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Applying parametric cost modelling to Technology Insertion

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Abstract

Abstract *- The paper will describe the UK MOD need to develop a Whole Life Cost modelling tool to enable the exploration and justification of up-front investment in different acquisition scenarios for characteristics that facilitate subsequent Technology Insertion.*

This paper will describe a case study regarding how to apply parametric cost modelling to the attributes which are associated with Technology Insertion. The case study applies this modelling to an Unmanned Combat Air Vehicle (UCAV), although it is equally applicable to all generic system types.

This application of the PRICE H, PRICE HL and True S parametric models result from a Technology Insertion Major Programme Area (TIMPA) study which has been funded by the Research Acquisition Organisation (RAO) of the United Kingdom (UK) Ministry of Defence (MoD).

The technique is transferable and equally applicable to all Integrated Project Teams (IPTs) wishing to investigate Technology Insertion (TI) options.

Caveat

The information contained within this report is for illustrative purposes only. It has been developed to provide sufficient information to allow the cost modelling of the options to be evaluated. It is not intended to represent an actual cost estimate of a UCAV programme.

Introduction

QinetiQ, the UK Defence Research organisation, is managing a study on behalf of Dr John Simpson (Research Director, Theatre Airspace) at the Research Acquisition Organisation (RAO) investigating Technology Insertion.

The Technology Insertion Major Programme Area (TIMPA) study has completed an initial study and the second phase began at the start of October 2006 and will run until July 2007. As part of this second phase Dr Simpson has recognised the need to establish a TIMPA cost model. The aim being;

"To explore and justify up-front investment in system characteristics that will facilitate subsequent TI"

QinetiQ approached PRICE Systems to support the creation of a cost model for the TIMPA study. A preliminary meeting was held which concluded that although the User Requirements were not explicitly known, there was sufficient common ground for both parties to work together in the short term to establish a proof of concept (see Figure 1).

This proof of concept was presented in January 2007 which proved to be satisfactory, to both Qinetiq and their customer. As a result, approval was given for the second stage to further refine the established methodology

This paper describes the application of the PRICE Estimating Suite (PES) to the problem of TI, hence satisfying the TIMPA Concept of Analysis (COA) and User Requirements Document (URD).

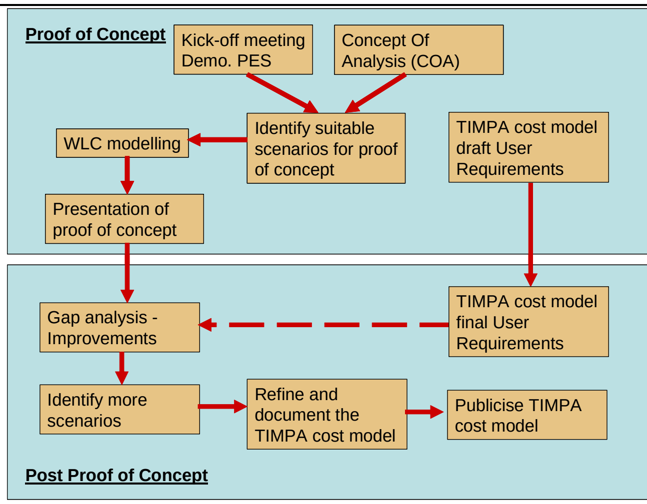

Figure 1 - TIMPA Cost model Study structure

TIMPA Cost modelling

General Approach

The draft TIMPA URD identified many requirements for the TIMPA cost model. As a result it was broadly recognised that the TIMPA WLC model needed to be based on a tool set that was:

- Easily accessible to the UK MOD (they have an unlimited license for all the PRICE Tools)
- Appropriate across all domains (Land, Sea, Air, Space, C4ISR)
- Detailed enough to consider technology
- Validated and Verified
- Would provide time phased cost estimates.

The Concept of Analysis (COA) identified the case study which was to be used to demonstrate this proof of concept. This will be detailed later in this paper.

The real starting point of this study was the identification of the Technology Insertion issues that would require cost modelling. Several meeting were conducted when the technologists and scientist described the issues or enablers that needed to be modelled in the TIMPA cost model. These were originally nothing more than a list of topics, which were discussed, debated and concluded. QinetiQ had a good understanding of the TI issue and the effect that was desired, but to enable the cost model to be influenced in the correct way it was important that the cause was properly understood.

The TI issue to be examined are listed here:

- Support and maintaining Configuration Management information for multiple concurrent versions
- Dependency on previous procurements
- Capturing user feedback

- Discontinuity costs within procurements
- Modularity of architecture
- Spare capacity
  - Space
  - Cooling
  - Band width, etc.
- Documentation of system to facilitate change
- Configuration management information
- IPR Ownership
- Openness
- Availability of relevant knowledge, skills and tools
- Obsolescence

The first step was to ensure that the team understood the terminology used. The initial TIMPA study had defined the terms acquisition, procurement, upkeep, upgrade, etc. which was a good starting point (see Figure 2).

