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Historical Trend Analysis Analysed

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This article describes three alternative approaches to historical trend analysis. First, the study considers the trend over time of the complexities of past systems. This results from the application of a parametric cost model (PRICE H) to the normalisation of historical projects' costs and to the plotting of the complexity over time. Second, the trend over time of the equipment production cost, which has been observed as 'the cost of successive generations of equipment to continue to rise at above the rate of inflation,' commonly referred to as 'Defence equipment cost growth.' Finally, an analysis of technology over time through the application of multi-variable, forward step-wise regression (true concepts methodology)—one of the variables in the regression analysis being the cost residual versus time representing the cost of technology growth. The article describes the advantages and disadvantages of each historical trends analysis method. The research study indicates when each method might be applicable and in what circumstances it is dangerous to consider their usage. A case study has been used to consider the effect and accuracy of each of the methods. This review has considered the historical trend for a particular system and predicted the future cost of a possible acquisition. The objective of the study is to stimulate discussion amongst the cost community as to the usage of historical trends analysis, a common term that has not matured in many ways. The historical trends analysis technique is transferable and equally applicable to commercial or government organisations wishing to predict their own costs.

Introduction

At the time of writing this article, the UK was awaiting a General Election and an imminent Strategic Defence Review (SDR). In preparation for the SDR, the current government published a green paper in February 2010 (UK MOD, 2010a) that describes a number of issues that need to be considered by the next government when tackling the problem of the defence acquisition programme overspend.

Two issues are quoted below,

> 1.29 On the basis of experience in the United Kingdom and internationally, if we continue to search for a technological edge, including improved protection for our personnel, we can expect the cost of successive generations of equipment to continue to rise at above the rate of inflation.
>
> 1.31 These are enduring trends, and other advanced militaries around the world face the same challenge. Historically, rising unit costs have been offset by increases in capability and changes in the nature of the threat which have led us to reduce numbers of both personnel and platforms. But there are limits to how far capability improvements or efficiency can compensate for numbers.

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In response to this issue regarding increasing unit costs, the Defence Equipment and Support organization has issued an Acquisition Reform document (UK MOD, 2010b) with broadly similar observations.

> 1.7 Around 98% of our major projects deliver the operational performance needed at the front line. But they also tend to increase in cost—by an average of 2.8% each year. And they suffer delay, averaging 5.9 months (though some for reasons beyond [Ministry of Defence] MOD's control).
>
> 2.4 Part of the problem of cost growth we have faced has come from not fully understanding at the outset what the costs and risks of a project might be.

In simple terms, the United Kingdom (UK) MOD has the need for a mechanism to plan future cost growth, beyond the acknowledgment of inflation and escalation. The solution stated in the Acquisition Reform document is to "Put aside sensible levels of funding to deal with cost growth." The question then remains, "What is a sensible level?" And how should it be determined?

Historical Trend Analysis (HTA)

Three alternative approaches to HTA have been discussed and considered in the following sub-sections. By their very nature of the analyses, each has a time element in order to qualify as 'Historical Trend' approaches. What has varied in the three analyses has been the vertical y-axis and what is plotted on it against the historical time on the horizontal x-axis.

The three HTA methods used here have been published in full. References have been provided to enable the full analysis conducted in this article to be studied in more depth and repeated, but as the focus of this article is the comparison of these HTA techniques, only a summary of the techniques have been described in the following sub-sections.

Complexity versus Time

Darryl Webb (1990) in the 1990s produced a series of papers looking at complexity over time. Manufacturing complexity (MCPLX) is the outcome of product calibration using the PRICE H model. This model is capable of predicting cost using parametric techniques or normalising historical cost when used in product calibration mode. When calibrating historical technical, programmatic and cost information is entered into the model and the algorithms produce a MCPLX value representing the technology and productivity of that project. This technique is used to refine the accuracy of the cost estimate when used for estimating purposes.

