Institution: 10007822

Unit of Assessment: 12

Title of case study: Controlling uncertainty with cost engineering tools

1. Summary of the impact (indicative maximum 100 words)

Substantial savings have been made using Cranfield's Cost Engineering software tools and techniques. These are used in BAE Systems, Airbus, Rolls-Royce, GE Aviation, Ford Motor Company and increasingly in the UK defence industry through the MoD. DTZ (Debenham Tie Leung Ltd) estimates £213 million per annum financial benefit for BAE Systems and MoD alone, with an additional £200 million per annum for other companies.

Cranfield's team has significantly influenced the national and international policy of The Association of Cost Engineers and manufacturing companies in methods and procedures. Cranfield has trained over 700 engineers from over 50 companies in cost engineering based on our research.

2. Underpinning research (indicative maximum 500 words)

Cranfield University started research on cost engineering to understand the extant basis of cost prediction in the design, manufacture and service of components and industry's understanding of affordability, in the late 1990s. The goal was to understand the science and engineering behind current industrial practice so that cost engineering could become more scientific and systematic in the future. Our studies established the best practice in true cost prediction, and have developed software tools and training, which have improved the competitiveness of UK manufacturing companies. We studied how cost engineers think, and modelled the cognitive processes behind the engineering judgement necessary for the cost prediction [G1, 3, P1]. The study involved analysing the reasoning process followed during cost estimating by both experts and novices. Research into this cognitive process became the foundation for our cost engineering training, which has been developed for industry since 2003.

The Cranfield team progressed to research best practice in predicting the cost of new technologies, based on analogy, in collaboration with the automotive industry [P2]. Then the team focused on predicting cost of design, manufacturing and assembly at the conceptual design stage for complex engineering systems, e.g. for aircraft wings and hydraulic systems. The scope of this prediction covered the design effort, including both the thinking time and the Computer Aided Design model development time, based on the complexity of the product [G2-4, P3]. The research included both mechanical and electronic components design and testing. Novel techniques (e.g. function based cost estimating for automotive components) were developed which can predict more realistic cost at the conceptual design stage, in the absence of data of good quality and quantity [P4].

Our research focused on predicting the cost of in-service issues, especially within performance based contracts. The key challenges addressed in the research are:

- predicting the cost of the resolution of component and material obsolescence, based on a probabilistic approach [G5, P5];
- modelling service uncertainty within the cost estimates using an analogy based approach [G5, P6].

The probabilistic cost estimation approach identified the relationships between component complexity and obsolescence resolution profile. We identified that the cost efficiency achieved by

organisations in relation to obsolescence correlates with how proactive they are in managing the problem. Understanding of this has informed the design of new tools for predicting the non-recurring engineering effort/cost for obsolescence resolution [P5].

The analogy and uncertainty based cost estimating technique identifies the new challenges related to availability contracts, and enables a systematic approach that reflects the impact of uncertainties on the cost drivers [P6]. The research identifies a cost distribution for the service provision using a stochastic simulation. The research also allows us to understand the enduring cost profile across a product/system/service life cycle and is fundamental to improving UK capability in cost modelling for large and complex projects in industry and the public sector.

Key Researchers	Post details*	Dates involved	Research
Dr. P Baguley	Research Fellow	2006 – to date	Artificial intelligence application for cost estimation, parametric cost estimating
Dr. Y Xu	Lecturer	2008 – to date	Design for cost, detailed cost estimation
Dr. E Shehab	Reader	2004 – to date	Cost of obsolescence, Cost of information preservation
Dr. C Wainwright	Senior Lecturer	2001 – 2008	Parametric cost estimation, CADCO project
Prof R Roy	Professor	1997 – to date	All the above, plus uncertainty- and analogy-based service and qualitative cost estimation

* highest grade in period given

3. References to the research (indicative maximum of six references)

Evidence of quality – peer-reviewed journal papers

P1* Rush, C and Roy, R, "Expert judgement in cost estimating: modelling the reasoning process", *Concurrent Engineering: Research and Applications (CERA)*, **9**, (4), pp. 271-284, 2001. DOI: 10.1177/1063293X0100900404.

