16

An Agile Cost Estimating Methodology for Aerospace Procurement Operations: Genetic Causal Cost CENTRE-ing

R. Curran[1], P. Watson[2] and S. Cowan[3]
[1]*Air Transport and Operations,*
Delft University of Technology, Kluyverweg 1, Delft,
[2]*Queens University Belfast*
[3]*Procurement and Logistics, Bombardier Aerospace Belfast*
[1]*The Netherlands*
[2,3]*UK*

1. Introduction

In an effort to be more competitive, aerospace companies have to embrace a more integrated and concurrent approach to their operational processes. The aim is to meet the key requirements of being more cost effective, lean and agile while delivering consistently high quality performance in their operational practices. This requirement is further set against the backdrop of changeable global events, fluctuating markets, and technological progress in both the commercial and military spheres. Therefore, cost engineering issues are becoming increasingly dominant in Product Lifecycle Management (PLM) and as a consequence, the role of procurement is recognized as evermore influential due to its impact on acquisition cost.

In an effort to address some of the above challenges through practical means, the research presented investigates the development of a methodology and associated tooling for the estimating of supply chain cost management (Pugh et al, 2010a; Pugh et al, 2010b). The main aim is to provide an agile approach to cost estimating that can draw on the in-house engineering experience of an aerospace company, their procurement knowledge, product specification and their knowledge of the procurement market. This is integrated into a methodology that is generic and can therefore assimilate whatever information and relevant knowledge is available in a manner that can be utilized in an agile manner, i.e. dealing with large amounts of historic information in order to provide a agile estimating capability that is based on all of the information (past, present and projected) relating to the acquisition of new supply, parts, and assemblies. The following presents the methodology developed and a number of large case studies undertaken with Bombardier Aerospace Belfast to validate the accuracy and relevancy of the derived tools.

2. Aerospace procurement context

The importance of the procurement function is highlighted by the fact that it is common today for aerospace Original Equipment Manufacturers (OEM) to externally procure as much as 80% of their programmes externally [Flemming, (2003); Dubois, (2003)]]. Momme

(2002) even states that in general any typical industrial company spends 50-85% of its turnover on purchased goods, including raw materials, components and semi-manufactures. This continues to be an increasing trend whereby industrial firms exploit outsourcing for those products and activities deemed to be; (1) performed better by other organizations therefore offering value improvement opportunities or (2) outside the company's core business [Dulmin, (2003)]. Yoon & Naadimuthu (1994) state that the strategic decision to 'make or buy' can often be the major determinant of profitability, making a significant contribution to the financial health of a company.

A recent report from AT Kearney (2004) states that industrial leaders are creating value and gaining competitive advantage through the use of supply markets by focusing on four key areas: 1) Innovation and growth; 2) Value Chain Optimization; 3) Advanced cost-management; (4) Risk management and supply continuity. From the areas offering opportunity for value creation, the wider focus of this current research is that of facilitating improved cost-management for sourcing applications given the 'practical-industrial' constraint of not always having the required degree of cost and financial breakdown data desired (Curran, 2010; Curran et al, 2010c). It is clear that the enhanced significance of the supply chain has made procurement a strategic function [Dubois (2003)] and cost management (Pugh et al, 2010a; Pugh et al, 2010b) and assessment a critical activity for aerospace companies [Ellram, (1996)]. Monozka and Morgan (2002) proposes that increased attention to cost management is a critical factor to the operational control and sustained improvement of the procurement function as it provides a quantifiable basis upon which to assess related activities. Fleming (2003) states that the objective when sourcing is to; "negotiate a contract type and price (or estimated cost and fee) that will result in reasonable contractor risk and provide the contractor with the greatest incentive for efficient and economical performance". The term 'cost' from the AICPA Inventory [Humphreys (1991)] is; "the amount, measured in money or cash expended, property transferred, capital stock issued, services performed, or liability incurred, in consideration of goods or services received". Cost and price are often used interchangeably as parts can be made internally or be externally sourced from the extended supply chain, as shown in Figure 1 [Chen, (2004]; consisting of the internal and external supply chains as depicted. In this sense, the price of the external supplier is equivalent to the cost of internal production, being integrated into some product that is delivered to a customer.

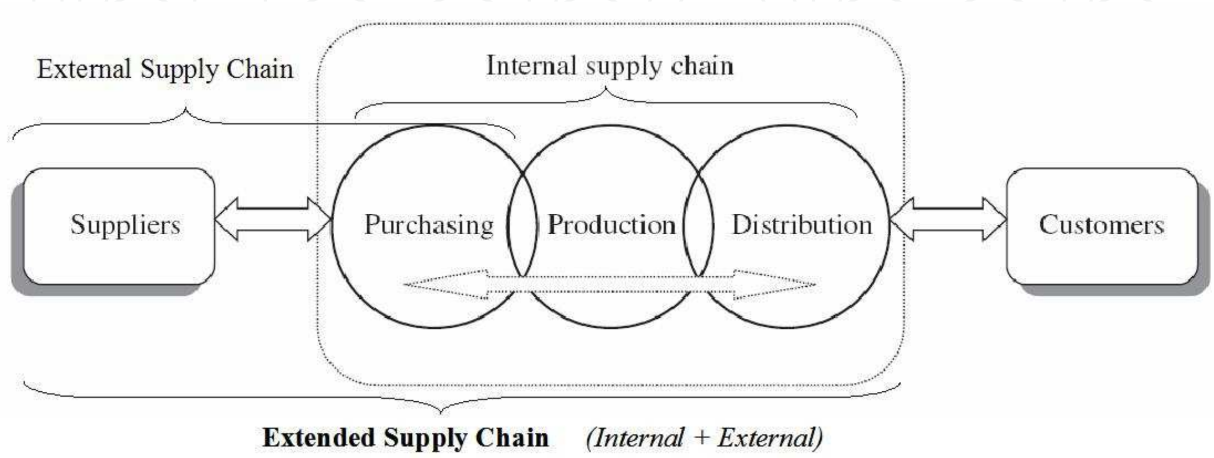


Fig. 1. Elements of extended supply chain (Adapted from Chen, 2004)

Parts that are externally sourced from world-class suppliers operating within a competitive market place often do not exhibit such a discrepancy between the actual manufacturing cost and supplier's selling price; the latter including a fair and reasonable mark-up, as illustrated by Scanlan (2004) in Figure 2. When however orders are placed with suppliers who operate towards the left hand side shown in the Figure for low-efficiency and an uncompetitive market, then a potentially excessive mark-up is likely. It is in the interest of the buyer to understand actual manufacturing cost as well as to have to the ability to assess the quality of potential suppliers before entering into business with them.

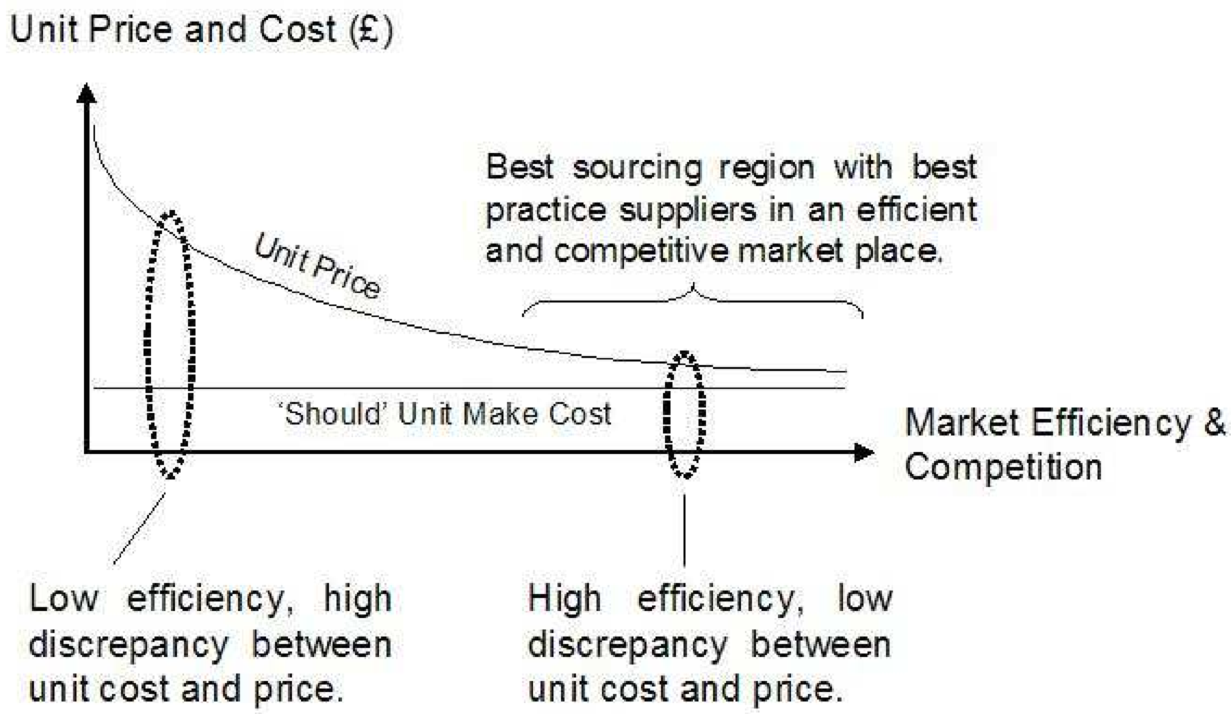


Fig. 2. Cost and price relationship with market efficiency (effects of volume removed), [Scanlan, (2004)].

Figure 3 highlights that unit price is influenced by a number of issues such as; (1) procurement strategy and requirements, (2) the technical requirements which directly influence manufacturing cost, (3) the actual cost basis on which the company operates, and (4) the external forces that determine an acceptable market price. All this is required to actively interface in the activity of negotiation: aimed at identifying mutually satisfactory terms for contract specification and price determination with potential suppliers. Specialist parts for which a buyer is dependent and has little internal knowledge of in terms of design and manufacture tend to result in supplier leverage and a potentially significant difference between cost and price. For standard parts a small difference between unit cost and price is expected. Understanding the costs involved in the production of a part with other specified requirements enables a procurement buyer to physically negotiate and determine price and contract particulars with potential suppliers; based upon a platform of informed judgment.

