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COST ESTIMATION IN PRODUCT DEVELOPMENT: ACADEMIC RESEARCH AND COMMERCIAL SYSTEMS EVALUATION

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ABSTRACT

During the past three decades, cost estimation systems have experienced some major technological innovations and paradigm shifts both in industry and academic research. There are numerous papers available reporting on research findings and the techniques used in cost estimation. This paper presents a review of current academic work and an evaluation of the available commercial cost estimation systems. However, there are few publications available covering current research and commercial applications, in particular in the area of cost estimation in product development. The aim of this paper is to provide the reader with an understanding of cost estimation techniques from the perspective of the past and present, their applications and commercial practice to support the product development processes.

KEYWORDS

Cost Estimation, Costing Methodologies, Product Development, Commercial Cost Estimation Systems

1. INTRODUCTION

This paper presents a review of current academic research in cost estimation and commercial cost estimation software systems. According to the Digital Enterprise Technology framework, 'cost' is one of the three important factors used to support to shorten the product development and realisation process for products at an early stage in their lifecycle (Maropoulos et al, 2006). This review of academic research is therefore focused on product development phases of multi-disciplinary engineering projects. The paper is organised into two main sections: (1) a review of cost estimation research, and (2) an evaluation commercial cost estimation systems. The review of the research is subdivided into the following sections:

- Review of Costing Estimation Methodologies
- Cost Estimation in Aerospace and Defence Industries
- Cost Estimation in Construction and Building Industries

- Cost Estimation in Electronics Industry
- Cost Estimation in Manufacturing Industry

This is followed by a discussion of the capabilities of each of the commercial cost estimation software.

2. REVIEW OF COST ESTIMATION

2.1. REVIEW ON COST ESTIMATION METHODOLOGIES

Niazi et al (2006) states that, "accuracy of cost estimation has a direct effect on the performance of a business enterprise. Over-estimation can result in loss of business, whereas underestimation may lead to substantial financial losses."

According to Niazi et al (2006) and Layer et al (2002), cost estimation can be categorised as having qualitative and quantitative approaches. Qualitative cost estimation techniques are used to identify the similarities of new products and manufactured products. This is particularly useful at the conceptual stages of product development. On the other hand, quantitative cost estimation techniques do not depend on historical information of a product. In contrast, these techniques are based on detail analysis of a product, for example, its design features and direct resources such as manufacturing requirements, materials and labour. A high level representation of the relevant techniques and methodologies is illustrated in Figure 1.

Roy et al (2003) observed that there is a lack of understanding about the processes used to estimate, manage and control costs across the lifecycle of a product. As a result, they presented a business case to understand the principles of 'Cost Engineering' within manufacturing industries. The main focus of the paper was to describe the techniques and tools used in cost estimation. Five different methods of cost estimation were discussed along with cost management issues including risk analysis. The methods discussed were (1) Traditional cost estimating, Activity Based Costing (ABC), (2) Parametric methods, (3) Feature Based Costing, (4) Neural Network Based Costing and (5) Case Based Reasoning.

Curran et al (2004) review the current state of the art in engineering cost modelling as applied to aerospace, in particularly costing issues directly relevant to the engineering processes in design and manufacture. Their work described the definitions and nature of cost which provides the reader an all round understanding of the basic requirements in cost estimation, and included the hierarchical representation of the total product cost. It also described the importance of controlling cost (the main factor of implementing cost modelling) in the context of engineering, product design, supply chain management and the application of knowledge-based systems. Another main focus of the research was the 'state-of-the-art review of cost estimation', this included detail descriptions of various costing techniques and methods which are also illustrated in Figure 1. The authors also discussed a new approach "genetic causal cost theory" in cost modelling. "Genetic Causal Cost Theory" provides a consistent classification of cost estimation methodologies namely compilational costing and relational costing. According to the author, "Compilational costing represents the compilational method of modelling cost within a designated cost breakdown structure. Relational costing represents the relational method of linking cost to one or more attributes to form discrete associations".