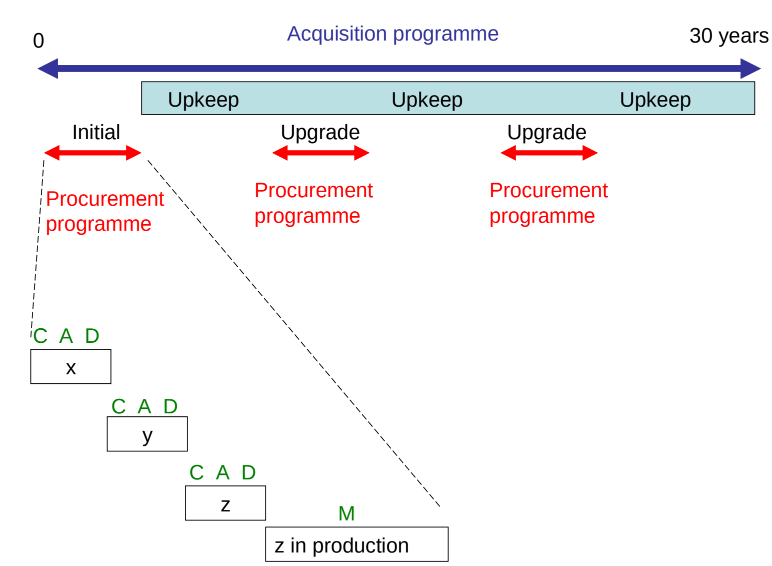

Figure 2 - Acquisition & Procurement Definitions

Modelling

The following cost models used in the development of the TIMPA cost model:

- PRICE H – Hardware Procurement (Development and Production)
- PRICE HL – Hardware Operating and Support
- PRICE True S – Software Procurement and Support

Rather than develop a cost model from scratch the approach was to use the existing cost models and determine how to apply them to this task. The PRICE Estimating Suite (PES) has many applications, for example, Supplier Assessment, Cost As an Independent Variable (CAIV), etc. and this would be considered another application to add to this list.

Table 1 maps the TI issues to PRICE parametric cost model input parameters, these parametric inputs are further described in the case study, together with the appropriate input values.

Technology Insertion Cost Driver	Parametric model cost driver
Support and maintaining Configuration Management information for multiple concurrent versions	The costs associated with configuration management are a combination of the detailed cost drivers identified below (marked thus #)
Dependency on previous procurements	If previous procurements have been designed to be receptive to TI then the associated costs in the current procurement will be reflected. See other TI Cost Drivers below (marked thus *).
Capturing user feedback	This requires the model to model the influence of an incremental approach to procurements. PROSUP & PSF for the hardware and Development Process for software ensure that the costs associated with capturing feedback are modelled.
Discontinuity costs within procurements[1]	The capturing of feedback above will potentially lead to pauses in industry effort. It is possible that industry will request funding of the core team to ensure continuity. The size of that core team is not predictable, but can be evaluated on a case by case basis depending on the size of the core team; it can be included in the cost estimate as a ThruPut item to provide a total cost.
Modularity of architecture*	Modular architecture will lead to simpler integration activities. The INTEGE/S parameters for the hardware model and Internal/External Integration complexities for the software model are used to reflect the receptivity of the technologies. The REUSE in software and NEWST/EL parameter in hardware increases the necessary non-recurring engineering to achieve the modular architecture. In production, modularity leads to potential benefits in larger quantities. The parameter Total QTY can be used where identical items are being procured by different programs offering cost reductions to each project due to economies of scale.
Spare capacity – Space*	The systems are procured with sufficient electronics (WE) for the current requirements, but additional structural weight (WS) for the relevant sub-system. At the TI point no additional structure is required, just additional electronics. INTEGE/S parameters reflect the ease of integration at TI for a receptive system, compared to modifications of airframe / hull / chassis for non-receptive systems.
Spare capacity[2] – Cooling*	Normalised cost density can be plotted against performance to conduct CAIV trade-offs. In this instance, increased MCPLXS/E would be used to reflect higher performance than initially required. INTEGE/S parameters reflect the ease of integration at TI for a receptive system, compared to modifications of airframe / hull / chassis to accommodate additional cooling in non-receptive systems.
Spare capacity – Band width*	Normalised cost density can be plotted against band width performance to conduct CAIV trade-offs. In this instance, increased MCPLXS/E would be used to reflect higher performance than initially required.