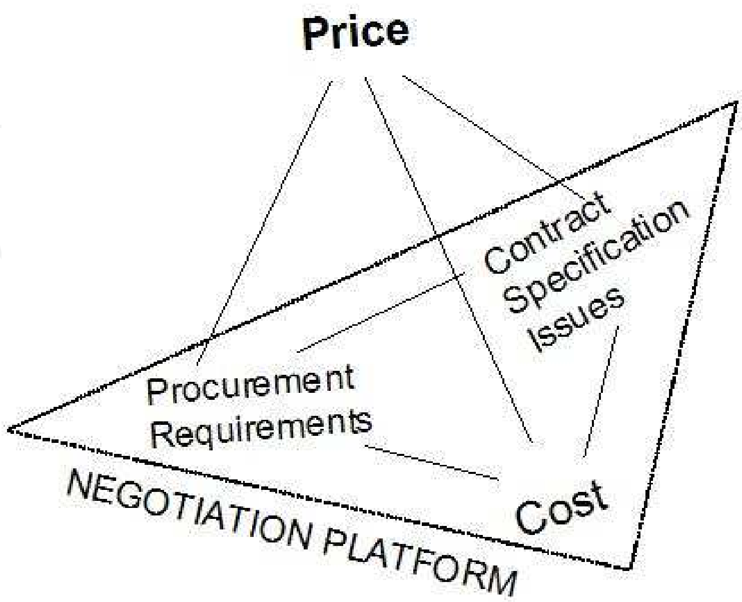


Fig. 3. Underlying components of Unit Price

3. State-of-the-art: Procurement cost analysis

Procurement transactions that occur between companies (buyer to supplier) are characterized by adding value up through the chain and consequent payments down the chain. The procurement function tends to be characterized as exploiting the supply chain in order to develop opportunities for increased profitability. It has been noted by [Hicks, (2000)] that this is envisaged through manipulation of the areas that directly effect asset and resource utilization, as well as profit margins, including: production decisions, outsourcing verses in-house management, supplier relationship type sought, and inventory turnover. The best practice principles that are identified as procedurally correct need to be supported by facilitating tools that provide quantitative measures of cost, time, risk, quality, etc. In particular cost modeling tools can easily be related to the following procurement needs as described in the literature [Fitzgerald, (2002); Handfield, (2002)]:

- Eliciting support from top management,
- Understanding cost drivers in appropriate detail,
- Make / buy opportunity analysis for improved value identification,
- Integrating and modeling the supply chain,
- Developing cooperative supplier relations,
- Measuring the performance of suppliers, systems, and employees,
- Delivering and establishing a culture of continuous improvement,
- Facilitating a cross-functional approach linked through cost,
- Managing and reducing costs across the whole operational structure,
- Developing integrated data management systems and;
- Justifying investment in procurement/supply tooling and management.

The challenge with developing supporting technologies is that of making them as widely applicable as possible and thus providing scope for system integration and cross-functional knowledge extraction. An important factor to consider when discussing best practices in procurement however is that no two companies are exactly alike, and as a result there is no simple generic approach to best practice policy [Handflield, (2002)]. Best practices often depend on people, suppliers, processes, or other operational elements that are specific to a certain situation [Handfield (2002), Fitzgerald (2002). Specifically considering cost analysis; Ellram (1996) states; "there are many cost management tools and techniques and they continue to proliferate. Thus, it is difficult to determine which type of analysis should be used in a given situation, and time pressure may inhibit the purchaser selecting the right tool". Consequently, it is proposed that a methodology be developed to help procurement operators determine what kind of cost assessment technique should be applied to given purchase situations by exploring the following issues:

- How should purchased items be classified into a framework, so that standard procedures can be developed for the analysis of items that fit into certain classifications?
- What cost analysis techniques best support each classification in the framework?
- What cost analysis techniques are more strategic in nature, and can really help purchasing add value to the organization?

The Genetic Causal Approach to cost modelling (Curran et al, 2004) adapted in the presented work addresses these issues directly through the classification into 'genetic part categories' implied in Questions 1 & 2, and through the use of causal models to address Questions 2 & 3.

Probert (1996) recommended the use of sophisticated techniques which offer greater accuracy to those classes of parts that are deemed to be of 'high-importance' and conversely simpler techniques to parts which belong to groups that are thought to be of lesser importance. Fleming noted that purchases may be: (1) big and others small in terms of both quantity and value, (2) some complex whilst others routine, (3) some high risk and others with perhaps no attached risk at all, (4) some requiring a lengthy contract whilst others needing only a short time commitment between the buyer and seller. As procurement needs are different for different purchases, many researchers [Flemming, (2003); Probert, (1996); Ellram, (1996)] recommend categorizing procurements into broad but distinct families before conducting any cost analysis. The old adage of 'not putting all one's eggs in the same basket is known as portfolio theory, which dates back to financial investment analysis in the 1950s [Markowitz, (1952); Olsen, (1997); Kulmala, (2004)]. This in fact can help management to focus more thoroughly on problems or issues specific to each category of procured part [Flemming, (2003)]. Following from this it is thought that optimal analysis approaches may then be identified for application to each particular grouping [Ellram, 1996]. In a similar fashion to that of Flemming (2003) it is acknowledged that before purchasers can choose the right analysis tool for a particular situation, they must understand the nature of the buy (which considers: scale, complexity, duration, contract type, dependency/risk, etc.) and the type of the supplier relationship sought. Ellram (2002) recognizes that this can range potentially from a loose agreement to a strategic alliance which importantly affects the availability of data as well as how much time or additional resources the organization is perhaps willing to devote to both supplier and cost analysis.

Classifying Suppliers / Purchases for Cost Analysis

Nature of Buy		Arm's-length	Strategic Alliance
	Ongoing	**Leverage** Items purchased in large quantity that are made to stock with many available sources Items available on commodity exchanges	**Strategic** Items important to distinctive competency Items important to the future success of organisation
	One-time	**Low Impact** Most specialised Low price, repetitive buys	**Critical Projects** Critical project Long-term capital investments

Type of Relationship Sought With Supplier

Fig. 4. Classifying Suppliers / Purchases for Cost Analysis, [Ellram, (1996)].

Figure 4 provides a matrix of buying situations consisting of varying; types of buy and types of supplier relationship sought. Purchases are classified as *low impact, leverage, strategic and critical,* in terms of their cost and impact on the organization and relationship potential. Ellram (1996) acknowledges that, the type of cost analysis techniques used should support the relative importance of the item being purchased, as well as the type of supplier relationship that the organization currently has or desires. Following from Figure 4, Figure 5 highlights potential cost analysis techniques to be used in each of the buying-type situations identified.

Cost Analysis Techniques

Nature of Buy		Arm's-length	Strategic Alliance
	Ongoing or Major Impact	**Leverage** **'Cost Analysis Focus'** Estimate cost relationships Value Analysis Analysis of supplier cost breakdowns Cost estimate / 'should cost' Industry analysis Total cost modeling	**Strategic** **'Continuous Improvement Focus'** Open books Target Cost Analysis Competitive Assessment / teardowns Total cost modeling of the supply chain
	One-time or Limited Impact	**Low Impact** **'Price Analysis Focus'** Competitive bids Comparison price list / catalogues Comparison to established market Price Indexes Comparison to similar purchases	**Critical Projects** **'Life Cycle Cost Focus'** Total cost modeling and life-cycle costing

Type of Relationship Sought With Supplier

Fig. 5. Cost Analysis Techniques applicable for various types of supplier relationship and types of buy situations, [Ellram, (1996)].

Figure 5 implies that relatively simple analysis techniques are recommended for low impact purchases which focus primarily on *analyzing price*, where competitive bidding is viewed as the most common basic method of analysis. Moving from *low-impact* to *leverage items* it can be seen that greater attention is given to the analysis of *cost* rather than *price* in supplier cost breakdowns. Price analysis is simpler and faster than cost analysis. The simpler price analysis may be satisfactory for *low-impact* items however cost component understanding is desirable for *high-impact* parts. Even though cost analysis requires more processing time to practically employ; it generates a greater breakdown of cost information over that of price analysis and is therefore better able to support informed 'fair-price' negotiation. The technique involving the use of cost estimating relations is similar to that of the price analysis approach [Ellram, (1996)] of comparing similar purchases at price or sub-component cost levels. 'Should-costs' estimates involve attempting to independently construct the current or potential suppliers' product cost structure. Value analysis is a methodology which compares the function of an item or the service it performs to cost, in an attempt to find the best value alternative (Curran et al, 2006; Curran et al, 2010a, Curran, 2010; Curran et al, 2010c) and identify which quality or features that are causing cost but are not required or at least less desirable. Ultimately, total cost modeling or life cycle cost analysis (Curran et al 2003; Curran et al, 2007a; Curran et al, 2007b); goes beyond the focus upon suppliers' cost structures and looks specifically at; "the cost of doing business with a particular supplier for a particular item over the life of that item" [Ellram, (1996)].
The Society of Cost Estimating and Analysis (SCEA) state that cost estimating is: "the art of approximating the probable worth or cost of an activity based on information available at the time" [ISPA (1999)]. The main function of cost estimation is the provision of independent, objective, accurate and reliable capital and cost operating assessments that can be used for investment funding and project control decisions. In particular, accurate cost estimation is important for cost control, successful bidding for jobs and maintaining a competitive position within the marketplace [Ben-Arieh, (2000)]. There are two main approaches towards cost estimation: cost estimation based on past experience variant [Curran, (2004)] and generative cost estimation [Weustink, (2000)]. We can refer to *generative* or *compilational costing* as an approach which seeks to aggregate the various constituent cost elements identified for a given exercise whereas in variant or relational costing, comparative relation of product defining parameters is adopted in order to target/interpret causal reasons for cost differences between similar items, as highlighted in the Genetic Causal Approach Curran (2004). According to Humphreys (1991), variant (analogy) estimating involves identifying a similar part cost and then using this actual cost as a basis for the estimate of the new part. Generative estimating methods can be further divided into explicit (rule-based) cost estimating, Rough-Order-Magnitude (ROM) estimating, parametric and feature based cost estimating as well as detailed estimating potentially using Activity Based Costing (ABC) [La Londe, 1999], all of which are often based upon past experience. ROM or ratio estimating is a factor based technique which is used to arrive at a preliminary cost estimate inexpensively and quickly [Humphreys (1991)]. It is based upon the application of a ratio determined factor, from a previous contract, to a particular variable in order to calculate the value of a second. Parametric estimating is a technique that uses validated Cost Estimating Relationships (CERs) to estimate cost. Parametric cost models [Collopy, 2001] statistically estimate part cost based on the correlation between historical cost data and part properties which are considered

to be related to cost. Parametric models can use a small number of independent variables or in the case of feature based modeling, which is more generative in nature; any number of variables can be used to adequately describe the required detail present in an item. As discussed earlier, Activity Based Costing [La Londe, (1999); Mileham, (1993); Esawi, (2003)] is an accounting practice which specifically aims to identify the activities of an organization and the associated cost of each, using which activity costs are then allocated to cost objects.

Approaches involving the use of Knowledge Based Engineering [Curran et al 2010b; Verhagen et al 2011], artificial intelligence such as fuzzy logic and neural nets [Rush and Roy, (2000); Villareal et al, (1992)] are rapidly developing which mimic the human thought process. Using neural nets for costing involves the training of a computer programme given product-related attributes to cost. A number of researchers are investigating the use of neural nets for cost estimating purposes [Smith and Mason, (1997); Bode, (1998); Cavalieri, (2004); Idri, (2002); Wang, (2005)]. A neural net [Rush and Roy, (2000)] learns which product attributes most influence the associated cost and then approximates the functional relationship between the attribute values and cost during the training. Consequently, when supplied with product attributes describing new parts, the neural net selects the appropriate relationship function and generates the required cost estimate. Neural networks are entirely data driven models which through training iteratively transition from a random state to a final model. Brinke (2002) identifies that both neural nets and regression analysis can be used to determine cost functions based on parametric analysis; whereby parametric analysis is becoming an increasingly employed tool in industry for cost estimating purposes, e.g. SEER software. Both techniques use statistical curve fitting procedures however neural nets do not depend on assumptions about functional form, probability distribution or smoothness and have been proven to universal 'approximators' [Funahashi, (1989); Hornik, (1989)].