P2 Roy, R., Colmer, S.[a] and Griggs, T.[a], "Estimating cost of a new technology intensive product: a case study approach", *International Journal of Production Economics*, **97**, pp. 210-226, 2005. DOI: http://dx.doi.org/10.1016/j.ijpe.2004.08.003.

P3 Oduguwa, P., Roy, R. and Sackett, P. J., "Cost impact analysis of requirement changes in the automotive industry: a case study", *Journal of Engineering Manufacture, Part B*, **220**, Number B9, pp. 1509-25, 2006. DOI: 10.1243/09544054JEM275.

P4* Roy, R., Souchoroukov, P. and Griggs, T.[a], "Function-based cost estimating", *International Journal of Production Research*, **46**, (10), pp. 2621-50, 2008. DOI: 10.1080/00207540601094440.

P5* Romero, Rojo F.J., Roy, R., Shehab, E., Cheruvu, K. and Mason, P.[b], "A cost estimating framework for electronic, electrical and electromechanical (EEE) components obsolescence within the use oriented product-service systems contracts", *Journal of Engineering Manufacture, Part B*, **226**, (1), pp. 154-166, 2012. DOI:10.1177/0954405411406774.

P6 Erkoyuncu, J. A., Durugbo, C., Shehab, E., Roy, R., Parker[b], R., Gath, A.[b] and Howell, D.[c], "Uncertainty driven service cost estimation for decision support at the bidding stage", *International Journal of Production Research*, **51**, pp. 5771-5788, 2013. DOI: 10.1080/00207543.2013.794318.

* 3 identified references that best indicate the quality of the research.

Key
[a] Ford Motor Company, UK [b] BAE Systems, UK [c] GE Aviation, UK

Further evidence of quality – underpinning research grants

G1 EPSRC (GR/N21321). Developing an Integrated Costing Approach for Conceptual Design Evaluation (ICOST), £275,000 (total: £575,000 including cash and kind contribution from industry partners), 2000-2003, PI Roy. Partners: BAe, MA&A, Ford and XR Associates..

G2 Cranfield IMRC (EPSRC) sub project. Integrated Requirements Management for Digital Product Development (e-RM), £317,000 (total: £907,000 including contribution from industry partners), 2002-2005. Industry Partners: Nissan Technology Centre Europe, JCA, EDS and SMMT. PI Roy.

G3 Cranfield IMRC (EPSRC) sub project + Four TSB/KTP with Airbus. Formalisation of Expert Judgement in Cost Engineering and Integration (CostExpert), £621,700 (total: £1,205,000 including cash and kind contribution from industry), 2002-2006, PI Roy (CI on the KTPs) and CI Wainwright (PI on the KTPs). Industry Partners: Airbus UK, Galorath UK and Smiths Group.

G4 EU FP6 SSA, Virtual Cost Engineering Studio, £304,500, 2004-2006, PI Roy. Partners: Centro Ricerche FIAT, PRICE Systems, DAS and IZET.

G5 Cranfield IMRC (EPSRC) sub project: Whole Life Cost Modelling for Product-Service Systems (PSS-Cost), £380,000 (total: £630,000 including cash and kind contribution from industry partners), 2007-2010. Industry partners: BAE Systems, GE Aviation, Lockheed Martin (Insys), MoD, Rolls Royce, Galorath, APMP, SBAC. PI Roy and CI Shehab.

4. Details of the impact (indicative maximum 750 words)

Cranfield developed a best practice process and software tool to predict the obsolescence resolution cost for electronic components and materials (figure 1). The tool helps to reduce the UK defence costs in two ways:

- the contingency sums that defence contractors would have incorporated into availability contracts to resolve obsolescence issues will be lower because the tool enables the costs to be predicted with greater accuracy and confidence
- defence contractors will have a greater incentive to design equipment with a view to minimising obsolescence issues.

A DTZ estimate shows £213 million per annum financial benefit for the sectors (BAE Systems and MoD only) [C1, 2]. Cranfield's software tool is disseminated to other defence companies by MoD through a support contract [C3].