He conducted a series of system level calibrations and plotted the resulting MCPLX complexity over time, as seen for example in Figure 1. In the analysis, there was a consistent upwards trend in all military systems. At the time of this analysis, all the systems calibrated were historical data with the exception of the Seawolf submarine estimate. The two trend lines are drawn depending on whether or not the Ztech cost driver is used in the calibration. The PRICE H model has a Z curve that simulates the rate of technology improvement in design and production. The slope of the Z curve is normally steeper for higher technologies and shallower for lower technologies (PRICE H, 2010). When the Ztech parameter is set to 1, then the nominal level of technology improvement influences the calibration in accordance with cost research. When set to zero, the technology improvement influence is eliminated. This analysis was made easier with the introduction of the

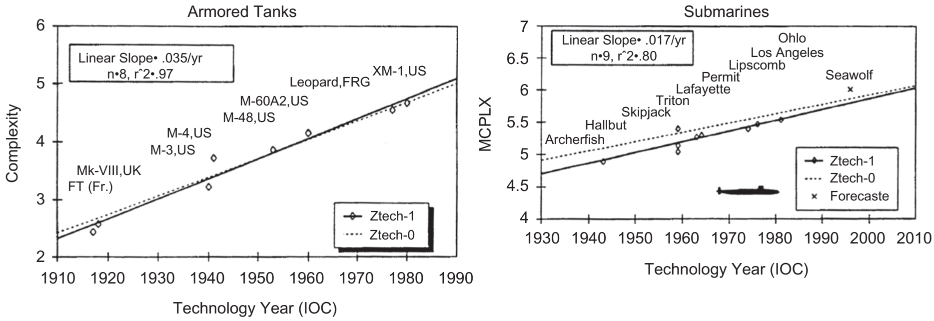

FIGURE 1 Complexity over time (Webb, 1990).

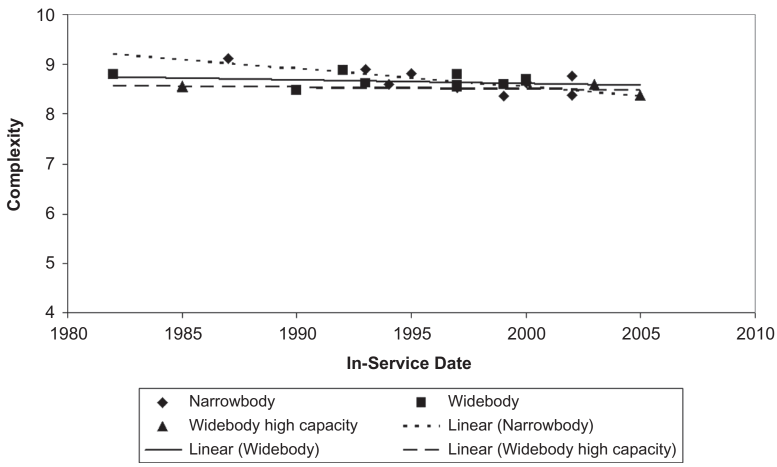

FIGURE 2 Commercial aircraft complexities by aircraft type.

PRICE Knowledge Management systems, which enabled the consistent storage, retrieval, and analysis of system level programs, such as the Future Carrier (Shermon, 2002).

However, not all systems follow an upward trend. Commercial aircraft have become more complex as time has passed, but they have a flat or declining complexity over time when reviewed by commercial aircraft type (see Figure 2). This is peculiar as commercial aircraft technology has become more complex with the introduction of fly-by-wire controls, composite components, and other technologies.

This picture changes when the complexity is analysed by manufacturer (see Figure 3) and provides reasons for the possible lack of upwards trend. The duopoly achieved by Boeing and AIRBUS provides for a very competitive environment, one in which productivity is key to survival. As the complexity parameter is an indication of both a technology index and productivity, it is possible to deduce that the productivity in the commercial aircraft environment is divergent from the technology increase.