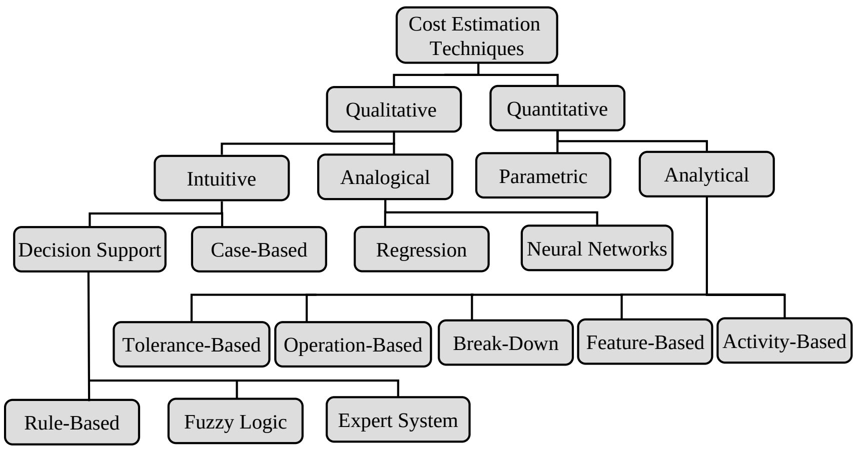

Figure 1 – A Hierarchical of Cost Estimation Techniques adapted from Niazi et al, (2006) and Layer et al, (2002)

2.2. COST ESTIMATION IN AEROSPACE AND DEFENCE INDUSTRIES

Meeting cost, schedule and performance targets is a high priority in the aerospace and defence industry, in particular where increasingly complex systems are under development. Table 1, represents the most recent academic research related to the aerospace and defence industries.

Scanlan et al (2006) identified the need for detailed and reliable cost information in order to optimize a product design to support preliminary designs for the Airbus A380 aircraft. A cost modelling methodology, the Implied Cost Evaluation System (ICES) has been developed to address multiple levels of abstraction, statistical modelling and decision support. A key feature of the ICES architecture was the provision of a statistical capability which allows the entire costing environment to be populated with statistical distributions where there is uncertainty associated with information. The method offers the potential for a common costing system to be used in support of the full range of design activity from initial optimization studies to detailed cost estimation.

Table 1- Cost estimation in aerospace and defence industries

Research in Aerospace, Defence Industry	*Functions / Techniques*	*Product Development Stages*	*Applications*
Scanlan 2006	Decision Support and Statistical Modelling	Conceptual to Detailed Design	Aerospace
Watson 2006	Parametric, Analogues (Regression Analysis)	Acquisition and Supply Chain	Aerospace
Mauchand 2006	Parametric and Decision Making	Conceptual	Military and Aviation Electronics
Sandberg 2005	Parametric, Decision Support	Conceptual to Detailed Design	Jet Engine
Filippazzo 2004	Complexity Based Cost Estimating and Design Trade Offs	Conceptual to Detailed Design	Space Electronics System
Roy 2001	Conceptual	Parametric, Feature-based	Aerospace

One of the cost cutting measures in product development is 'outsourcing' part of the design and manufacturing activities to suppliers. Research recently carried out developed a cost model and methodologies to measure suppliers' performance and analysed a company's overall spending and practices (Watson et al 2006). The research developed the Pro-COST model which focused on acquisition cost. The method can be used to generate multilevel and multifidelity cost relations for large volumes of parts utilizing process, supply chain costing data, and varying degrees of part design definition information. Estimates can be generated throughout the life cycle of a part using different grades of the combined information available.

Mauchand et al, (2006) state that, "The evolution of consumer electronic products are fast and have short lifespans. In contrast, electronics systems that are built for military and aviation applications have a much longer lifespan". Therefore, there is a need for economic and technical product evaluation in the micro-electronic design process. The research revealed that the methods deployed to integrate cost estimation into the design and subcontract of making the products are poorly developed. As such, a new method has been proposed to integrate decision making and costing tools to support the designer.