The advantages and disadvantages associated with regression analysis and neural nets have been identified by Bode (1998). Brinke (2002) states that when the cost parameters are known and the type of function is unknown or cannot be logically argued then neural networks are suitable to deduce cost functions, however that it is easier to quantify the quality of a result from regression analysis. Bode (1998) demonstrated that neural networks can produce better cost predictions than conventional regression costing methods if a number of conditions are adhered to. Smith and Mason (1997) indicate that in instances where an appropriate CER can be identified, regression models have significant advantages in terms of accuracy, variability, model creation and model examination. Considering the use of such techniques for cost estimating it is desirable that causal relationships are known between cost driving independent variables and cost. This subsequently strengthens one's case when attempting to enforce a cost reduction with a current supplier based upon non-disputable causal logic. Neural nets can sometimes be used to generate more accurate results than those from the use of regression however the challenge associated with the further diffusion and wider implementation of this methodology according to Cavalieri (2004) is that of making the approach more transparent to the analyst and developing tools which reproduce in a comprehensible, easy to use fashion the behaviour of the network. Finally with respect to fuzzy logic, a fuzzy expert system is one that uses a collection of fuzzy membership functions and rules to deal quantitatively with imprecision and uncertainty, and researchers [Gerla, (2001); Kishk, (1999); Ting, (1999); Klir, (1996); Mamdani, (1981)] agree that the major contribution of fuzzy set theory is the inherent capability of representing vague knowledge. Roy (2003) however states that fuzzy logic applications within the field of cost estimating have not been well established, well researched or published. The impact of uncertainty and sensitivity within cost modelling has been also well researched within aerospace to show that Monte Carlo techniques can be employed to increase the robustness of the analysis (Curran et al, 2009).

It should be noted that each of the estimating methods to varying degrees can be employed in either a 'top-down' or 'bottom-up' fashion. 'Top-down' involves the formulation of an overall estimate to represent the completed project which may then be broken down into subcomponents of cost as required. In contrast, 'bottom-up' estimating [Ting, (1999)] generates sublevel and component costs first which may then be aggregated in order to produce an overall estimate. Elements of each of these methods are more or less applicable at various stages of the product life cycle. Further reviews of these methods are provided by Curran (2004), Roy (2003) and Stewart (1995).

4. Methodology: Cost CENTRE-ing

The purpose of incorporating improved estimating methodologies within Procurement is essentially to provide additional information against which sourcing issues may be more readily considered. The research method presented in this Section gives attention to identifying opportunities for cost reduction from currently outsourced parts based upon unjustifiable cost or price variances amongst similar parts. Control follows estimate generation and usually involves the comparison with actual and other estimates for the purpose of identifying such variances and then attempting to understand their causes with the view to bringing cost to a desired baseline. Three types of cost variance are of interest when comparing cost information of similar items including: 1) comparison of actual cost to actual cost, or indeed lower level actual cost components, 2) comparison of actual costs to cost estimates, at any level of aggregation, and 3) comparison of an estimate to another estimate developed from a different approach.

Figure 6 presents a synthesis of procurement best-practice in unit cost/price analysis, with reference to the authors experience and the literature review in Section 3. It is reflective of the latest cost management research in the area (Pugh et al, 2010a; Pugh et al, 2010b) and involves tailoring cost analysis to given types of purchase situation.

It can be seen that the key elements identified are the roles of Classification, Data mining, Cost/Price Analysis, Supplier Selection and Cost Control. Consequently, the presented work was therefore directed towards the development of a modelling methodology and process that would support the Cost/Price Analysis stage in particular. The resulting methodology was termed (Genetic Causal) Cost CENTRE-ing, as the word 'CENTRE' is an anagram of the 6 key process steps to followed in implementing the methodology. The Genetic Causal basis (Curran et al, 2004) of the methodology refers the decomposition of procurement items into 'genetic' families of similar parts based either on part material, form, function or manufacturing process, so that then, historical costing data can be used to develop 'causal' relations to estimate the part-cost of any instance of an item from that genetic family.

The causality of the costing algorithms is a very significant issue so that the equations are robust and dependable, with the dependant variable as cost being a function of independent variables relating to the part definition, such as part, process or function information, rather than purely statistical in nature; as we find often in traditional parametric costing (see Curran et al, 2004). In addition, another requirement was that the Cost CENTRE-ing process could provide an agile method for up-to-date analysis, estimation, control and reduction of procurement costs and so it was decided at the outset that it should be able to easily incorporate new cost data and part information in order to upgrade the costing algorithms in an automated manner. As illustrated in Figure 7, the method is broken down into six key steps: (1) Classification, (2) Encircling, (3) Normalization, (4) Trending, (5) Cost Reduction Identification and (6) Enforcement. Steps 1 to 4 involve knowledge discovery incorporating data mining, statistical study (e.g. for variable selection, significance and hypothesis testing, trending and optimization) with scope for sensitivity and likelihood testing, which brings in concepts central to probability.