When using a parametric cost model to normalise the historical actual cost of projects, there are a number of algorithms applied. One of these sub-models is the technology maturity model. Figure 4 shows graphically the theory behind this model based upon a constant industry or operating environment, for example, commercial products, land vehicles, ships, aircraft, or space vehicles. Naturally, if the industry or operating environment is changing,

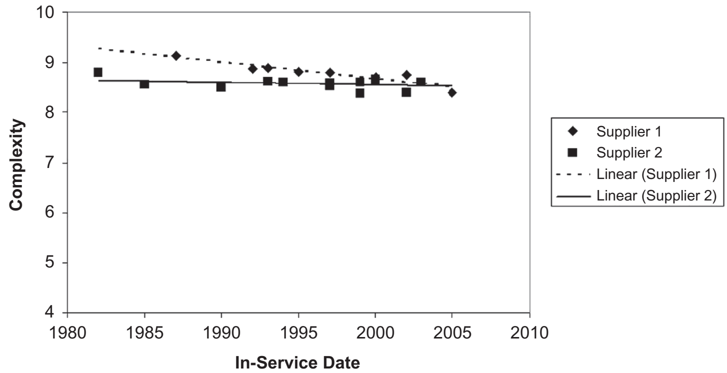

FIGURE 3 Commercial aircraft complexities by manufacturer.

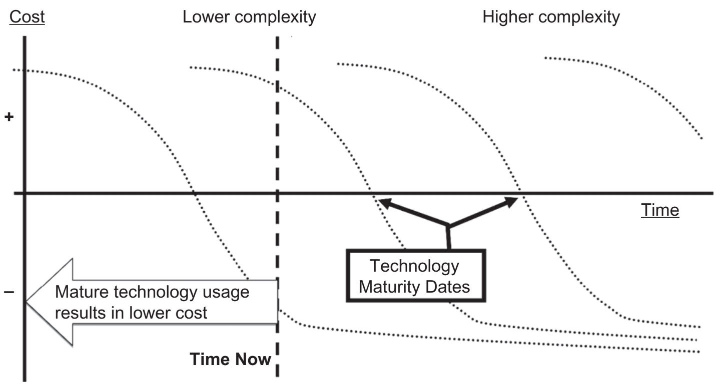

FIGURE 4 Technology maturity model.

the maturity of the technology can change. For example, space vehicles have used composite components for many years, aircraft have composite systems, and more recently cars have composite parts, but the technology has yet to mature in the high-volume commercial product environment (e.g., washing machines).

As time progresses, technologies are assumed to mature. Due to market forces, immature technologies are expensive due to the limited number of suppliers of material and manufacturing, resulting in higher costs. As time moves on, more suppliers join the market and competition ensures that the costs are reduced.

Part of the problem in defence is that mature technologies are seen as less capable. The Services constantly want to move to the next technology to ensure superiority on the battlefield. Equipment would be cheap if the current generation of equipment were reordered. However, the Generals, Wing Commanders, and Admirals require the next generation of equipment, not the present.

Production Cost over Time

The next approach to HTA was published by Philip Pugh (2007) and considers the unit production cost (UPC) per unit weight (tons) versus time. Pugh implemented the algorithms in the Family of Advanced Cost Estimating Tools (FACET) model produced by QinetiQ (http://www.qinetiq.com/home/products/facet_the_family.html).