Sandberg et al (2005) have identified that as functional total care products emerge in the jet engine industry, there is a need for product life-cycle models capable of definition and evaluation of life cycle properties. The key contribution of their work was the design support model and the application of parametric cost estimation techniques and knowledge-based engineering to assess life-cycle cost, i.e. to allow designers to see the effect of decisions making between a number of design, manufacturing, and maintenance activities at the conceptual design stage.

Filippazzo, (2004) developed a parametric method, named Complexity Based Cost Estimating Relationships (CCER), to support system design tradeoffs throughout the development phases of space system projects. CCER is used to quantify the risk content of a specific program and correlate these with the success or failure of a mission. As such, Filippazzo adapted the principal to the system and subsystem design processes in order to proactively manage complexity (cost, time and risk). The method aims to bridge the gap between cost, schedule and risk so that the information allows the design engineer to make design choices.

Roy et al (2001) described the development of a cost-estimating methodology for predicting the cost of engineering design effort during the conceptual stages of product development. The methodology was used within an aerospace manufacturer. The main objective was to generate a suite of technical Cost Estimating Relationships (CERs) that integrate both quantitative and qualitative non-recurring airframe engineering input for the design process. The two main cost estimating techniques utilized within this research were parametric cost estimating and feature-based costing.

2.3. COST ESTIMATION IN CONSTRUCTION AND BUILDING INDUSTRIES

In the construction and building industries, accurately forecasting the cost of future projects is vital for winning business contracts. Table 2 highlights relevant research in this industry.

Ugwua et al (2005) reported research focussing on design from the concept stage through to the detailed and construction stages of design to identify which areas need to be considered in order to determine future maintenance requirements of a bridge project. The research was to determine bridge maintenance costs based on the environmental impact in material specification, construction methods and durability of structural components. This accounted for all the costs and benefits in the project throughout its design life. The approach was to integrate the bottom-up and top-down approaches for project level design decision-making.

Yu and Lai (2003) developed a web-based real time cost estimation request system (WICE) for the construction industry. The development was based on the application of nero-fuzzy software for the data mining of conceptual cost estimation knowledge from historical cost data. The system provides an all-time assessable feature to enable users to perform real-time cost estimation globally. In addition, within the WICE framework there was a centralised knowledge-based maintenance and management mechanism to ensure that up-to-date cost estimation knowledge was available.

Table 2- Cost estimation in construction and building industries

Research in Construction and Building Industry	*Functions / Techniques*	*Product Development Stages*	*Applications*
Ugwua 2005	Bottom-up and Top-down approach	Concept to Detailed	Bridge Construction
Yui 2003	nero-fuzzy, historical data	Concept to Detailed	Construction
El-Harm 2002	Cost Breakdown Structure	Whole Life Costing	Building
Nicolini 2000	Target Costing	Whole Life Costing	Construction

El-Harm et al (2002) developed a framework for capturing 'whole life cost' (WLC) data for a construction project. In the framework, they proposed that the first step of WLC analysis was to create or adopt a cost breakdown structure that identifies all relevant cost categories in all appropriate life cycle phases. The proposed WLC breakdown data structure was divided into five levels: (1) Project Level, (2) Phase Level, (3) Category Level, (4) Element Level, and (5) Task Level. In the centre of the cost breakdown structure there was a pool of data and information. Based upon these conditions, they developed a WLC breakdown data structure of a building, this was then computed as a system dictionary in which all data was listed and defined. The generic WLC data structure was used by all project team members for the collection of consistent WLC data. The benefits of the methodology were:

- Enabled the project team to generate alternatives and consider "what-if" scenarios to obtain optimum WLC.
- Reduced bidding and design time by reusing data from previous projects.
- Encouraged the project team to use WLC which helps in designing a cost-effective building which results in the building being more effective to operate and maintain.