[1] This refers to the cost of maintaining an industry team between feedback regarding prototypes.
[2] For example changing from Passive to Active cooling

Technology Insertion Cost Driver	Parametric model cost driver
	INTEGE/S parameters reflect the ease of integration at TI for a receptive system, compared to non-receptive systems.
Spare capacity – etc.*	Normalised cost density can be plotted against any performance measure to conduct CAIV trade-offs. In this instance, increased MCPLXS/E would be used to reflect higher performance than initially required. INTEGE/S parameters reflect the ease of integration at TI for a receptive system, compared to non-receptive systems.
Documentation of system to facilitate change*#	Increase in initial NEWST/EL & ECMPLX will result in increased design and systems engineering costs which have an influence on documentation costs. E/SPLANS will generate appropriate documentation in integration and test plans and procedures.
Configuration management information*#	Configuration management costs are included with in project management costs. These development costs are incurred at each additional TI point. In the maintenance period at each TI point, additional supply administration costs are incurred.
IPR Ownership*	This TI issue was considered and, due to its business nature, it will need to be addressed on a case by case basis due to the commercial nature. Although the IPR Ownership cost cannot be modelled, it can be included in the cost estimate as a ThruPut item to provide a total cost.
Openness[1]*	Following its definition this TI issue can be modelled as a Purchased item with Design Integration (DLEVE/S) for the Systems Integrator. The DLEVE/S parameters will be lower for Open systems compared with conventional equipments. When considering integration and testing activities, INTEGE/S will be lower to reflect easier integration and possible lower costs in travel and communications i.e. project management
Availability of relevant knowledge, skills and tools.*	Both the hardware and software models have technology maturity algorithms that reflect market forces. When knowledge, skills and tools are in short supply, the models adjust the costs accordingly. As market forces make these more readily available, the costs reduce. These factors can be influenced by the Users of the model using the Global parameter ZTEC. The other side of this curve is the effect of obsolescence when these knowledge, skills, tools and parts become rare again.
Obsolescence*	The effect of increased cost of spares, during the In-Service phase of the equipment, due to components (mainly electronics) no longer becoming available can be modelled in the PRICE HL using the escalation tables provided.

[1] Openness is defined as standard interfaces in the public domain, not requiring IPR. For example, ISO standards, RS232, Bluetooth, USB connections. There are multiple sources of suppliers. These interfaces can be referenced; they do not require a specification.

Table 1 - TI Cost Drivers

Technology prediction

Input parameters in the PRICE H model include Complexity (or Normalised Cost Density) which is a representation of the Technology implicit in the item and the productivity of the manufacturing organisation producing it. Figure 3 diagrammatically shows the principle of Historical Trend Analysis (HTA) which has been used by the UK MOD to cross check procurement proposals. This approach can be used to predict the likely complexity of equipments resulting from TI in the future based on time trend analysis.

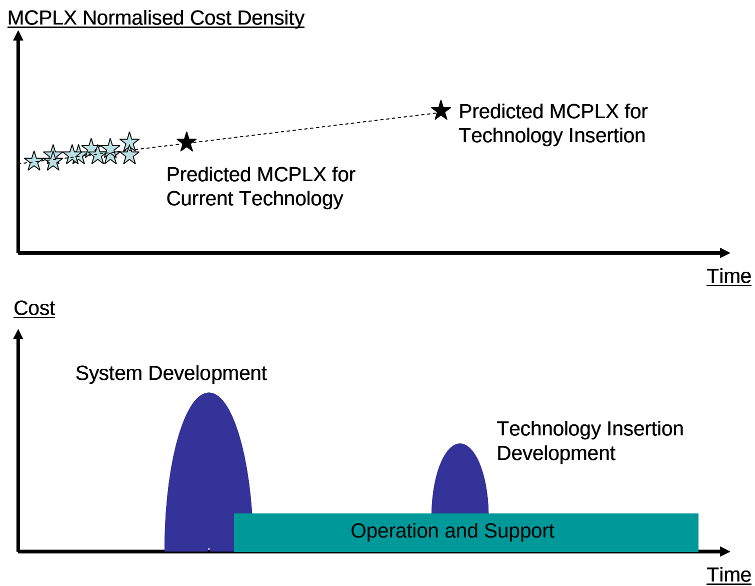

Figure 3 - Historical Trend Analysis

Spare Capacity and Modular Architecture

Discussion regarding these two TI issues are summarised in the approaches drawn in Figure 4. On the left is a traditional non-receptive approach. The architecture is a “spaghetti” of connections and interfaces. The equipments are designed to fully satisfy the requirements of the current system, with no thought about future growth.

The architecture on the right has a common interface box. All equipment are connected to each other via this interface, consequently, any future TI only requires the new technology to interface with the one box, which will deal with all timing, compatibility and interface issues of the system. The right-hand architecture is also over sized. The weight of electronics is the same as the required initial need, but the structure has been over stated to ensure that there is space for electronics at any future TI point.