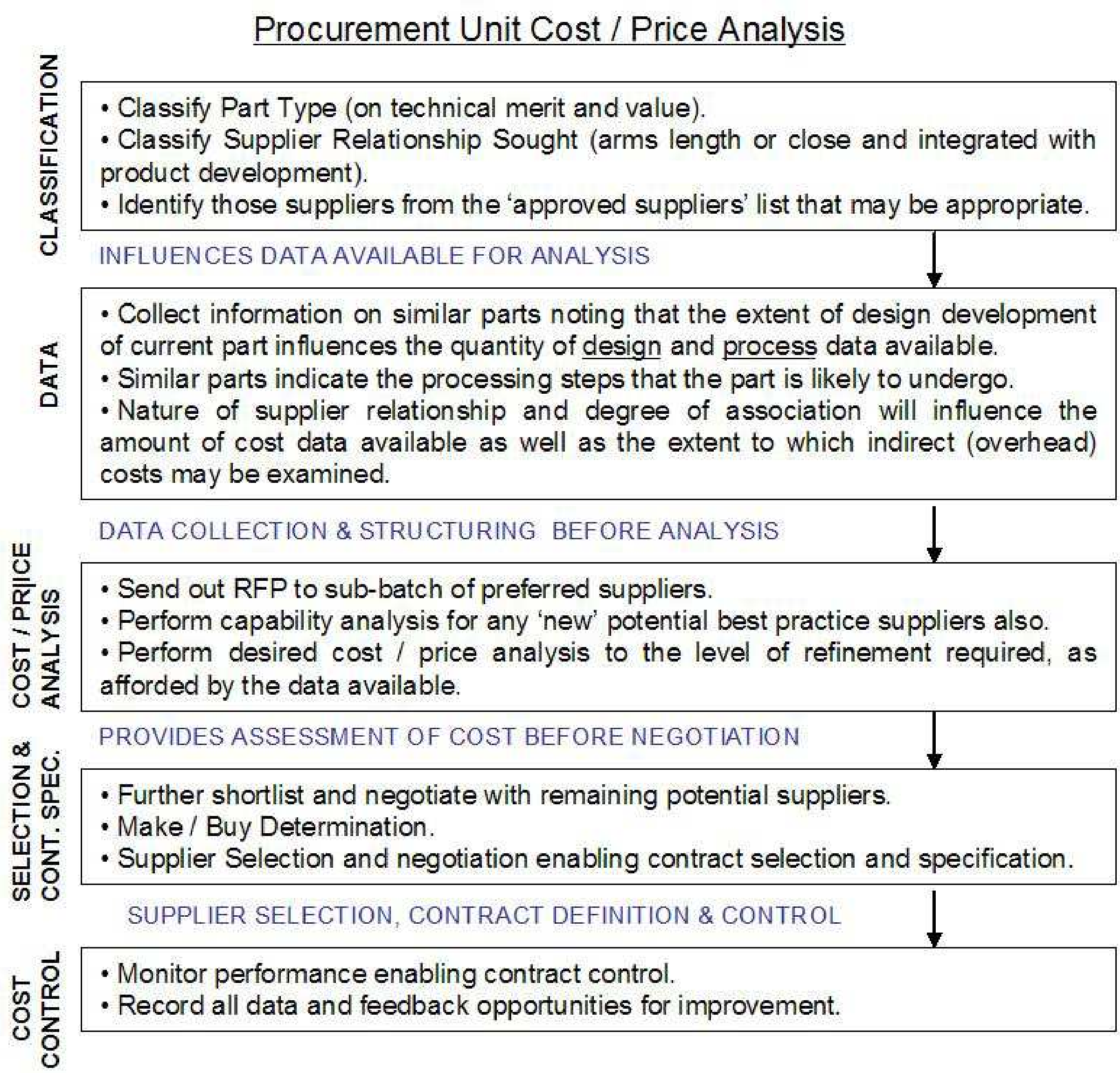


Fig. 6. Procurement best practice in unit cost or price analysis

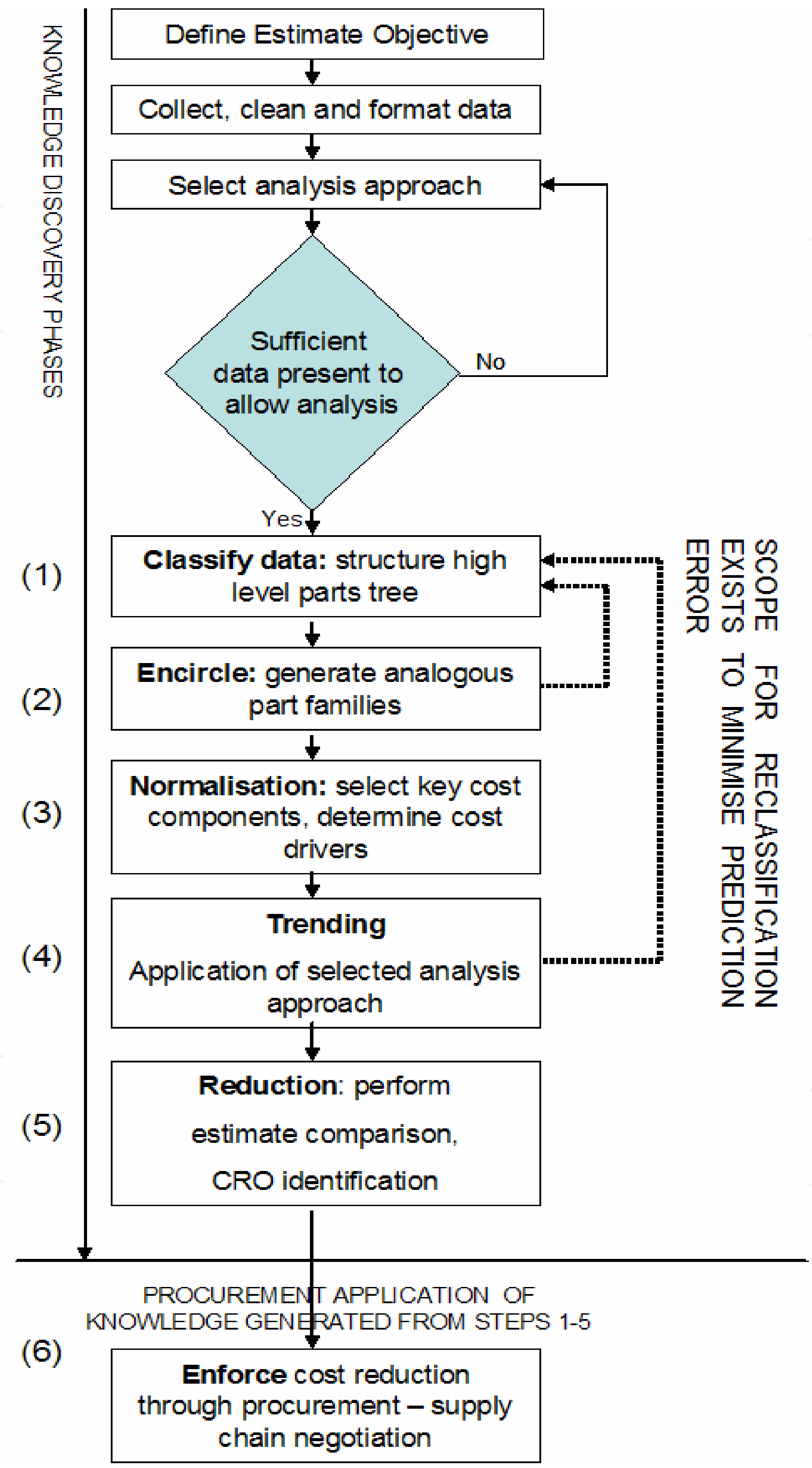


Fig. 7. The Cost CENTRE-ing methodology

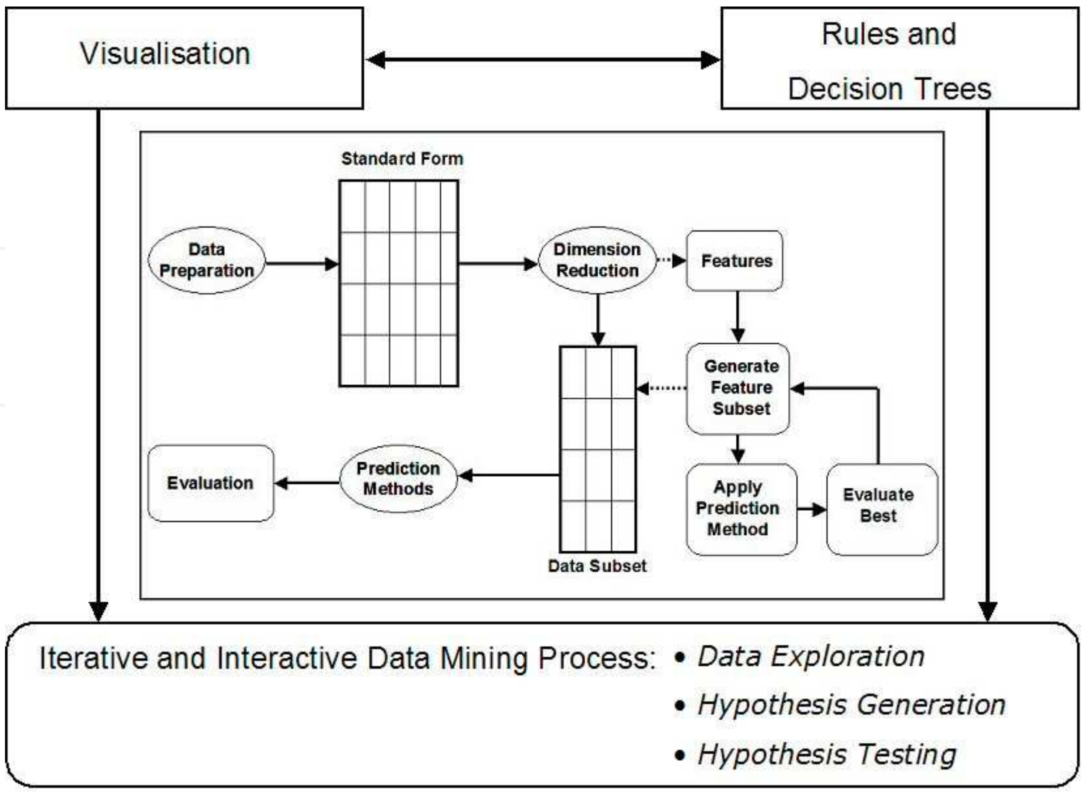


Fig. 8. A hybrid approach to data mining

The steps associated with Cost CENTRE-ing are further expanded below and map equally well to the requirements presented through Figure 6, starting with Classification and finishing with the application to Cost Control:

(1) Classification: as a key aspect of the methodology and was implemented to define families of parts. There is an obvious trade-off in terms of increasing the complexity through the number of Cost Estimating Relationships (CERs) embodied in the eventual methodology. Classification was developed according to the following descriptors as taken from a part's Bill of Material: Procurement Part Type, Aircraft Type, Sub-Level Contract, Process, Material Form and Material.

(2) Encircling: involves analysis of a data set's principal components and allows clusters to be identified in order to improve grouping refinement and proceeds as follows: Machine Type, Part Size and Batch Size. Figure 8 highlights a hybrid data mining approach involving data exploration, standardization, and visualization, reduction with subset generation as well as statistical testing and iterative evaluation (Weiss 1988, Fayyad 2002). Considering this, the process of pattern matching that is being used in the presented approach to data grouping is analogous to having degrees of freedom in a formal statistical test.

(3) Normalization: After surveying the more advanced methods being developed, such as Neural Networks and fuzzy logic etc, it was decided that Multiple Linear Regression would be used to model the link between part attributes, as independent variables, and unit cost, as the dependant variable (Watson et al, 2006). This requires that the data be normalized in order to distil out the key cost drivers to be used in the formulation of parametric relations. There is a trade-off here in terms of the number of drivers, which may be used to optimize a given result and the corresponding actual improvement considering the additional processing time required to generate the result.

(4) Trending: also considering knowledge capture and formalization, this step allows the appropriate trend which describes the mapping relationship of cost to the independent variables to be selected. The most appropriate trend to use may change from case to case although what is common is the means by which the goodness of fit of a relationship may be measured (through the R^2 value that describes the degree of statistical fitting), with the trend that best minimizes random variance or error being selected in each case.
(5) Reduction and (6) Enforcement: these steps are linked to Procurement's use of the relationships and trends developed at this point in the process. 'Reduction' entails application and comparison of prediction trends to current 'actuals' or to results developed by other estimating techniques for the purpose of identifying Opportunities for Cost Reduction either by direct total cost comparison at part level or sub-cost components (e.g. Make, Material, Treatments, etc.). Once identified, the Procurement function must then decide upon the appropriate course of action to be taken in order to attain reductions through 'Enforcement'.

5. Results and validation

The effectiveness of the Cost CENTRE-ing methodology and process was validated on three separate studies (including four specific cases in total) in collaboration with the procurement function at Bombardier Aerospace Belfast. Three studies of a different nature were chosen to represent the range of parts procured within aerospace. This included: 1) a machined parts example with a data set of 850 'Outside Production' aircraft items on one contract and another data set of 117 parts from a different aircraft contract, 2) a vendor-specialized 'systems' part in the form of Thermal Anti-Icing Valves of which there was a typically small data set of 6, and 3) a more common fastening part in the form of a spigot for which there was a data set of 201. The results from these validation studies are presented in the following Sections 5.1 through 5.3, where the methodology is presented according to the six key steps of: (1) Classification, (2) Encircling, (3) Normalization, (4) Trending, (5) Cost Reduction Identification and (6) Enforcement. The machining case study was just one of many carried out on the whole part base of some 7,000 machined parts at Bombardier (Watson et al, 2006).

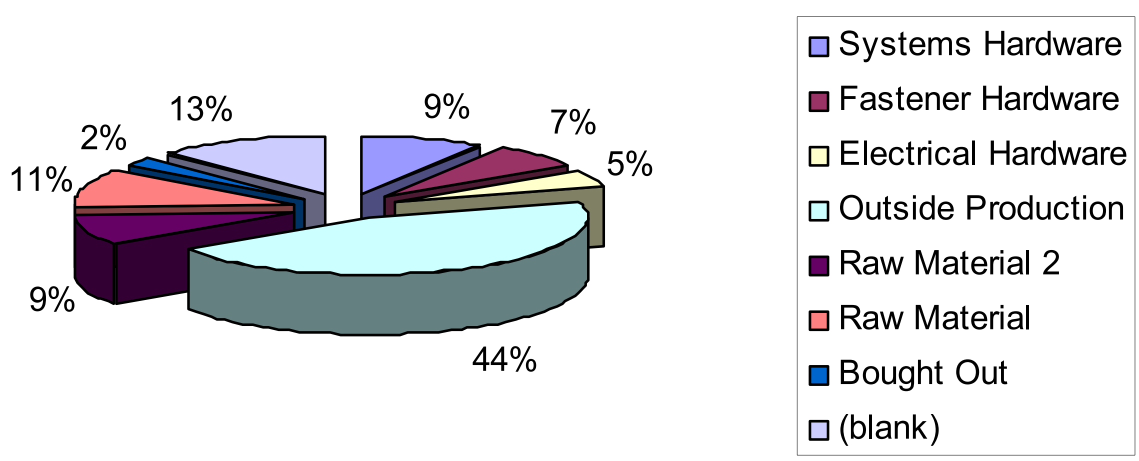


Fig. 9. An example of the procurement spend breakdown for Bombardier Aerospace Belfast

5.1 Validation study 1: Outside-production machined aerospace parts

(1) Classification: Figure 9 presents the general breakdown of procurement spend at Bombardier Aerospace Belfast while Figure 10 further disaggregates the spend on 'Outside Production' parts. Consequently, one can see the opportunity to define and develop families of parts of a similar in nature.