Nicolini et al (2000) address the question of whether 'target costing' and whole life costing can be applied in the construction industry. Nicolini states that "Target costing is an approach for the development of new products aimed at reducing their life-cycle costs while ensuring quality, reliability and other consumer requirements, by examining all possible ideas for cost reduction at the product planning, research and development and prototyping phases". The key impact of Nicolini's investigation was to develop an innovative practice to improve supply-chain management in the design and delivery of major capital assets. It is based on the adoption of a market-driven attitude combined with a disciplined effort to involve the whole supply chain in developing products which offer the best achievable balance between through-life cost and functionality.

2.4. COST ESTIMATION IN THE ELECTRONICS INDUSTRY

"Competitive pressures continue to force the electronics industry to keep costs down and to reduce the duration of the development cycle for its products. These goals must be accomplished while maintaining the quality of the products and keeping up with the latest technology" (Haberle and Graves, 2001). Table 3 highlights relevant research in this industry.

Kleyner et al (2004) present a method for calculating desired reliability demonstration for a product validation process, based on LCC minimization. The proposed method suggests a way to optimize the target reliability based on minimization of the sum of the validation cost and expected reliability-related warranty returns, by analytically linking the product validation cost with the expected warranty. Validation cost usually includes engineering and capital expenses associated with full-scale environmental, mechanical, electrical, and other types of testing at various stages of product development.

Giachetti and Arango (2003) developed an activity-based printed circuit board (PCB) cost estimation model that estimates PCB cost based on the design parameters. The activities were defined so that the design decisions become the cost drivers and thus enable the cost estimation model to be utilised early in the design process to compare different PCB design alternatives and to let the designer assess the impact of their decisions on final cost. The activities were defined based on the impact of design features on the activity. Based on this approach, cost centres can be modelled as individual sub-systems. Cost centres can be established at the conceptual stage initially, but when there is more information available as the design progresses, the cost drivers associate with the cost centre can be updated accordingly and hence the cost of the design can be estimated.

Table 3- Cost estimation in electronics industry

Research in Electronics Industry	***Functions / Techniques***	***Product Development Stages***	***Applications***
Kleyner 2004	Lifecycle Cost (LCC)	Through Lifecycle	High-Volume Automotive Electronics
Giachetti 2003	Activity-Based and IDEF0	Manufacturing	PCB Fabrication
Sandborn 2003	Genetic Algorithms	Manufacturing	Avionic PCB
Miraglia 2002	ABC and spreadsheets	Manufacturing	Semiconductor Wafer
Hooper 2001	ABC and spreadsheets	Manufacturing	PCB
Trichy 2001	'Bottom-up', Sensitivity Analysis Monte Carlo,	Manufacturing	Electronic Assemblies
Jiao 1999	ABC and Historical Data	NPI to Total Product Cost	PCB Assembly

An alternative approach in PCB cost estimation was by Sandborn et al (2003). They developed a methodology for the assessment of manufacturing costs associated with embedding resistors and capacitors in PCBs and provide cost modelling results for an avionics board. The methodology employs genetic algorithms coupled with a cost model to help in identifying an optimum solution of mixing various passives to embed on a PCB.

Miraglia et al (2002) present a methodology to be used to aid cost reduction activities by providing semiconductor wafer cost breakdown. The cost breakdowns allow a more complete understanding of the cost contribution of different factors in productivity studies. The approach utilised the ABC technique and historical data (such as manufacturer, machine type and process type) by adding cross-referencing tags within the tooling database in association with relevant production operations to produce a specific product. However, this methodology is only used to predict and analyse production cost at a generative level.

Hooper et al (2001) explored the ability of an electronic enterprise that manufactures PCBs for customers in the aerospace, automotive and telecommunication industries. The research was to develop and implement no-cost/low-cost methods and techniques for a "total solution costing system" using ABC and spreadsheets techniques. The objective of the methods was to enable the electronic enterprise to shift from mass/lean production to the customisation environment of agile manufacturing. However, the approach defined in the research was mainly focused on examining its operational cost for inter and intra enterprise activities such as overheads and direct labours.

