- No application of both micro and macro models was considered.

There is no fundamental reason why these limitations cannot be addressed given more time being available for such a study. The advantages of the approach outweigh the limitations which have been considered below:

- Cost modelling capability to match the phase of the project;
- Both macro and micro parametric cost models accommodated within one framework;
- First level ROM analysis of multiple capability solutions can avoid claims of project or solution bias;
- Saving of time (and cost) for training by utilising the same hybrid cost framework;
- Demonstration of the cone (or funnel) of uncertainty;
- Reduced license fees by adopting one universal cost framework;
- Detailed cost analysis can support the design phase when appropriate;
- The analysis assumptions and input parameters are recorded for future scrutiny and debate.

The most significant item is the progressive nature of this analysis. The cost engineer is able to bring whole life cost modelling to the project at the appropriate level of detail for the phase of the project, rather than having to force a model which is too detailed into a project which is too immature.

Summary

This paper has examined the possibility of utilising high level macro-parametric models and more detailed micro-parametric models on the same project and comparing the results.

At the pre-concept and concept phases of a project the nature of the solution is varied and the number of options abundant. There are many ways to satisfy the capability need. At this point the estimating accuracy is such that the output tolerance is broad. Macro-parametrics are applicable to quickly establish the WLC of multiple system level solutions.

As the project moves into the definition and assessment phases the feasibility studies begin to produce more information for the purpose of estimating and the number of options starts to reduce. Micro-parametrics are applicable to refine the cost modelling with more information.

In a hybrid cost estimating framework solution it is possible to migrate from a macro to a micro modelling solution without the need for re-training saving time and cost.

Application of the correct estimating approach at the correct project phase provides decision makers with quality, appropriate information when it is needed.

Using the examples of an advanced training aircraft and a UCAV it has been demonstrated that the funnel or cone of cost estimating accuracy can be observed when moving between cost models.

The approach has been specifically designed to be equally applicable to other domains (land, maritime, space) and provides the cost community with the ability to migrate across parametric cost models as appropriate.

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Annex A – macro-parametric cost model input parameters – BAE Systems Hawk

		Value	Pessimistic	Optimistic	Units
1	Start Date				
2	Performance Data				
3	Training Load	3484.00	3484.00	3484.00	kg
4	Maximum Speed	1001.00	1028.00	990.00	km/hr
5	Design Data				
6	Basic Mass Empty	4480.00	4481.00	4400.00	kg
7	Syllabus Code, SC	2.00	2.00	2.00	
8	Technology Standard				
9	Year	1990	1990	1990	
10	Programme Data				
11	Number of Participating Nations	1.00			
12	Percentage to be included in the estimate of Development	100.00			%
13	Percentage to be included in estimate of Production Investment	100.00			%
14	Number of additional variants to be developed	0			
15	Development Status	New Design			
16	Production Quantity (including all variants)	1020			
17	Production Rate	20.00			Units Per Year
18	Crew Data				
19	Number of Instructor Pilots	0	0	0	
20	Instructor Pay	0	0	0	£
21	Number of Student Pilots	0	0	0	
22	Student Pay	0	0	0	£
23	Crew Overhead	0			%
24	Operations Data				
25	Hours Flown per year	0	0	0	hours per year
26	Service Life	0			years
27	Number of Units				
28	Units in Active Fleet	1020.00			
29	Units as Rotable Spares	0			
30	Units in Reserve	0			

Annex B – macro-parametric cost model input parameters – UCAV

	Value	Pessimistic	Optimistic	Units
1 Start Date				
2 Performance Data				
3 Endurance	12.00	20.00	10.00	Hours
4 Transit Speed	635.00	700.00	500.00	km/hr
5 Design Data				
6 Launch Mass	5,611.00	5,611.00	5,611.00	kg
7 Technology Standard				
8 Year	2000	2000	2000	
9 Programme Data				
10 Number of Participating Nations	1.00			
11 Percentage to be included in the estimate of Development	100.00			%
12 Percentage to be included in estimate of Production Investment	100.00			%
13 Number of additional variants to be developed	0			
14 Development Status	New Design			
15 Production Quantity (including all variants)	55			
16 Production Rate	25.00			Units Per Year
17 Operations Data				
18 Hours Flown per year	200	200	200	hours per year
19 Service Life	26			years
20 Number of Units				
21 Units in Active Fleet	55.00			
22 Units as Rotable Spares	0			
23 Units in Reserve	0			