The research in cost engineering helped BAE Systems and MoD systematically to identify uncertainties in cost estimation, and the tool developed is used within BAE Systems to prepare bids [C4]. The research has also significantly influenced the national and international policy of the Association of Cost Engineers (ACostE), and promoted the need for a scientific approach to cost engineering in industry and government organisations [C5]. In addition, the Cranfield team developed cost models that were used within Airbus as part of the "CADCO" project toolbox to evaluate

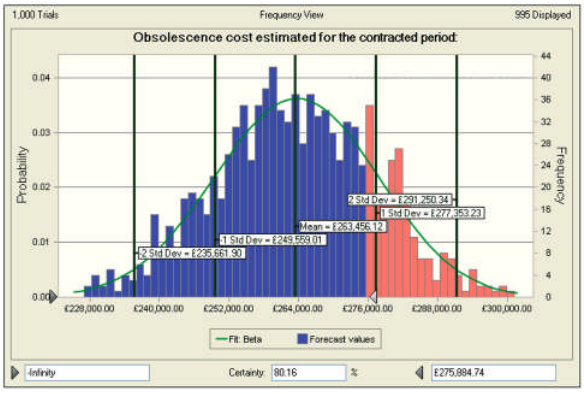

Figure 1: Predicted cost of obsolescence resolution with uncertainties

conceptual designs of new aircrafts [C6]. This enables Airbus to understand better the costs in the early phases of new projects, with calculated uncertainty. The team helped Airbus to implement the CADCO tool set across Europe and provided extensive training.

Cost Engineering at Cranfield has developed novel approaches and tools to predict the true whole life cost of complex engineering systems [C7, C8]. Cranfield has provided cost engineering training for over 12 years and has trained over 700 engineers in over 50 companies with an indicative financial impact of £12 million per annum. Cranfield's effort in improving the cost engineering practice across defence, aerospace, automotive, railway, oil and gas companies has resulted in more recognition of cost as a design driver and has helped in improving the competitiveness. The indicative financial benefit from cost engineering software developed at Cranfield (figure 1) is over £400 million per annum [C2], and the UK MoD is disseminating the software to more companies such that and the financial impact will be further increased significantly.

To estimate savings, we consider that the UK civil aerospace sector alone has revenue of £12 billion per annum [C9]. The training delivered by the Cranfield team is estimated to help British aerospace companies to gain at least an additional 0.01% of this market, which is an additional £12 million per annum new business.

Cranfield developed cost engineering training and education programmes, based on this research, with BAE Systems, Airbus, Ford Motor Company, Rolls-Royce, Bombardier Transportation and the Ministry of Defence (MoD) since 2001 [G1]. The initial training programme at BAE Systems focused on bridging the gap between the technical/ engineering functions and finance. The training improved the communication between the two groups and therefore improved the cost estimating practice and policy, encouraging the company to establish "cost engineering" as a distinct function. Once the cognitive model for the cost engineers was captured, the team developed detailed cost engineering training for the automotive industry with Ford Motor Company and for the MoD in 2003, which is used to reduce the learning curve of the novice. The training also included a 'cost awareness development programme' across Airbus (within Europe) and BAE Systems. The training supported design engineers, manufacturing engineers and procurement team members to improve their cost awareness. Since 2006, the Cranfield team has delivered an online cost engineering course on 'Principles of Cost Engineering'. UK and international manufacturing (aerospace, automotive, railway, oil and gas) and defence companies use the course regularly. The face-to-face and online training courses have supported companies like Airbus, Rolls-Royce, and BAE Systems to become more competitive and manage their costs better, [C3,4,5,6].

5. Sources to corroborate the impact (indicative maximum of 10 references)

C1 Contact: Consultant Engineer, Ex BAE Systems, now AIG Synergies Limited.
C2 Contact: Consultant, DTZ.
C3 Contact: Obsolescence Management Lead, MoD.
C4 Contact: ILS Manager, BAE Systems.
C5 Contact: President of the Association of Cost Engineers
C6 Contact: Systems Engineer, Airbus.
C7 Services to Estimating Award from Industry. 2008. URL: http://www.galorath.com/index.php/news/ukconference2008 (last accessed November 2013)
C8 Contact: Vice President – Europe and RoW, PRICE Systems Ltd.
C9 KPMG report on the future of UK civil aerospace industry. 2013. URL: https://www.adsgroup.org.uk/articles/35553 (last accessed November 2013)