Trichy et al (2001) present a Technical Cost Modelling (TCM) methodology for an electronic assembly environment that included test/diagnosis/rework processes. They defined "TCM as a process based and 'bottom-up' approach for cost estimation. The goal of TCM was to understand the overall and component costs of a product and how these costs change when product and/or process changes are made". In TCM, the total cost was broken down into a set of individual cost elements. For example, they divided costs into:

- Variable cost elements, which include materials, labour, and utility.
- Fixed cost elements, which include equipment, tooling, maintenance, and the cost of capital.

Each of these elements was estimated separately and was summed up to provide the total cost. Once these costs are established, sensitivity analysis can be performed to understand the impact of changes to key parameters like annual production volume, process yield, throughput and tooling cost.

Jiao and Tseng (1999) proposed a pragmatic approach to product costing prior to the actual production run by adopting the ABC concept and utilising historical cost data. The approach involves two stages, namely the preparatory stage and the production stage. In the preparatory stage, standard routings are first extracted from existing products. A generic activity hierarchy is established according to the analysis of standard routings, where cost drivers for each activity are identified and summarised by appropriate Cost-related Design Features (CDFs). Then the Maynard Operation Sequence Technique is employed to analyse each operation of standard routings to determine the associated standard time. Historical cost data are analysed to induce the relationships between the CDFs and standard time, namely Time-Estimating Relationships.

2.5. COST ESTIMATION IN MANUFACTURING INDUSTRY

In manufacturing industry, cost estimation is the procedure of approximating the costs of producing a product before all stages of the product development cycle have been executed. The estimator's goal in manufacturing is to accurately estimate the costs to associate with making products. Table 4 summarises a few of the recent research in this industry.

Table 4- Cost estimation in manufacturing industry

Research in Manufacturing Industry	*Functions / Techniques*	*Product Development Stages*	*Applications*
Chougule 2006	Analytical and Parametric	Conceptual	Casting
Feldman 2006	Analogues (Group Technology), Parametric (top-down) and Detailed Models (bottom-up)	Conceptual to Detailed	Machining parts
Ten Brinke 2004, 2000	Variant-based and ABC	Conceptual to Detailed	Batch Manufacturing
Koltai 2000	Simulation-based model, ABC	Detailed	Manufacturing and Product Costs
Ben-Arich 2000	Analogous	Detailed	Machining Parts
Jiao 2000	Commonality	Detailed	Product Platform
Thevenot 2006	Commonality	Detailed	Product Platform

Chougule and Ravi (2006) present a hybrid model combining analytical and parametric approaches developed for early cost estimation of castings, and implemented it in an integrated product process design environment. The development of this early cost estimation tool is to aid decision making when a choice needs to be made among various alternatives for geometric, material or process parameters. In particular tooling cost that is the most difficult to estimate and a parametric approach has been applied for this purpose. In addition, the model will enable the analysis of the combined effect of preliminary design of product and process on cost, the overheads are assigned based on casting weight.

Feldman and Shtub (2006) state that “Methods for cost estimation are classified into three major groups: (1) analogous approaches, (2) parametric models and (3) detailed models.” In the analogous approaches, the products are classified into product families with similar characteristics. Group Technology (GT) is one way of using an analogous approach for cost estimation. Parametric models for cost estimation are top-down and are usually based on some calculations. Models in this group include regression analysis and neural networks. In the detailed engineering approach, cost estimations are done bottom-up, starting with the cost of the smallest component and aggregating to the total product cost.