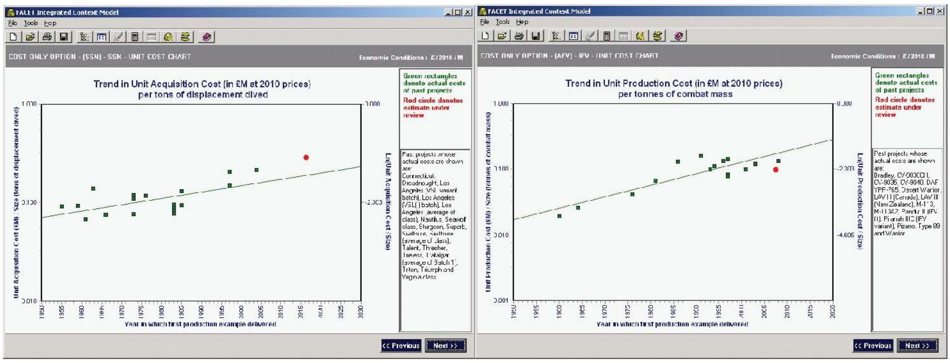

FIGURE 5 Unit production cost per weight versus time (Pugh, 2007) (color figure available online).

As Figure 5 shows, Pugh plots the historical data points on a log-linear graph. Although the trends appear to be linear, they are exponential curves due to the choice of axis format. The exponents in the two graphs are 0.024 and 0.045 indicating a shallow concave shape when converted back to arithmetic space from logarithmic.

In his publication, the true annual average cost growth has been published. But why is the whole weight used? It would seem logical that any cost growth would be limited to certain sub-systems, rather than the whole system. For example, in a destroyer, the significant weight is in the hull and super structure. Surely, this part of the ship, welded steel, has been the same for the last 50 or more years. If anything, the cost of this part of the system has been reduced due to modular construction and other manufacturing techniques.

The real cost growth has been in the radar, communication, propulsion, and navigation systems. Perhaps the focus should be on these rather than the cost density overall.

Multivariable Analysis over Time

The final HTA to be considered looks at multiple variables (Shermon, 2009). Before any cost estimating relationships (CERs) analyses are conducted, the historical project data is normalised, which is the dependent variable. This normalisation ensures that the costs have a single currency (US$), one economic condition (constant 2006), and a uniform point in production (theoretical first piece, namely T_1). The challenge is to find multiple independent variables that can be linked by CERs that will reproduce these T_1 US$ cost at 2006 constant economics that can be easily explained and justified.

The first independent variable considered is a weight hypothesis (see Figure 6); the more the system weighs the more it costs. But this leaves a random error term that can be represented as a residual.

If these residual figures are plotted against a time axis, representing the date when the systems went into service, it becomes apparent that there is a relationship over time (see Figure 7). The term "2006 ec" in the label of the vertical axis is a European term that stands for "2006 economic conditions," roughly translatable into American usage as "constant 2006 dollars."

This most likely represents the technology influence, isolated from the overall weight effect. Again, this is not a perfect statistical fit and leaves an error term that needs to be explained. Experience has shown that a performance variable will often explain this residual, for example service ceiling, maximum range, maximum velocity, payload, and so forth.

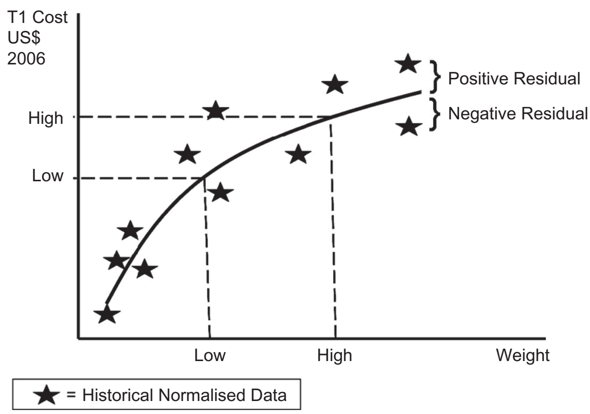

FIGURE 6 Cost versus weight.