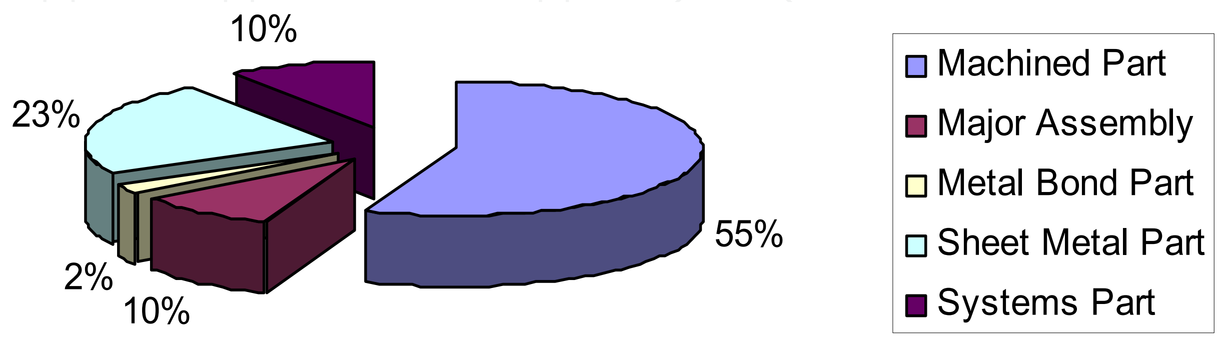


Fig. 10. The breakdown of outside product parts for Bombardier Aerospace Belfast

(2) Encircling: In Figures 9 and 10, it can be seen that the parts have been categorized in order to group parts with a increased degree of commonality. Primarily, at this level of distinction it is paramount to choose associated part attributes that have been identified as driving manufacturing cost, thereby following the principle of causality. For example, weight might be used well as an independent variable for material cost but is less relevant to unit cost (when in aerospace it typically costs money to take weight out of a structure) while other independent variable may be less obvious but still of a causal nature such as using direct as part count as an assembly cost driver. It is also important to choose attributes that are already defined at whatever stage of the product life that the model is to be utilized, and of course that these are also readily available. If the Cost CENTRE-ing implementation is fully coupled to design platforms (Curran et al, 2001; Curran et al, 2007a; Curran, 2010) it is then possible to impose a much greater level of definition, through actual part volume etc, which would increase the accuracy but also the operational complexity of the Model. However, this is more relevant to validation, improvements in the costing algorithms and cost reduction exercises while as procurement costing at the conceptual design phase does not have the design definition one would want for very accurate causal modelling of costs.

(3) Normalization: A simple initial causal parametric relation was generated from the data for machined parts using the Multiple Linear Regression facility within the MS Excel Data Analysis module. The detailed manual cost estimates of the machining times for 850 parts were used as the dependant variables while the readily available independent variables were all based on size attributes (thickness, length and breadth). In terms of driving the parametric relation, the size envelope is primarily linked to the material removal although the relation would be much improved with more detailed attribute data. Work is progressing in also linking part complexity, as driven by key design attributes of the part.

(4) Trending: Trending was carried out using Multiple Linear Regression, where machining time was the estimated time for a given component made from a billet of thickness T, length L and width W; according to three regression coefficients and a constant. It is interesting to also note that the regression in question had a 'Multiple R' value of 0.71, which can be interpreted as the mathematical formulation account for approximately 70% of the variation in the historical data. A Multiple R value of 0.8 would be preferable and could be feasible by improving the range of independent variables used to characterize the parts, e.g. through the additional normalization according to part size and design/machining complexity, as available. However, this machining case study was one of many carried out on the whole part base of some 30,000 parts at Bombardier (Watson et al, 2006).

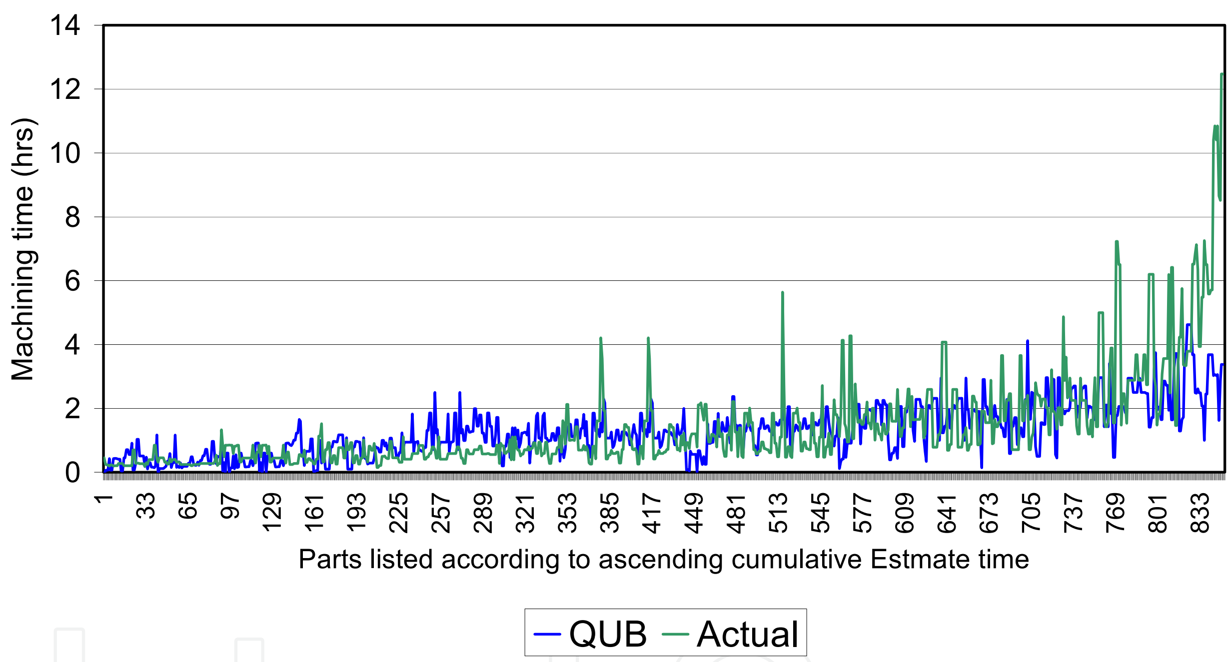


Fig. 11. Cost comparisons of 850 parts using 'actuals' (with more deviation) and the model

The resulting estimates for the 850 parts are presented in Figure 11 where the Cost CENTRE-ing 'QUB' estimate is compared against the actual times. However, the 'Actuals' were not directly available from the suppliers due to the sensitivity of the information and had to be derived from a detailed estimate of the parts using the actual supply price and an averaged machining rate. Anywhere on Figure 11 that there is significant disparity between the two characteristics highlights those parts that require further investigation for potential cost reduction, as presented in the following Section.

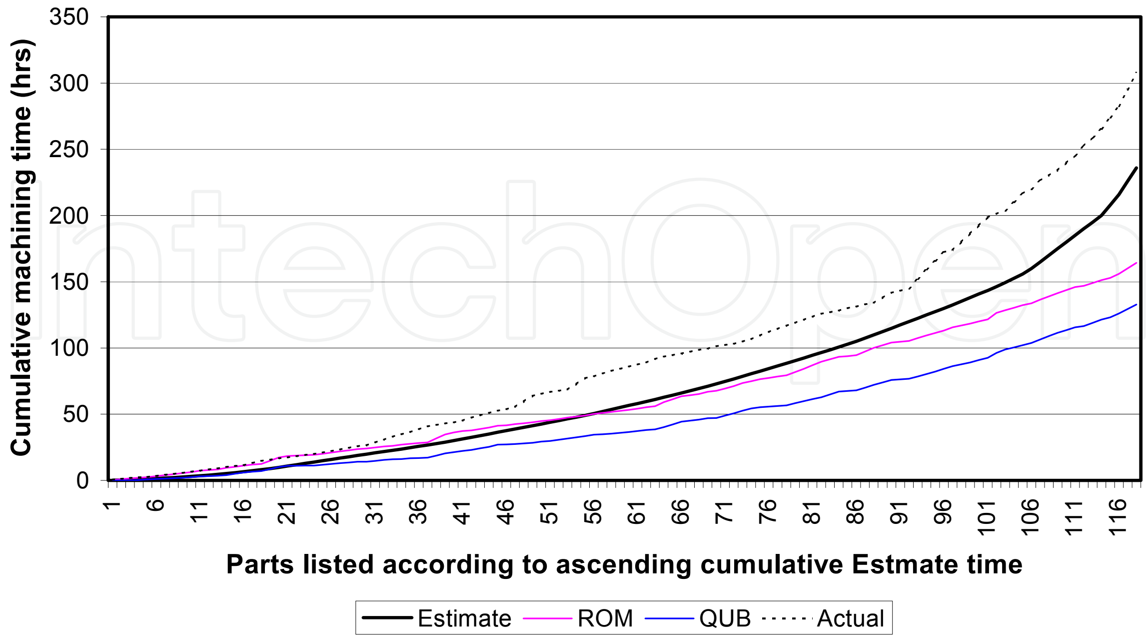


Fig. 12. A detailed comparison for part costs with 'Actuals', the manual ROM and the 'QUB' model values and the current detailed manual estimates (the solid line)

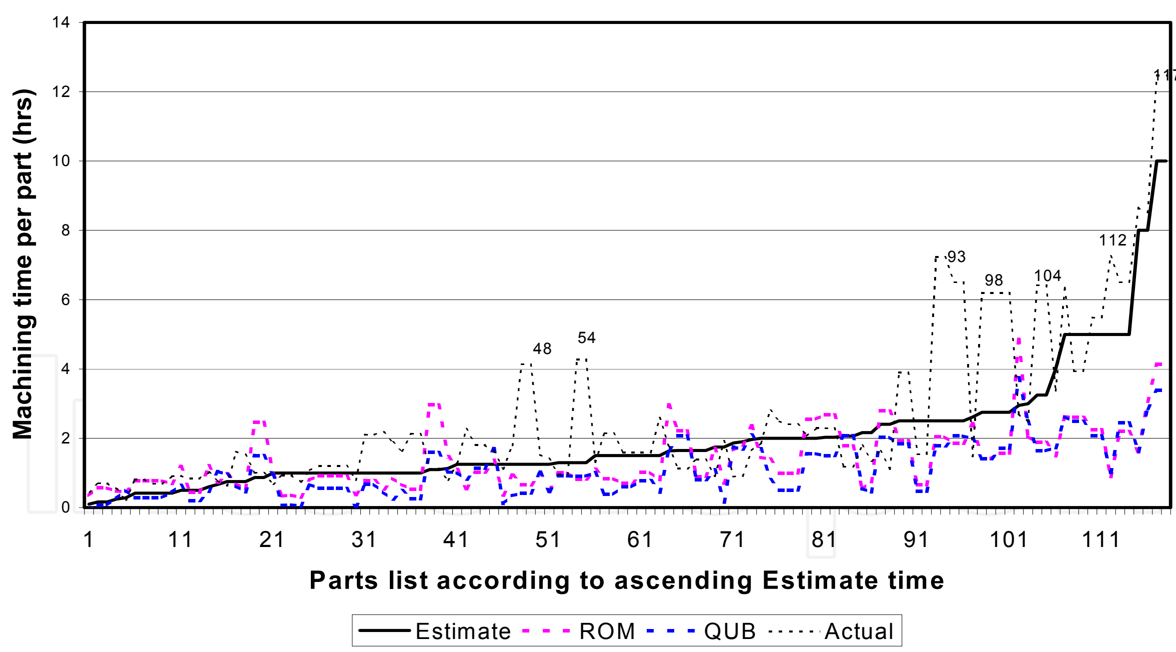


Fig. 13. A comparison of the cumulative cycle times of the parts detailed in Figure 12