According to Ten-Brinke et al (2000), (2004), there are two further cost estimation methods being used to predict manufacturing cost, these are:

1. Generative cost estimation: a method is based on the fact that the cost of a product depends on the required production processes and materials. By determining the required manufacturing operations and materials and the extent to which these are used, it is possible to generate a cost estimate. In general, generative cost estimation generates a detailed and accurate cost estimate. A disadvantage of generative cost estimation is the fact that it requires much detailed information. The generation of this information is usually very labour intensive and time consuming.
2. Variant-based cost estimation assumes that geometrically similar products are manufactured with the same production processes. The costs of historical products that are similar to a certain degree can be used to generate a cost estimate, i.e. the average costs of these products. It is clear that adequate historical information is essential. Because no information has to be generated for the cost estimation process, it is a relatively quick method and very useful in the early product development phases.

Rather than use the traditional accounting method, Koltai at al (2000) offer a simulation-based model that uses ABC technique to estimate the manufacturing and product costs in an advanced manufacturing organisation that was run under either a push or pull system (Ghiani et al, 2004). The simulation model has identified every single activity that either directly or indirectly affects the cost of an item. As a consequence, a prototype manufacturing system operating under both push and pull control strategies has been built using the ABC-based mathematical model to calculate the manufacturing and product costs.

Ben-Arieh (2000) proposed a hybrid system for cost estimation of rotational parts. The system combines the analogous approach with the detailed approach. The analogous approach is used for retrieving machining parameters from the shop’s database, and the detailed cost calculations are based on those parameters, the part’s geometry and the available cutting tools.

Jiao and Tseng (2000), state that unless standardisation efforts have been institutionalised, designers are likely to design new parts each time a new product is planned rather than trying to use as many existing parts as possible. As such, their research has recognised the necessity to understand the product family (Meyer and Lehnerd 1997) through developing commonality measurements. The goal of their research is to present design and process engineers with insight into product family design and manufacturability. They identified two sources of commonality: (1) the component part commonality and, (2) the process commonality. The component part commonality is based on counting the average applications per component part and takes into account product volume, quantity per operation, and the price/cost of the component part. The process commonality concerns process flexibility, lot sizing, and scheduling/sequencing into one analytical measurement.

Other research using 'commonality' as the cost estimation method to reduce product development cost was reported by Thevenot and Simpson (2006). Their research developed a framework for redesigning a product family using commonality indices. The research investigated the relationships between the product design and the resulting degree of commonality within a product family using six commonality indices.

The impact of both research methods using commonality criteria is that they can be used to determine cost based on process and product parameters directly. In particular, the methods can be used in the conceptual design stage to identify common components in any level of a specific design.

3. COST ESTIMATION SYSTEM EVALUATION

Table 5 illustrates a selection of cost estimation systems and their principal requirements. The cost estimation systems have been examined via the providers' website and software evaluations, subject to availability. The aim in such a review was to examine the current development trends and offerings of the commercial systems. There are several basic requirements relating to cost estimation tool selection, and the selection of these were based on experiences. The key requirements and their associate comments are shown in Table 6.

The evaluation of the system review is shown in Table 5. The result shows that there is no one software system can fulfil all requirements. However, each of the software systems has their own advantages and applications. For example:

- ACEIT (2007) plug-ins allow users to incorporate data from external third party applications, these plug-ins enable integration with MS-Project, Price-S, Price-H/HL, SEER-SEM and SEER-H.
- Cost Advantage (2007) provides a user-parameterised output module. Its Enterprise Cost Management (ECM) application creates a central repository for the collective cost expertise of an organisation and makes that knowledge available on demand across functional boundaries.
- KAPES (2007) is a manufacturing cost planning application and database which enables manufacturers to determine the cost to make, buy, and sell individual parts and assembled products.