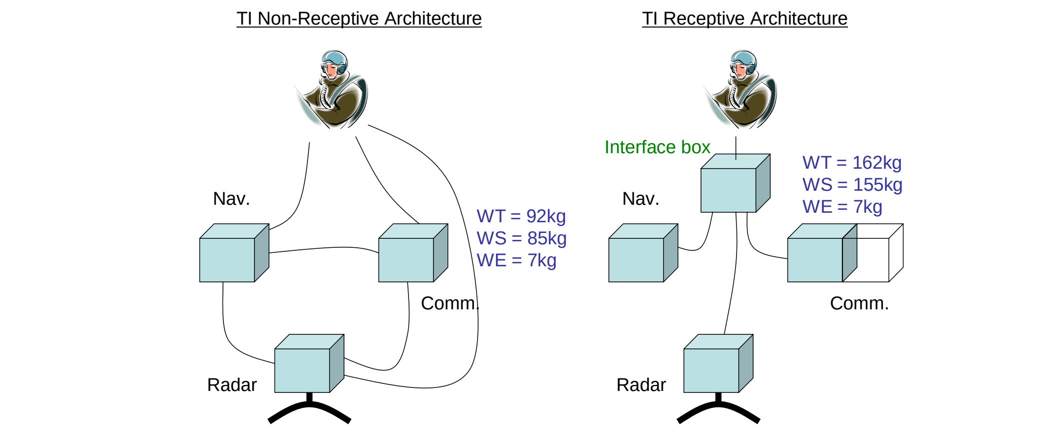

Figure 4 - Possible technical architecture of Receptive & Non Receptive systems

UCAV Case Study

To demonstrate the proof of concept regarding the application of this cost modelling to TIMPA a case study was conducted. An Unmanned Combat Air Vehicle (UCAV) was the selected system in the COA. In the COA document the technical description was discussed together with the options to be considered.

Options to be considered

The full options to be costed when considering technology insertion are considered in Figure 5.

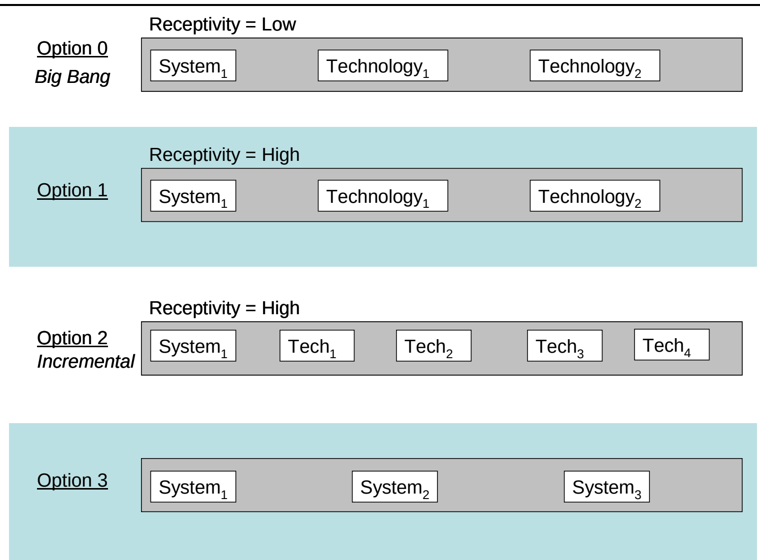

Figure 5 - COA Full Options

In support of this Proof of Concept options 0 and option 2 are considered, being the worst case situations.

The options are described as:-

- **Option 0 - “Traditional” – Baseline UCAV Design** - An option to consider the traditional method of dealing with technology in what is perceived to be a typical defence project. This is the baseline UCAV design.
- Option 1 – “Low Receptivity – Technology Insertion” - This option is to consider the cost of the Traditional approach but forcing technology insertion onto the programme. This will not be costed, unless time permits.
- **Option 2 – “High Receptivity – Technology Insertion”** - This option is to build new systems in an Incremental manner with the philosophy of technology insertion planned from the inception of the project; hence it will have built in receptiveness to smaller upgrades (TI activities) through the life of the programme. The subsequent TI will be obtained using a Waterfall procurement philosophy. This is the Adaptable UCAV design.
- Option 3 – “System replacement” - This option assumes that rather than technologies being inserted in the existing systems, the systems themselves are replaced with new systems containing the new technologies. Thus capability being maintained throughout the required period. This option will not be costed.

Master Data and Assumptions List (MDAL)

The first modelling step is to agree the CBS in the MDAL. This will act as a framework and prompt for all costs. Figure 6 has the CBS for this task.

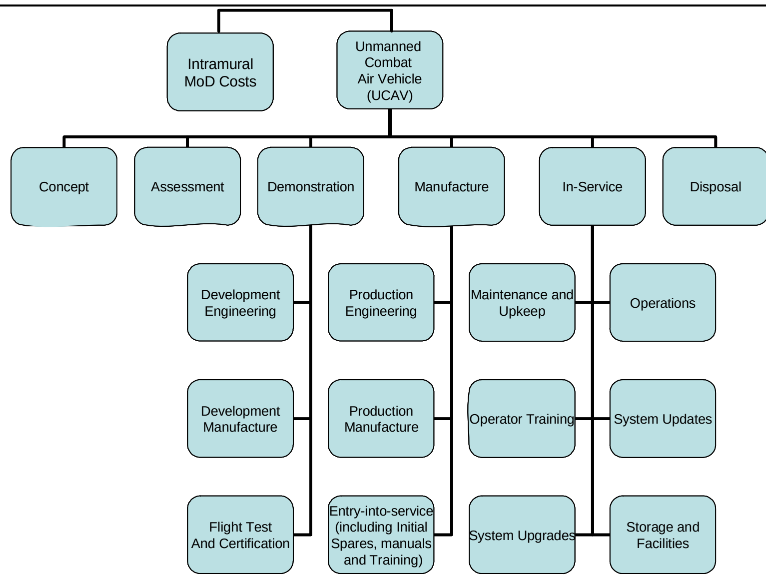

Figure 6 - Cost Breakdown Structure (CBS)

An Equipment Breakdown Structure (EBS) was agreed for each of the options to be parametrically modelled. For option 0 and 2 these were identical, but for option 0 none of the items were conceived with the idea of subsequent TI.