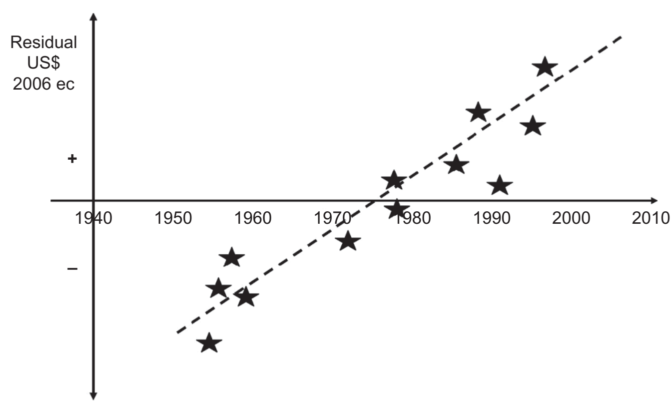

FIGURE 7 Residual cost versus time.

This technique of repeatedly eliminating the error term (or residual) is the explanation of forward stepwise regression. It is possible with this type of multi-variable regression to identify and justify the next significant independent variable, thus, progressively reducing the remaining residual.

Comparison

To determine the relative accuracy of these three approaches to HTA, a dataset was employed of more than 50 fighter aircraft. This dataset was started by Simon Meridew (1995) and more data has been added. See the appendix for the dataset containing the actuals and estimates of them. The approach was to normalise the cost and technical data. Cost data were normalised against:

- currency to bring all costs to US$ using a purchasing power parity (PPP) (Webb, 1990);
- economics to have all cost at 2006 base year; and
- quantity to reduce the cost to the theoretical first piece (T_1).

Then the data were run through the parametric model to conduct product calibration and produce the complexity (MCPLX).

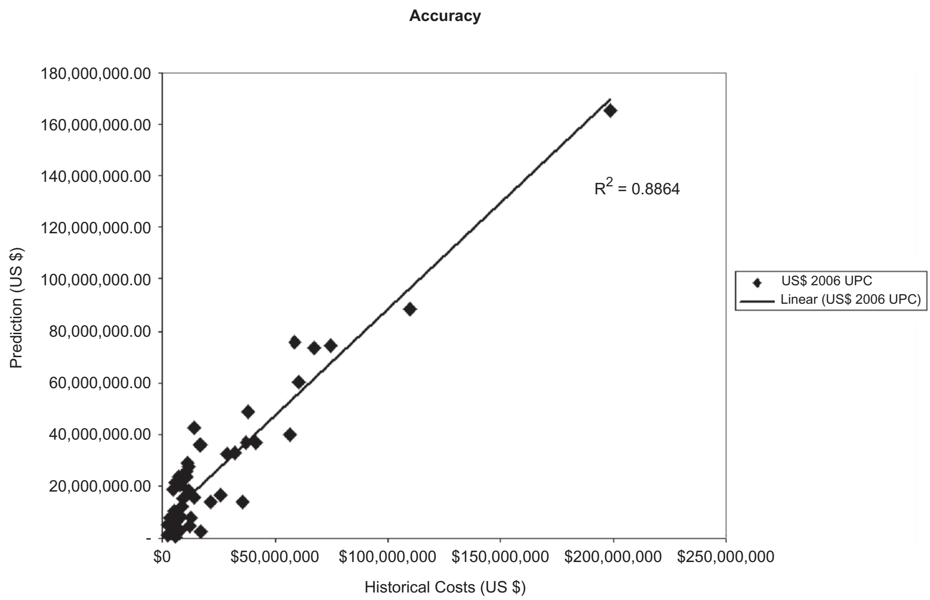

FIGURE 8 Historical cost versus predicted cost.

The technical data were also normalised for metric (kg) versus imperial (lbs) weight and other such anomalies.

After normalisation, the fighter aircraft data were subjected to the three trend analysis processes described earlier and the historical projects had their costs predicted based upon the trend. To assess the accuracy of these techniques, the predictions were plotted against the historical data and the coefficient of determination (R^2) for the graphs compared, as shown in Figure 8.

All three HTA techniques were assessed to determine the relative accuracy of the prediction. The results are recorded in the conclusion of this article.

Case Study

As an example of how these three techniques could be applied on a real project, a case study from 2003 (Shermon & Nicholls, 2003) has been updated on the F-35.