(5-6) Reduction/Enforcement: The Cost CENTRE-ing model developed for machined parts was then applied to older 2nd contract where it was believed there might be greater opportunity for cost reduction. Figure 12 presents a direct comparison between all cycle time values for the 117 listed parts associated with the aircraft contract. Four types of estimated values are presented, including: the detailed manual estimate, the Rough Order of Magnitude (ROM)

estimate from an in-house parametric model, the Cost CENTRE-ing 'QUB' estimate and the derived 'Actuals' estimate. It can be seen that a significant number of 'Actuals' are extremely different. Figure 13 provides a cumulative comparison for each of the estimate types in which the cumulative differentials again imply that the 'Actuals' are too high. Consequently, a number of these parts were identified and the differentials calculated to estimate the potential savings if the current suppliers were to reduce their price to the appropriate should cost or else via supplier sourcing. For this case, potential savings of £100,000 were generated through *(6) Enforcement.*

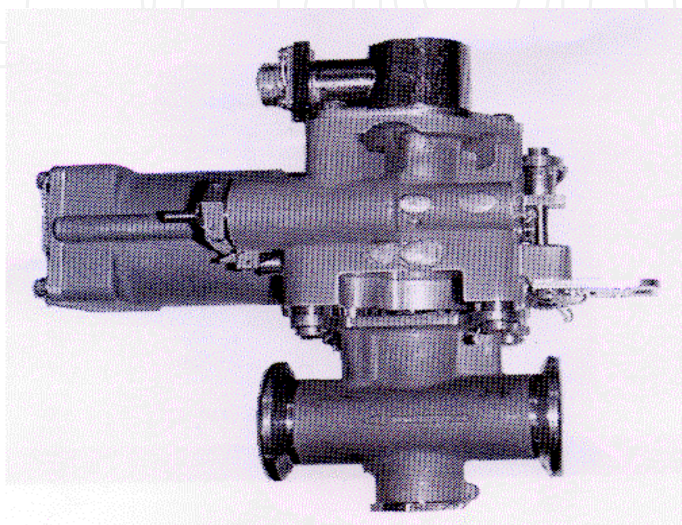


Fig. 14. An example of a typical Off-The-Shelf item used as a case study: an anti-icing valve

5.2 Validation study 2: Off-the-shelf systems items – Aircraft engine anti-icing valves

(1-2) Classification/Encircling: This study considers the procurement of Thermal Anti Icing (TAI) valves as a general off-the-shelf item, relating to the system hardware category in Figure 9 and shown in Figure 14. Ice protection relates to the prevention and removal of ice accumulation (anti-icing and de-icing respectively) on either a wing leading edge or more typically on the Nacelle inlet to an aircraft engine. However, there are a range of pneumatic and electrical systems that supply the required heat from the engine bleed hot air for: wing anti-icing; engine nose cowls and inlets and centre engine inlet duct; the upper VHF antenna; fuel filter de-icing (more under power plant). The case study was undertaken with a view towards determining why there is a cost variation between those TIA valves currently being sourced so that this improved understanding would lead to a better 'Should Cost' estimate; a term commonly used for a target cost or price. As such, the valve was classified within the vendor item group with the valves identified as an encircled grouping of parts with an obvious commonality.

(3) Normalization: The normalization procedure was implemented as set out previously in order to deter-mine the cost drivers that differentiate the cost of one instance of the encircled group from another. It was found that the cost of a valve is dependent for example upon; casing and seal materials, performance specifications, testing and scale of production or order quantities. The valves being examined were particularly challenging as they are vendor-supplied items with little information available over that of the original operational specifications and the actual buying price. Naturally, the implication is that one is dealing

with price as the dependant variable rather than cost, which means that it is less feasible to look for a causal linkage between price and item parameters. Notwithstanding, the more fairly an item is priced the more likely it is that a trend can be established with statistical significance. The initial process followed was that of extracting from the source documents all operational specifications and requirements with a view towards removing any common characteristics and then analyzing the remaining variables, to ascertain their influence on the unit price. It was recognized that there are many attributes that contribute towards any item's overall cost, as well as other environmental factors that affect the part's price, but in such a case with very little or no knowledge of the cost breakdown, basic relationships for those variables considered to be the major performance/functionality cost drivers can be used.

(4) Trending: As previously, the trending relied on Multiple Linear Regression as the means of relating the available cost drivers to the measure of cost, or more accurately price in this case. Figure 15 plots some of the regression findings that were carried out to investigate the relations between performance drivers and the Purchase Order value per part. Some of these initial relations are of use in terms of a Rough Order Magnitude (ROM) estimate and also provide the rationale and negotiating leverage for cost reduction dealt with in the next Section. It should be noted that there is often interaction between such performance parameters so that it is important to use more than one independent variable in calculating a robust estimate.

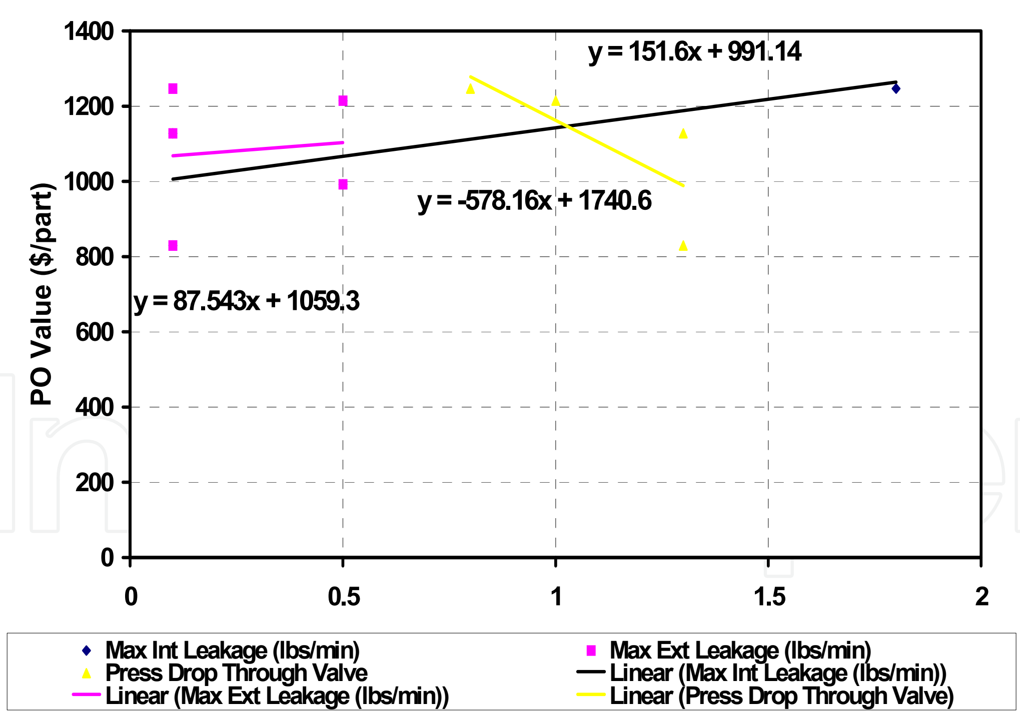


Fig. 15. Indicative cost benefit modeling with regards to performance specification

(5-6) Reduction/Enforcement: It was found from the studies that there was a deviation of almost 50% in the cost of the procurement of these various valves but very little discernable difference in the performance specifications. A more influential parameter

was the order quantity although again there were anomalies in the trending. Ultimately, however, these anomalies were then exploited as the negotiating rationale for cost reduction as part of the *Enforcement* step. Consequently, for these procured parts that are very difficult to cost the Cost CENTRE-ing approach as been used to identify the more likely opportunities for cost reduction due to disparity in the estimates, rather than trying to accurately cost a quite bespoke off-the-self system item, of which there are many on an aircraft.

5.3 Validation study 3: General aerospace supply items - Spigots

(1) Classification: In total Bombardier Aerospace Shorts Methods Procurement currently outsource in region of 34,000 parts across 618 suppliers for use within aircraft sub-assembly build contracts. Of those parts, the overall part list was first classified according to commodity code, for example, 'Machinings' accounting for some 7000 parts. This study focused on what is termed 'General Supply' items, or more minor parts that are used in very large quantities and are directly used typically in fastening and assembly.
(2) Encircling: In encircling a particular cluster of General Supply items for analysis those parts used in engine Nacelle manufacture were considered, reducing the part count down to 840. Of these 840, a further filtering step was carried out to generate a list of those items, which are considered to be similar in nature to a number of other parts within the grouping. This included the main characteristics of a part being present in each item contained within the 'Similar to' part set. The parts list of 840 parts was condensed to a list of 'Similar-to' part sets which contained in total a shortlist of 201 parts. In this instance the encircling was driven more by product orientation and function-role approach, rather than primarily for part family, such as for valves; fuselage panels, Nosecowls etc. One such 'Similar-to' part set related to a particular style of Spigot, which is a member of the 'Round Bar & Tube' part family, as shown in Figure 16.
(3) Normalisation: The individual General Supply items/parts are normalized according to make-cost, material cost and treatments. According to the 'Should Cost' Approach, parts with similar attributes in terms of material, geometry, manufacturing and treatments requirements should approximately have close make, material & treatment costs.