Figure 7 shows the hardware EBS that was considered.

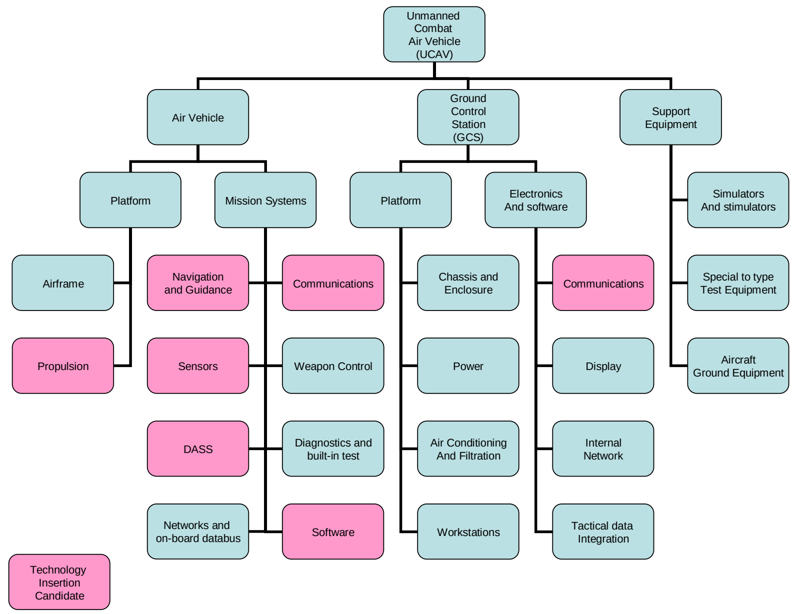

Figure 7 - Option 2 EBS

Figure 8 provides an estimating breakdown structure (EBS) for option 2 software elements, again option 0 is the same, but without the candidates for TI identified.

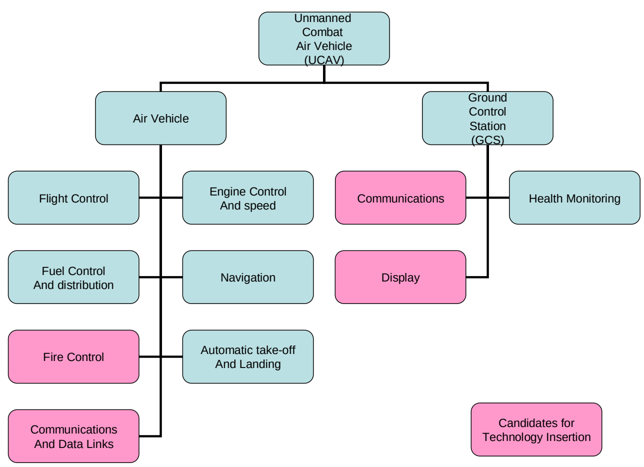

Figure 8 - Option 2 Software EBS

Information was gathered against the elements of the EBS from the sources specified in the Data and Assumptions section of the MDAL. These technical inputs to the cost model determined the differences between options 0 and 2. The algorithms within the cost model used these technical inputs to determine the appropriate costs to be generated.

Degree of Technology Insertion

In Figure 9 the degree of technology replaced or upgraded is indicated at each technology insertion point. Being less receptive to technology insertion the TIMPA team considered that the TI points would be more intense and in the case of the propulsion and sensors delayed until absolutely necessary.