Table 1 has updated assumptions for the F-35 from public domain sources. These technical and programmatic details have been used in the three techniques to estimate the production cost of the F-35 aircraft.

TABLE 1 F-35 updated assumptions

Empty weight = 13,300 Kg
Length = 15.67 m
Height = 4.33 m
Wingspan = 10.7 m
Crew = 1
Total installed power (kw) = 11,472
Production quantity = 3,181
In-service date = 2012

Each of the three HTA techniques was applied to the assumptions and the results are recorded in the conclusions of this article.

Conclusions

The accuracy of the three techniques is captured in Table 2. The results would indicate that, judged according to comparative R^2 values, the complexity versus time approach is the most accurate methodology to forecast fighter aircraft systems.

This conclusion is probably due to the greater level of normalisation that is applied to the raw data within a parametric model. As discussed, there are a number of sub-models within a parametric model, such as technology maturity, schedule effects, quantity effects, and so forth, leading to increased normalisation. When the resulting complexity is used to predict the cost, these models are also applied to the cost estimate. Additional normalisation of the historical cost data has the effect of stripping away inconsistencies and reducing the cost data to a homogenous format.

It appears that all three methods are satisfactory, with even the least accurate method, production cost versus time, producing a coefficient of determination (R^2) that is acceptable statistically. The accuracy of an approach usually reflects the data that it requires. It follows that more information is needed for the complexity versus time approach both when normalising the data and estimating. If this estimating technique is to be applied at the early, pre-concept stages of a project, this need must be considered.

Table 3 displays the outcome of the F-35 study. The three methodologies were applied, and they resulted in estimates that have an average of \$137 M and a range of \$12 M (less than 10%) from highest to lowest at 2010 constant economic conditions.

A recent US Government Accountability Office (GAO) (2010) report updated the F-35 production cost to \$131 M in Then Year (out-turn) costs. As the majority of the program remains to be executed, this figure would be reduced if converted to constant 2010 economics. This would indicate that the GAO has still underestimated the potential cost, if the HTA approaches are to be believed.

Table 4 has an indication of the cost growth experienced by fighter aircraft. These results were determined by the prediction of the same F-35 assumption at an in-service date of 2002, ten years earlier, and determining the average annual percentage increase in cost between these dates. Both sets of cost are at constant 2010 economics, thus, this increase

TABLE 2 R^2 values of the historical trend analysis techniques

HTA	R^2 for fighter aircraft forecasting
Complexity versus time	91.15%
Production cost versus time	88.76%
Multi-variable versus time	90.58%

TABLE 3 F-35 unit production cost (UPC) using the three techniques

Case study—F-35	Cost in 2010 US\$ M
Complexity versus time	132 M
Production cost versus time	144 M
Multi-variable versus time	135 M

TABLE 4 Aircraft cost growth generated by the three techniques

Case study—F-35	Average annual increase (%)
Complexity versus time	4.6%
Production cost versus time	1.9%
Multi-variable versus time	2.1%

in production cost represents the influence of defence equipment cost growth beyond the effects of inflation.

Summary

Three different approaches to historical trend analysis (HTA) are viable. Their various merits have been discussed and analysed. There are examples outside of defence (e.g., commercial aircraft) of historical trends that are neutral or decreasing. This article speculates that this is caused by the rate of productivity reduction exceeding the level of technology growth.

All three HTA methodologies have a high degree of accuracy when applied to fighter aircraft. The results indicate that utilising a parametric model is the most complete approach to normalising raw cost data prior to extrapolation.

Specific conclusions drawn from the analysis are that: (1) updated assumptions for the Case Study predict the F-35 UPC to be in the range of \$132 M to \$144 M, and (2) cost growth for fighter aircraft is from 1.9 to 4.6% above inflation.

Planned Future Research

This initial study demonstrates the use of HTA methodology to estimate costs for one set of data. To learn more about cost growth in general, more systems (e.g., sea, land) need to be analysed. Funded research in this area would result in cost growth tables that could be applied to new program predictions and to avoid their unanticipated underfunding.