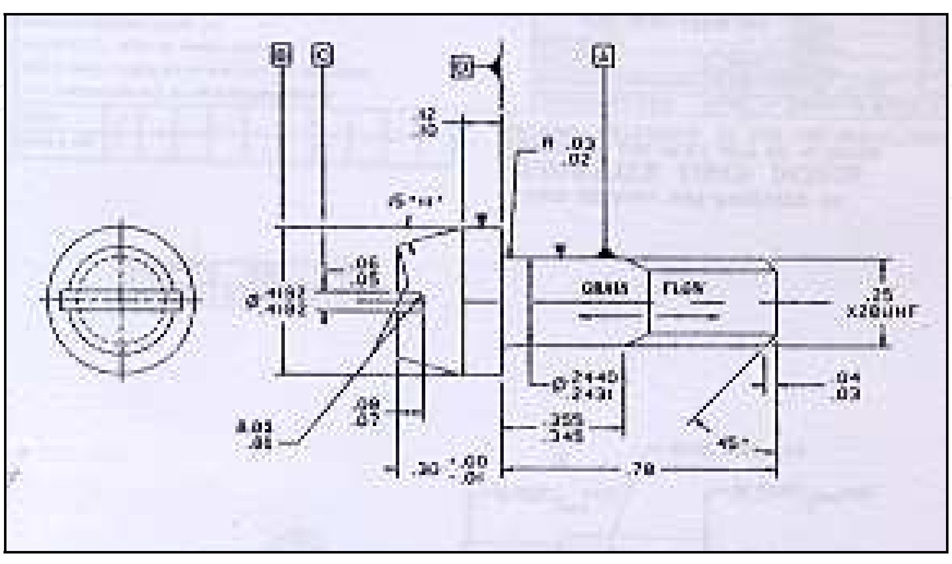


Fig. 16. A example of a General Supply item: a spigot

(4) Trending: Again the procurement information is more price oriented and therefore rather than direct modeling, the lowest component cost for each within the part set is then considered to be an initial baseline value to which the others should be brought in line with, remembering again that the Should Cost target is an estimate of a unit price that accurately reflects reasonably achievable contractor economy and efficiency.
(5) Reduction: For each part set, the opportunities for cost reduction are identified by calculating the differential between each parts' current Make Cost, Treatments Cost & Materials Cost for each of these parts. However, in addition the Should Costs for these Costing components (within each part set) needs to also factor in the quantity of parts per delivery batch, the rate of usage per year and the expected duration of build contracts to which the parts are being used [Marquez and Blanchar, (2004)]. This gives the overall potential for savings for each 'Similar to' Part set.
(6) Enforcement: The projected potential savings across six contracts currently in development with Bombardier Aerospace Belfast are shown below in Figure 17 for the spigots. It is interesting to note that there is a greater potential for savings in three particular projects. This can be accounted for by the fact that Contracts D, E & F had been focused on for some time with the application of the Should Cost philosophy, hence less opportunity for cost reduction. If the other parts in the set have been sourced via the one supplier then procurement contacts the supplier to discuss the cost drivers for the set of parts to establish why each are not currently being supplied at Should Cost and ultimately look to renegotiate the part costs. If sourced via a few different suppliers then this process is more complicated but in essence the same as the cost drivers will indicate the true unit cost for an item so that through mutually beneficial discussion (supply and demand) it should be possible to bring the items to an agreed Should Cost. It should be noted that an activity that requires and develops increased understanding of the cost drivers is beneficial for both the supplier and customer and *Enforcement* is not carried out in order 'to eat unfairly into supplier profit margins' but to establish a profitable and sustainable relationship between the two based upon enhanced efficiency and best practice driven initiatives.

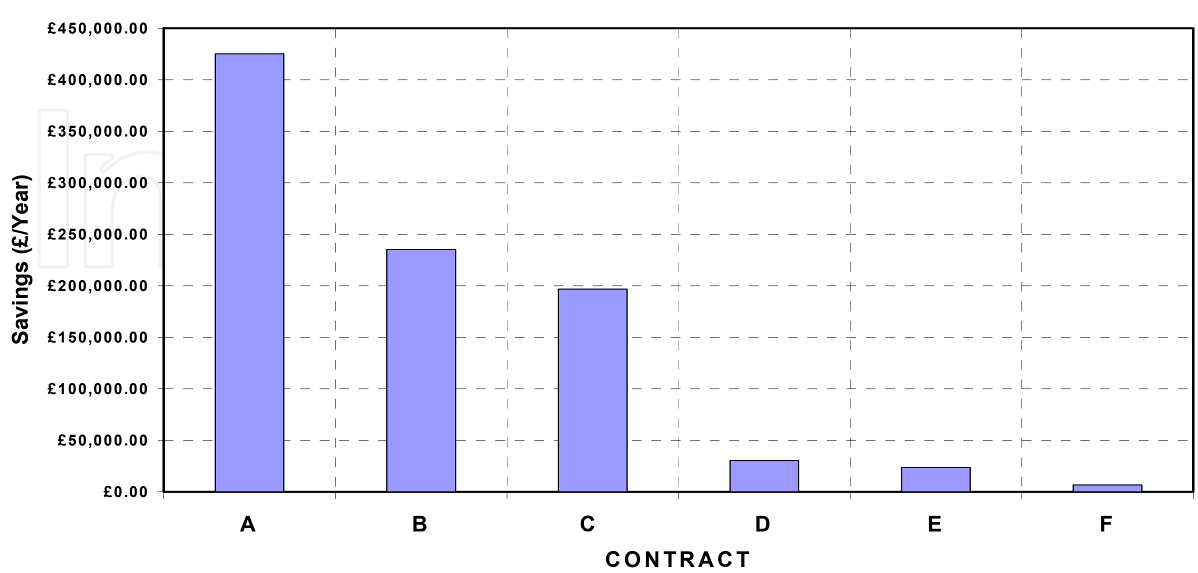


Fig. 17. Enforced savings for the spigot General Supply case study across a number of contracts

6. Discussion

In terms of key insights and contribution, Genetic Causal Cost CENTRE-ing utilizes part or product attribute information to build families of causal cost estimating relations that are based on rationale, rather than simply using market forces in procurement cost control and the traditional practice of buyer-purchasing based on part numbers without any insight into what is being purchased. Furthermore, the methodology has been applied to categorize very large quantities of parts in order to provide an agile and responsive tool for supply chain cost management. This provides the buyer with a stronger rationale in negotiating price reductions, ideally to be used in conjunction with some gaming theory for example and the more traditional assessment of market forces.

The application and relevance to real-world industrial situations has been validated in collaboration with Bombardier Aerospace Belfast and is synthesized into the model presented in Figure 7, the application of which was described in detail in Section 5. Essentially, this is encapsulated in the six procedural steps of: item Classification; data Encircling; cost driver Normalization; parameter Trending; cost Reduction identification; negotiated Enforcement; termed Cost CENTRE-ing. Following the Genetic Causal approach, this entails the categorization of part and product families stored in large data banks of cost information, the generation of associated causal 'Should Cost' estimation algorithms, and the application to current procurement operations through price negotiation. A tool was developed and is being used by Bombardier Aerospace Belfast which has automated the rapid formulation of the cost estimating functions, based on the most up to date data available, so that the buyer can select the generic type of part to be procured and then generate a 'Should Cost' range with associated limits of confidence relative to an ideal cost estimate.

It is envisaged that practitioners will extend the work to improve the gathering of more extensive data, including quantitative and qualitative knowledge capture, and that this would entail more effective integration within the companies' Design and Manufacturing functions; in collecting and utilizing key part and product information. Ultimately, the modeling capability could also explicitly facilitate the Design to Cost procedure to help drive the design process towards more effective design solutions that exploit key supply chain and procurement knowledge. However, in terms of a pure procurement tool, it is envisaged that the application can be developed and exploited more fully as a web-based technology that is more responsive in the identification and control of Lean suppliers who operate within an optimal cost basis.

7. Conclusion

This Chapter presents an agile cost estimating methodology to be deployed in a procurement operations tool for enabling more cost effective procurement control and cost reduction. The method is agile in being able to easily include the latest market data to generate its own costing algorithms that are established using the Genetic Casual Cost CENTRE-ing approach: item Classification; data Encircling; cost driver Normalization; parameter Trending; cost Reduction identification; negotiated Enforcement. It is shown that the Cost CENTRE-ing method provides an agile method for responsive cost analysis, estimation, control and reduction of procured aerospace parts. The methodology is based on the structuring of parts into product families and utilized both manufacturing and performance cost drivers to establish causal cost estimating relationships, according to the

Genetic Causal approach. Case studies have been presented to test the generic relevance and validity of the method. A 'machined part' example representing out-side production used both specific design and cost data while a General Supply spigot example used analogy applied to comparison of sub-cost components. An off-the-shelf Thermal Anti-Icing valve study relied exclusively on broad contract based information (not specific to the part) with purchase order value as the dependent variable and performance specifications as the independent variable. IN particular the latter was shown to be inherently difficult due to differing suppliers using alternative cost stack up and allocation policies, as well as profit margins, which makes it difficult to identify causal drivers that affect the cost differentials. However, once again the Genetic Causal method forces the use of causal cost drivers (performance related in the latter study) that can be clustered according to the cost family under consideration, while being facilitated by the Cost CENTRE-ing process. The Cost CENTRE-ing method uses 'comparison' in early data grouping and refinement but is also the basis of normalization and trend selection. It does this by selecting those drivers with the smallest measure of random error and which can be linked causally to cost.

The proposed methodology was applied to the three validation studies to show that it is effective in a wide range of applications (generic), has been used to significantly reduce the cost of supplied items (accurate), and is being adopted by a leading aerospace manufacturer (relevant). It is concluded that the proposed Genetic Causal Cost CENTRE-ing methodology exhibits all the above because it is based on an improved understanding of procurement operations and supply chain costing; thereby contributing to the body of knowledge in terms of process understanding; the importance of a causal relations in estimating; and identifying inheritance and family commonality in groups of products. It is envisaged that the application can be further developed into a web-based technology that is more responsive in the identification and control of Lean suppliers who operate within an optimal cost basis

8. Acknowledgements

The presented work was carried out in collaboration between Queens University Belfast and Bombardier Aerospace Belfast. The authors were involved in a range of cost modeling research projects within the Design, Manufacturing and Procurement domains, but the presented work was carried out as part of a Bombardier/DEL funded 'Cast Award' that resulted in the successful PhD work of Dr. Paul Watson, in association with that Department of Education and Learning (DEL), NI initiative. Within Bombardier Aerospace Belfast, acknowledgment and thanks must also be noted for the expert contributions of Mr. Neil Watson and Mr. Paddy Hawthorne, under the strategic direction of the Director of Procurement, Mr. Steven Cowan.

9. References

AT Kearney Report, (2004), "Creating value through strategic supply management – 2004 Assessment of Excellence in Procurement".

Ben-Arieh, D., (2000), "Cost estimation system for machined parts", International Journal of Production Research, Vol. 38, No. 17, pp. 4481 – 4494.

Brinke, E.T., (2002), "Costing Support and Cost Control in Manufacturing: A Cost Estimation Tool applied in the sheet metal domain", PhD Thesis, Printed by PrintPartners Ipskamp, Enschede, The Netherlands, ISBN 90-365-1726-5.

Cavalieri, S., Maccarrone, P. and Pinto, R., (2004), "Parametric vs. neural network models for the estimation of production costs: A case study in the automotive industry", International Journal of Production Economics 91, pp. 165 – 177.

Collopy, P.D., (2001), "Aerospace Manufacturing Cost Prediction from a Measure of Part Definition Information", Copyright © 2001 Society of Automotive Engineers, InC.

Chen, I.J., and Paulraj, A., (2004), "Understanding supply chain management: critical research and a theoretical framework", International Journal of Production Research, Vol. 42, No. 1, pp. 131 – 163.

Curran, R, Kundu, A., Raghunathan, & Eakin D (2001), "Costing Tools for Decision Making within Integrated Aerospace Design", Journal of Concurrent Engineering Research, 9(4), 327-338.

Curran, R, Kundu, AK, Raghunathan, S and R McFadden (2003). "Influence of Manufacturing Tolerance on Aircraft Direct Operating Cost (DOC)", Journal of Materials Processing Technology, Elsevier Science BV, ISSN; 0924-0136, 239-247.

Curran, R., Raghunathan, S. and Price, M., (2004), "Review of aerospace engineering cost modeling: The genetic causal approach", Progress in Aerospace Sciences 40, pp. 487 – 534.

Curran, R., and Watson, P., Cowan, S., Hawthorne, P., Watson, N., "Cost CENTRE-ing: A Procurement Methodology for Cost Reduction within Aerospace", Proceedings of Concurrent Engineering Conference, CE2004, Beijing, China, 2004.