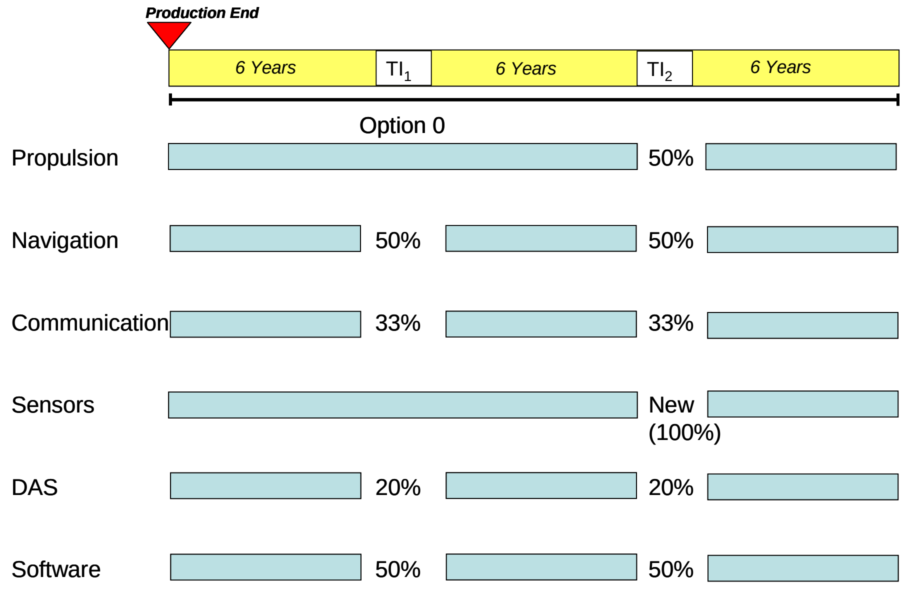

Figure 9 – Option 0 - Degrees of technology insertion

In Figure 10 the degree of technology replaced or upgraded in option 2 is indicated at each technology insertion point. In this instance the opportunities to conduct technology insertion are more frequent and less dramatic for the system. Hence, it is considered that the capability would be continuously topped up during the life of the system with smaller frequent TI.

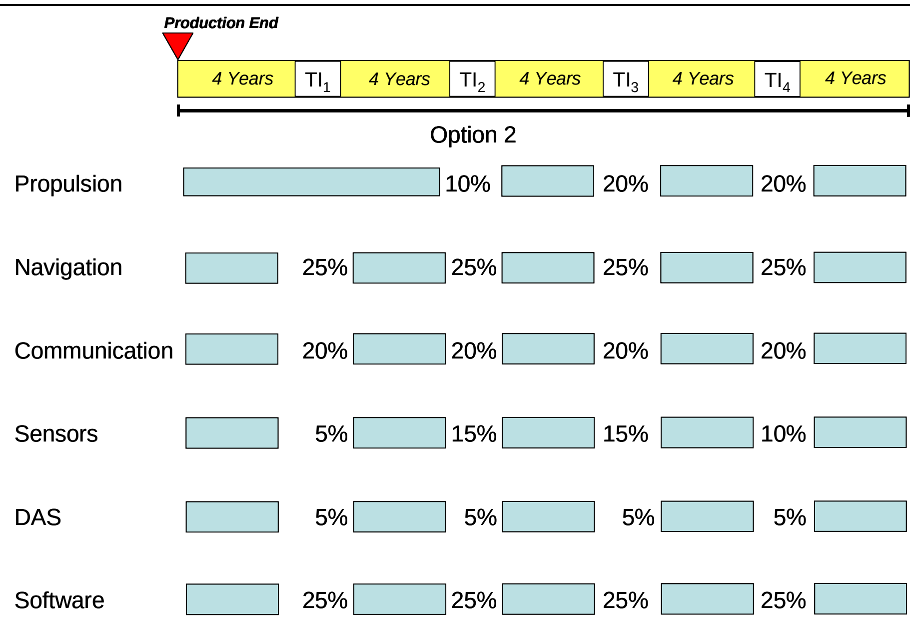

Figure 10– Option 2 - Degrees of technology insertion

For the purposes of this analysis the performance of the two vehicles will be the same at the end of the two acquisition programmes.

Technical Definition of Options

The complete description of the options to be costed came from QinetiQ and MOD (via PFG), where applicable.

General Assumptions

It is assumed that the procurement would be a European multi-national (tri-country) program to spread the development costs. Product integration will be carried out by individual member countries. It is assumed that all production will be conducted at multi-national manufacturing facilities to obtain the benefit of a large production run. The UCAV and GCS will be procured via a single continuous production run.

Financial Assumptions

- All output cost are in UK Pounds Sterling (£) unless otherwise stated.
- Costs will be discounted at the treasury discount rate of 3.5%. Financial year 2007 is assumed to be year 0.
- The baseline economic conditions will be at January 2007.
- For the purpose of this proof of concept PRICE Systems Default escalation tables[1] will be used.
- The cost analysis does not include any commercial mark ups i.e. Profit, G&A etc.

UCAV modelling

Parameters which are candidates to change as a direct result of Technology Insertion from option 0 to option 2 are likely to be;

Parameter		Option 0		Option 2	
		Initial	TI	Initial	TI
PSF	Prototype Scheduling Factor defines the sequence in which multiple prototypes will be initiated in the development phase.	Preset value = 0.25 (25% of previous prototype completed before next prototype is started).	Preset value = 0.25 (25% of previous prototype completed before next prototype is started).	When each prototype is 100% complete before the next one is started, PSF = 1.0.	Preset value = 0.25 (25% of previous prototype completed before next prototype is started).

[1] Source: International Monetary Fund (IMF) for historical perspective and Oxford Economic Forum (OEF) for future predictions.