References

QinetiQ FACET (2010). QinetiQ Ltd. Retrieved from http://www.qinetiq.com/home/products/facet_the_family.html

Meridew, S. A. (1995). *Cost of defence systems database*. Created to support research into cost escalation at University College London.

PRICE H. Help System and User Manual. (2010). PRICE Systems Ltd. Retrieved from www.pricesystems.com

Pugh, P. G. (2007). *Source book of defence equipment costs*. ISBN: 978-0-9556258-0-0.

Shermon, D. (2002). Knowledge management in parametrics. *The Cost Engineer*, *40*(3), 12–13.

Shermon, D. (2009). *Systems cost engineering*. Gower Publishing. ISBN: 978-0-566-08861-2.

Shermon, D., & Nicholls, A. (2003). *If a little bit of knowledge is dangerous . . . what is a lot of knowledge?* Paper presented at ISPA/SCEA 2003 Conference, Orlando, Florida.

US Government Accountability Office. (2010). *Joint strike fighter*. GAO-10-478T.

UK Ministry of Defence (UK MOD). (2010a). *Adaptability and partnership: Issues for the strategic defence review*. ISBN 978-0-10-177942-5.

UK Ministry of Defence (UK MOD). (2010b). *The defence strategy for acquisition reform*. ISBN 978-0-10-177942-3.

Webb, D. (1990). *Cost complexity forecasting historical trends of major systems*. Varese, Italy: Organisation for Economic Co-operation and Development. Retrieved from www.oecd.org

About the Author

Dale Shermon, Principal Consultant at QinetiQ in Bristol, UK, is responsible for a section focused upon cost forecasting and analysis within the Business Analysis team. He joined QinetiQ in 2010 after 8 years at PRICE Systems. Mr. Shermon has presented technical papers to the USA Department of Defense Cost Analysis Symposium (DODCAS), European Aerospace Cost Engineering (EACE) working group, Space Systems Cost Analysis Group (SSCAG), and PRICE Symposia. He has published articles in *Project* (Association for Project Management—APM), *The Cost Engineer* (Association of Cost Engineers—ACostE), *Parametric World* (ISPA), and *Defence Management Journal* (UK Ministry of Defence—MOD), and served as editor of and major contributor to *Systems Cost Engineering* (Gower Publishing, 2009).

Mr. Shermon has taught parametric estimating to MOD analysts to enable them to gain ISPA Certified Parametric Practitioner (CPP) status. During his 24-year-long career, he supported major QinetiQ proposals with cost estimates, conducted cost analyses on major MOD project budgets and cost studies for industry, and presented training sessions in several aspects of cost analysis and related subjects in the UK, Italy, USA, Sweden, Australia, Singapore, Taiwan, and Germany.

Mr. Shermon was responsible for developing the “PRICE HL Questionnaire” within the PRICE Estimating Suite and the TruePlanning for Concepts methodology. Prior to his work at PRICE, he served as Senior Cost Forecaster within the Pricing and Forecasting Group of the Defence Procurement Agency of the MOD, heading a cell studying submarine platform Whole Life Cycle costs and performing high-level studies covering all of the armed services. In addition, Mr. Shermon held estimating positions in various defence and aerospace companies, including Matra Marconi Space, British Aerospace (Space Systems) Ltd., British Aerospace (Dynamics) Ltd., and Rolls-Royce Ltd. Military Engine Group.

A Life Member of ISPA, Mr. Shermon regularly presents technical papers and training sessions at annual ISPA conferences and received “best track paper” awards for two of his papers. In 2009, he became the first European to receive ISPA’s Frank Freiman Award for lifetime contributions to parametric estimating and in 2003 he became the first European to earn ISPA’s CPP status. In addition to his ISPA affiliation, Mr. Shermon is associated with ACostE, APM, and the Society for Cost Analysts and Forecasting (SCAF). He earned his Bachelor of Arts degree from the Open University and Certified Diploma in Accounting and Finance from the Association of Chartered Certified Accountants (ACCA).