Curran, R., Rothwell, A., and Castagne, S., "A Numerical Method for Cost-Weight Optimization of Stringer-Skin Panels", Journal of Aircraft, Vol. 43, No. 1, 2006, pp. 264-274.

Curran, R, Gomis, G, Castagne, S, Butterfield, J, Edgar, T, Higgins, C and C McKeever (2007a), "Integrated Digital Design for Manufacture for Reduced Life Cycle Cost", International Journal of Production Economics (IJPE), 27-40.

Curran, R, Castagne, S, Early, J, Price, M, Raghunathan, S, Butterfield J & A. Gibson (2007b) "Aircraft Cost Modelling using the Genetic Causal Technique within a Systems Engineering Approach", The Aeronautical Journal, Royal Aeronautical Society, 409-420.

Curran, R, Castagne, S, Rothwell, A, Price, M, Murphy, A. & Raghunathan, s. (2009). Uncertainty and sensitivity analysis in aircraft operating costs in structural design optimization. Journal of aircraft, 46(6), 2145-2155.

Curran, R. (2010), Value Driven Design: Value Integration, Encyclopedia of Aerospace Engineering, ISBN: 978-0-470-75440-5, Volume 6, Part 31, Chapter 322.

Curran, R, T. Abu-Kias , M.J.F Repco, Y.L.J. Sprengers, P.N.C.S van der Zwet and W. Beelearts, A (2010a), Value Operations Methodology for Value Driven Design: Medium Range Passenger Airliner Validation, Proceedings of AIAA General Meeting, Orlando.

Curran, R., Verhagen, W.J.C., Van Tooren, M.J.L. & Van der Laan, A. (2010b). A multidisciplinary implementation methodology for knowledge based engineering: KNOMAD. Expert Systems with Applications, Volume 37, Issue 11, November 2010, Pages 7336-7350

Curran, R., Butterfield, J., Jin, Y., & Burke, R., Collins, R. (2010c), Value Driven Manufacture: Digital Lean Manufacture, Encyclopedia of Aerospace Engineering, ISBN: 978-0-470-75440-5, Volume 6, Part 31, Chapter 313.

Dubois, A., (2003), "Strategic cost management across boundaries of firms", Journal of Industrial Marketing Management, 32, pp. 365 – 374.

Dulmin, R., and Mininno, V., (2003), "Supplier selection using a multi-criteria decision aid method", Journal of Purchasing and Supply Management 9, pp. 177 – 187.

Ellram, L.M., (1996), "A structured method for applying purchasing cost management tools", The Journal of Supply Chain Management – A Global Review of Purchasing and Supply, Volume 32, No.1, pp. 11 – 19.

Ellram, L.M., (2002), "Strategic Cost Management in the Supply Chain: A purchasing and Supply Management Perspective", Copyright © 2002 by CAPS Research.

Esawi, A.M.K., and Ashby, M.F.*, "Cost Estimates to Guide Pre-selection of Processes", Mechanical Engineering Department, The American University in Cairo, *Engineering Design Centre, Cambridge University Engineering Department, January 2003.

Fitzgerald, K.R., (2002), "Best Practices in Procurement", Ascet Volume 4, Ascet – Achieving Supply Chain Excellence Through Technology.

Fleming, Q., (2003), "Project procurement management: contracting, subcontracting, teaming", Fmc Publisher, ISBN: 0974391204.

Funahashi, K., (1989), "On the approximate realisation of continuous mappings by neural networks", Neural Networks, Vol. 2, pp. 183 – 192.

Gerla, G., "Fuzzy Logic, Mathematical Tools for Approximate Reasoning", Kluwer Academic Publishers, ISBN 0-7923-6941-6, 2001.

Handfield, R.B., Krause, D.R., Scannell, T.V., and Monczka, R.M., (2002), "Avoid the pitfalls in Supplier Management", Sloan Management Review, January 2000.

Hicks, C., McGovern, T., and Earl, C.F., (2000), "Supply chain management: A strategic issue in engineer to order manufacturing", International Journal of Production Economics, Volume 65, Issue 2, 20 April 2000, pp. 179-190.

Hornik, K., Stinchcombe, M., and White, H., (1989), "Multilayer feedforward networks are universal approximators", Neural Netwroks, Vol. 2, pp. 359 – 366.

Humphreys, K.K., (1991), "Jelen's Cost and Optimisation Engineering", Third Edition, McGraw Hill Publishers, ISBN 0-07-053646-5, pp. 538.

Idri, A., Khoshgoftaar, T.M. and Abran, A., (2002), "Can neural nets be easily interpreted in software cost estimation?", 2002 World Congress on Computational Intelligence, Honolulu, Hawaii, May 12 – 17.

Kishk, M., and Al-Hajj, A., "An integrated framework for life cycle costings in buildings", RICS Research Foundation , ISBN 0-85406-968-2, 1999.

Klir, G.J., and Ruan, D.A., "Fuzzy logic foundations and industrial applications", Kluwer Academic Publishers, International Series in Intelligent Technologies, 1996.

Kulmala, H.I., (2004), "Developing cost management in customer-supplier relationships: three case studies", Journal of Purchasing and Supply Management 10, pp. 65 – 77.

La Londe, B.J., and Ginter, J.L. (1999), "A Summary of Activity-Based Costing Best Practices, The Ohio State University's Supply Chain Management Research Group", Ohio State Publications.

Mamdani, E.H., and Gaines, B.R., "Fuzzy reasoning and its applications", Academic Press, 1981.

Marquez, A. and Blanchar, C., (2004), "The procurement of strategic parts. Analysis of a portfolio of contracts with suppliers using a system dynamics simulation model", International Journal of Production Economics 88, pp. 29 – 49.

Markowitz, H., (1952), "Portfolio Selection", Journal of Finance 7 (1), pp. 77 – 91.

Momme, J., (2002), "Framework for outsourcing manufacturing: strategic and operational implications", Computers in Industry", Vol. 49, pp. 59 – 75.

Mileham, A.R., (1993), "A Parametric approach to Cost Estimating at the Conceptual Stage of Design", Journal of Engineering Design, Volume 4, Part 2, pp. 117 – 125.

Monczka, R. and Morgan, J., (2000), "Competitive supply strategies for the 21st century" Purchasing, January 13. pp. 48-59.

Olsen, R.F., Ellram, L.M., (1997), "A portfolio approach to supplier relationships", Industrial Marketing Management 26, (2), pp. 101 – 113.

ISPE Parametric Estimating Handbook, (1999), "Appendix A – Definitions of Estimating Terminology", 2nEdition, International Society of Parametric Analysis.

Probert, D. (1996), "The practical development of a make or buy strategy: The issue of process positioning", Integrated Manufacturing Systems, 7 (2), pp. 44-51.

Pugh, P., Faddy, D., & Curran, R. (2010a), Project Management: Cost Analysis, Encyclopedia of Aerospace Engineering, ISBN: 978-0-470-68665-2, Volume 8, Part 37, Chapter 386.

Pugh, P., Faddy, D., & Curran R. (2010b), Project Management: Cost Forecasting, Encyclopedia of Aerospace Engineering, ISBN: 978-0-470-68665-2, Volume 8, Part 37, Chapter 387.

Roy, R., (2003), "Cost Engineering: Why, What and How?", Decision Engineering Report Series, Cranfield University, ISBN 1-861940-96-3.

Rush, C. and Roy, R., (2000), "Analysis of Cost Estimating Processes used within a Concurrent Engineering Environment throughout a Product Life Cycle", Proceedings of CE2000, Lyon, France, July 17 – 21, pp. 58 – 67.

Scanlan, J.P., (2004), "DATUM (Design Analysis Tool for Unit Cost Modeling): a tool for unit cost estimation of gas turbine design within Rolls-Royce", The Cost Engineer, No. 4, November 2004, pp. 8 – 10.

Smith, A.E. and Mason, A.K., (1997), "Cost Estimation Predictive Modelling: Regression versus Neural Network", The Engineering Economist, Volume 42, Winter, No. 2, pp. 137 – 138.

Stewart, R., Wyskidsa, R., Johannes, J., (1995), "Cost Estimator's Reference Manual", 2nd Edition, Wiley Interscience.

Ting, P.,-K., Zhang, C., Wang, B., and Deshmukh, A., "Product and process cost estimation with fuzzy multi-attribute utility theory", The Engineering Economist, Volume 44, Number 4, 1999.

Verhagen, W.J.C., Bermell Garcia, P., Mariot, P., Cotton, J.P., Ruiz, D., Redon, R., Curran, R., (2011), "Knowledge-Based Cost Modelling of Composite Wing Structures", International Journal of Computer Integrated Manufacturing [in press].

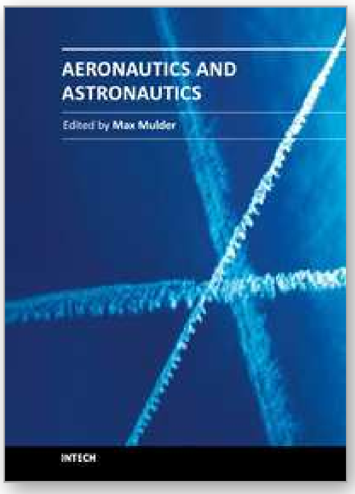
Villarreal, J.A.; Lea, R.N. & Savely, R.T., (1992), "Fuzzy logic and neural network technologies", 30th Aerospace Sciences Meeting and Exhibit, Houston, Texas, January 6-9.

Yoon, K., and Naadimuthu, G., (1994), "A make-or-buy decision analysis involving imprecise data", International Journal of Operations and Production Management, 14 (2), pp. 62 – 69.

Wang, Q. and Maropoulos, P. G., (2005), "Artificial neural networks as a cost engineering method in a collaborative manufacturing environment", Next Generation Concurrent Engineering © 2005 ISPE Inc., ISBN 0-9768246-0-4, pp. 605 – 610.

Watson, P, Curran, R, Murphy, A and S Cowan, (2006). "Cost Estimation of Machined Parts within an Aerospace Supply Chain", Journal Concurrent Engineering, Vol. 14, No. 1, 17-26.

Weustink, I.F., Ten Brinke, E., Streppel, A.H., and Kals, H.J.J., (2000), "A Generic Framework for Cost Estimation and Cost Control in Product Design", Laboratory of Production and Design Engineering, University of Twente, The Netherlands.



Aeronautics and Astronautics

Edited by Prof. Max Mulder

ISBN 978-953-307-473-3

Hard cover, 610 pages

Publisher InTech

Published online 12, September, 2011

Published in print edition September, 2011

In its first centennial, aerospace has matured from a pioneering activity to an indispensable enabler of our daily life activities. In the next twenty to thirty years, aerospace will face a tremendous challenge - the development of flying objects that do not depend on fossil fuels. The twenty-three chapters in this book capture some of the new technologies and methods that are currently being developed to enable sustainable air transport and space flight. It clearly illustrates the multi-disciplinary character of aerospace engineering, and the fact that the challenges of air transportation and space missions continue to call for the most innovative solutions and daring concepts.