Parameter		Option 0		Option 2	
		Initial	TI	Initial	TI
PROSUP	Prototype Support Adjustment Factor is a parameter used to adjust prototype manufacturing and development engineering costs when design & fabrication yield problems are anticipated.	Prototypes include the engineering models, test units and other common items that are qualified through acceptance tests during the development phase	Prototypes include the engineering models, test units and other common items that are qualified through acceptance tests during the development phase	PROSUP = Total Prototypes necessary to capture feedback + necessary to achieve qualification / Number of prototypes necessary to achieve qualification testing. $= \frac{2+5}{5}$ = 1.4	Prototypes include the engineering models, test units and other common items that are qualified through acceptance tests during the development phase
Total QTY	Total Production Quantity indicates the total size of a production lot when only a portion of the larger production lot is used by the specific project.	Total QTY > QTY	Total QTY > QTY	Total QTY > QTY	Total QTY > QTY
WT/WS/WE	Total Weight (WT) of the element being modelled. WT = Weight of Structure (WS) + Weight of Electronics (WE).	Nominal	WE & WS Increase	Nominal with increased WS	WE increase only
INTEGE/S	Defines the level of the contribution to the Integration and Test effort for this element.	Routine	Difficult	Routine	Simple
ECMPLX	A measure of the complicating factors of the design effort as they relate to the experience and qualifications of the engineering design team.	New Design – Normal Engineers	Extensive Modification – Experienced Engineers	New Product / Technology – Normal Engineers	Simple Modification – Experienced Engineers

Parameter		Option 0		Option 2	
		Initial	TI	Initial	TI
MCPLXE/S	A measure of the equipment item's technology, its producability (material, machining and assembly tolerances, machining difficulty and surface finish, etc. electrical components, circuitry, etc.), yield, and all major cost and schedule drivers within the Model.	Current Technology	Future technologies	Current Technology	Future technologies
NEWST/EL	Defines the amount of new electronic or structural design effort.	Nominal	Higher design effort	Initially increased to design for reuse.	Lower design effort

Table 2 - PRICE H parameters

Parameter		Option 0		Option 2	
		Initial	TI	Initial	TI
Design for Reuse	This value describes the planned level of reuse of the software (with no modifications) in other applications or projects.	Nil or nominal reuse	Nil or nominal reuse	Reuse plans for a few selected parts of the application or Reuse plans for much of the application with more than one project.	Reuse plans for a few selected parts of the application or Reuse plans for much of the application with more than one project.
Size	New, Adapted, Reused, Deleted, Auto Generated, Auto Translated	Nominal project inputs	Nominal project inputs, including Deletion and Adaptation	Nominal project inputs	Nominal project inputs, including Deletion and Adaptation
Development Team Complexity	This value represents the knowledge, capability, experience, and continuity of the development team assigned to the software	Nominal project inputs	Depending on Continuity of team, experience will be	Nominal project inputs	Depending on Continuity of team, experience will be relevant.

Parameter		**Option 0**		**Option 2**	
		Initial	**TI**	**Initial**	**TI**
	project.		relevant.		
Development Process	This value describes the software development project by its approach to defining requirements and implementing a software solution. The pre-defined values name four established processes: Waterfall, Evolutionary, Spiral, and Incremental.	Waterfall	Waterfall	Incremental Number of increments = 3	Waterfall
Internal Integration Complexity	This value represents the difficulty of integrating (and testing) the work packages within a software component to achieve full functionality of the software component.	Average team with many integration points	Experienced team with many integration points	Average team with few integration points	Experienced team with few integration points
External Integration Complexity	This value represents the difficulty of integrating (and testing) software components to an assembly or system.	Average team with many integration points	Experienced team with many integration points	Average team with few integration points	Experienced team with few integration points

Table 3 – True S parameters

Parameter		**Option 0**		**Option 2**	
		Initial	**TI**	**Initial**	**TI**
Mean Time To Repair	MTTR is the average time, in hours, required by the technician to locate and replace the failed part or the failed module, if there are modules.	Nominal project inputs from PRICE H	Nominal project inputs from PRICE H	Nominal project inputs from PRICE H	Nominal project inputs from PRICE H Nominal less an allowance to consider ease of integration
Mean Time to Repair on Equipment Failures	TRE represents the cycle time to remove, repair or replace a Module or a LRU, including time to get a spare LRU, Modules or Parts stocked at Equipment level, at the equipment level.	Nominal project inputs from PRICE H	Nominal project inputs from PRICE H	Nominal project inputs from PRICE H	Nominal project inputs from PRICE H Nominal less an allowance to consider ease of integration

Table 4 - PRICE HL parameters

The generated costs from the parametric models were peer reviewed to consider them for anomalies, for example typing errors. The outputs of the models are cost profiles and associated schedules. The appropriate discount rate was used to generate a discount factor for each year of the project life. The total figures obtained from the WLC will be multiplied by the annual discount rate to obtain the discounted annual cost. These will be aggregated to generate the Present Value (PV).

Results

Software

From the charts in Figure 11 and Figure 12 it is clear to see the initial procurements and the subsequent technology insertion points.