Appendix

Military Aircraft Costs and Cost Estimates
Normalised T1, US$, Constant 2006ec

Aircraft Program	Historical Costs (Actuals)	Estimates Based on UPC per kg	Estimates Based on Multivariable	Estimates Based on Complexity
A	2,107,280	992,687	6,017,229	2,758,962
B	8,274,583	8,368,175	6,839,349	4,041,000
C	16,644,248	2,424,755	−2,292,530	6,239,720
D	21,792,987	14,282,764	10,635,675	9,810,039
E	4,169,405	2,076,174	3,167,464	2,208,426
F	7,638,892	3,243,585	1,008,792	4,217,797

(*Continued*)

Appendix (Continued)

Aircraft Program	Historical Costs (Actuals)	Estimates Based on UPC per kg	Estimates Based on Multivariable	Estimates Based on Complexity
G	4,753,267	3,243,585	1,008,792	3,553,032
H	12,824,307	8,027,014	6,543,850	4,840,440
I	4,864,168	6,082,448	4,748,012	3,552,507
J	3,380,373	4,559,360	6,537,757	5,073,012
K	12,178,049	4,559,360	6,537,757	3,967,712
L	2,356,017	5,088,977	7,276,542	4,313,947
M	4,955,615	4,883,590	6,982,970	7,145,468
N	3,633,188	4,883,590	5,900,693	5,650,656
O	5,224,213	10,378,939	11,238,564	13,008,403
P	4,478,427	5,810,147	7,121,110	9,797,006
Q	13,883,754	15,670,775	15,154,523	6,577,972
R	8,904,847	12,322,964	8,054,316	10,294,146
S	35,650,669	14,153,879	11,395,601	6,931,269
T	11,874,661	18,214,282	12,866,519	16,378,018
U	31,991,489	33,068,504	42,626,691	27,544,352
V	4,920,591	18,636,606	17,342,066	16,612,126
W	10,464,384	23,550,924	20,777,903	8,557,689
X	3,644,244	7,762,191	10,665,654	3,465,055
Y	5,368,625	7,832,450	10,721,931	5,344,249
Z	5,703,969	21,754,263	17,529,220	19,114,897
AA	10,279,884	25,636,810	23,525,337	9,546,871
BB	6,750,012	23,524,254	19,860,571	18,243,969
CC	11,605,790	27,722,696	26,272,770	9,492,541
DD	16,081,822	36,071,954	36,271,007	15,370,565
EE	7,543,997	20,510,866	22,971,720	7,400,431
FF	10,786,167	28,839,075	26,861,010	24,639,720
GG	16,961,559	36,071,954	36,271,007	27,284,119
HH	13,896,217	42,335,327	44,520,835	16,704,011
II	9,416,649	14,968,563	18,959,683	9,570,689
JJ	25,423,896	17,049,427	21,725,750	22,141,255
KK	28,462,717	32,422,694	34,323,886	13,842,203
LL	60,411,564	60,458,714	70,369,701	44,921,360
MM	37,976,559	48,719,770	45,523,682	19,100,156
NN	58,465,497	75,701,680	81,063,020	54,600,852
OO	41,374,213	36,735,433	40,462,504	32,247,691
PP	37,173,145	36,735,433	40,462,504	39,904,341
QQ	67,389,633	73,230,136	88,010,265	63,943,198
RR	56,446,085	40,029,497	47,374,439	49,984,608
SS	74,279,379	74,541,666	94,563,519	96,473,789
TT	109,669,523	88,929,878	101,453,607	118,850,272
UU	198,992,889	165,247,676	194,168,745	161,662,336
	R^2 =	88.76%	90.58%	91.15%
	Standard Error =	10,170,532	10,982,240	9,488,152