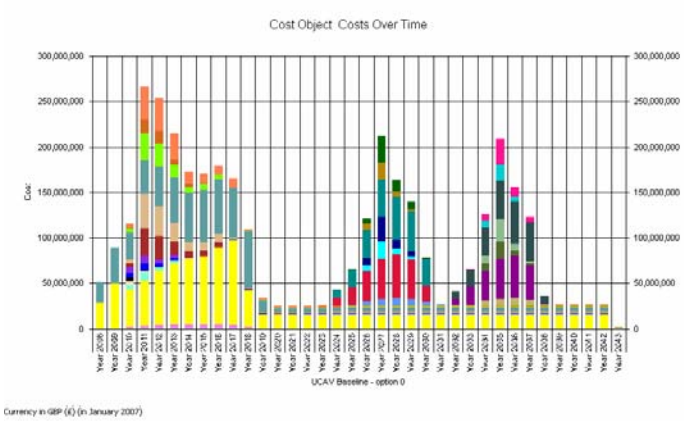

Figure 11 - Option 0 - software estimate - all nations

From the results of option 2 it is interesting to observe that the technology insertion point (TI_1) is merged with the initial procurements (Figure 12).

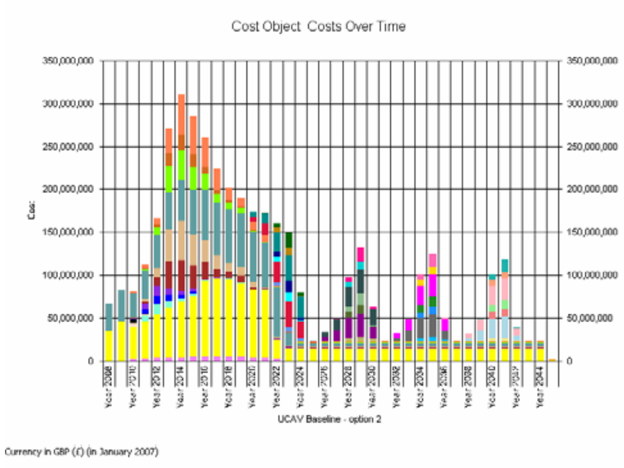

Figure 12 - Option 2 - software estimate - all nations

When added to the hardware and combine (see Figure 13) it is clear to see the initial increased investment in option 2 when compared to option 0. followed by the reduced procurement activity at the subsequent technology insertion points.

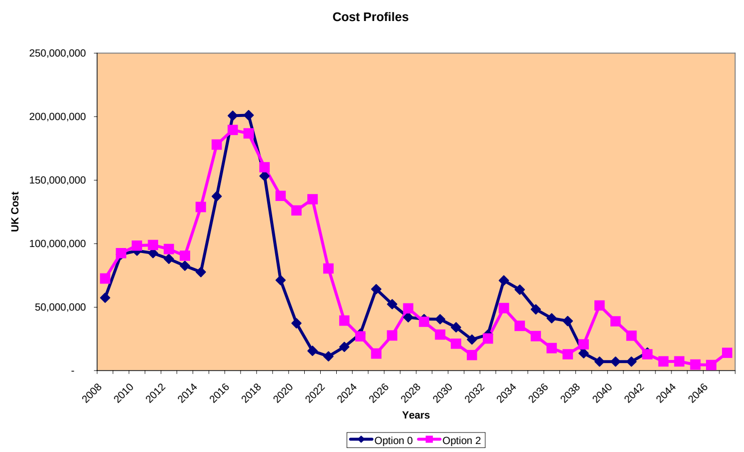

Figure 13 - Hardware and Software combined

When the cost estimates are compared it is possible to see the difference on an equitable basis. Both options have been calculated using the same models and are therefore directly comparable. For this UCAV system the non-recurring costs are dominant compared to the rest of the life cycle costs.

Cost (£m)	Option 0	Option 2
Development **(Software)**	**1,298** **(1,128)**	**1,539** **(1,309)**
Production	**618**	**718**
Support **(Software)**	**230** **(48)**	**274** **(46)**
Total **(Software)**	**2,146** **(1,176)**	**2,531** **(1,355)**
NPV	**1,449**	**1,721**

Table 5 - Results for a single nation (Jan 2007) - Hardware with software included

Conclusion

Even when compared on a NPV basis, there would seem to be no economic argument to select the TI receptive solution. However, all the TI issues have been considered together, further investigation is necessary to determine if any one TI issue or combination of TI issues could be beneficial.

All Technology Insertion (TI) issues were able to be modelled using the PRICE models. These models exist and are capable of estimating all domains; however implementation was complex in some areas. Expansion of the PRICE models would help for:

- Obsolescence
- Hardware development Life Cycles

UK MoD would be capable of applying this methodology to all appropriate projects with the aid of some comprehensive documentation of this application of the models and awareness training.

Having proved that the PRICE Estimating Suite (PES) can successfully model the cost of Technology Insertion, the next phase of the study will conduct a sensitivity analysis to provide guidance regarding the values for the inputs to the model. It will complete the analysis of options 1 and 2 identified in the COA and finally it will consider the application of this technique in three other domains to see if the results are different from those of a UCAV project.

If you would like more information regarding the project, or would like to comment on this paper there are two relevant website:

- TIMPA website: http://www.timpa.co.uk/
- RAO website: http://www.science.mod.uk/