Table 5- Cost Estimation Systems Evaluation

	Requirements \ Package Name		SEER	Relex	Vanguard	PRICE	COSYSMO (SoftStar)	lccWare	Pulsar	KAPES	Cost Advantage	ACEIT
1	Domains Specific	Aerospace		■			■			■		■
		Automotive		■						■		
		Construction						■	■			
		Defence		■		■		■				■
		Electrical		■								
		Electronics	■	■		■				■	■	
		Mechanical	■	■		■				■	■	
		Ships		■				■				
2	Whole Life Cycle	Concept	■	■		■	■	■			■	
		Development	■	■		■	■	■		■	■	
		Production	■	■		■	■	■		■	■	■
		Utilization		■		■	■	■	■			■
		Support		■			■	■	■			■
		Retirement	■	■				■				
3	Modular Modelling and Modular Libraries		■	■	■	■		■			■	
4	Parametric Models Availability		■		■	■					■	
5	Detailed Modelling		■	■		■	■	■	■	■	■	■
6	Mix and Match of Parametric and Detailed Models		■		■							
7	Expressive Model Communication to User				■			■				
8	Statistical Analysis	Regression			■	■						■
		Learning Curve	■								■	■
9	Risk Analysis	Uncertainty	■		■	■						■
		Sensitivity	■	■	■	■	■	■				
		Trade-off	■	■		■	■					
		Monte Carlo	■		■	■						■
10	Knowledge-Based Support		■		■	■				■	■	■
11	Historical Database				■	■			■	■	■	■
12	Web Based Interface				■	■					■	
13	Open Architecture		■	■	■		■				■	■

■ Presence □ Absence

It offers a unique combination of software tools and online manufacturing knowledge.

- Pulsar (2007) is used to create estimates for facilities construction and maintenance. It was specifically developed for use with job order and delivery order contracts. The software allows estimators to compare and contrast construction bids, providing a standard basis for contract negotiations.

handling user-defined cost breakdown structures, net present value calculations, inflation factors, calculations multiple time intervals and sensitivity analysis. It is also supplied with pre-built cost breakdown structure templates based on industry standards.

- Vanguard system (2007) is a general purpose graphical modelling tool that allows users to build models in the form of hierarchical trees. Thus, it has the advantage of solving a complex problem by simply dividing the complex issue into more simpler problems and further breaking down the problem into finer element. The software also provides a great deal of visual feedback that makes a model more open and transparent.

Table 6 - Cost Estimation Systems Basic Requirements

	Key Requirements	Comments
1	Domain Specific	Industrial sectors the software focus on
2	Whole Life Cycle	Stages of the lifecycle the software focus on
3	Modular Modelling and Modular Libraries	Ability to perform modular based cost modelling and support by a specific library
4	Parametric Models	Ability to perform parametric modelling
5	Mix and Match of Parametric and Detailed Models	The ability of allowing user to implement cost model based on little information and gradually building up a detailed analysis
6	Detailed Modelling	Ability to perform accurate and precise analysis based on detail information
7	Expressive Model Communication to a User	The ability to allow users to see the relative importance of input parameters to the output, for example, to enable the user to see a picture of how the result is arrived
8	Statistical Analysis	Supporting by basic functionalities of statistical analysis
9	Risk Analysis	Supporting by basic functionalities of risk analysis
10	Knowledge-Based Support	To allow user to use existing knowledge-based and create their own knowledge to support their analysis.
11	Historical Databases	The availability of previous data and allow users to store current data for future references.
12	Web Browser Interface	The ability to allow users to interact and performing tasks remotely via web browsers.
13	Open Architecture	Product built on this standards-based platform is usually supported by wide arrays of applications and integrations. Thus, to ease the ability of sharing data with other products and allow users to create an add-on to enhance their collaboration.

- LCCWare (2007) was developed to establish a life cycle costing model. The cost elements are represented in the form of a tree structure that is created interactively. The objects at the bottom level of the tree represent cost functions that can comprise both local and global variables and constants. Libraries of frequently used cost functions allow rapid development of the model.
- COSYSMO Costar (2007) was built for software development based on the Constructive Cost Model (COCOMO) (Hale et al, 2000). It allows estimates to be produced of a project's duration, staffing levels, effort, and cost. It also allows users to make trade-offs and experiment with "what-if" analyses to arrive at the optimal project plan.
- Relex LCC (2007) was developed to calculate the cost of a product over its lifetime. It is capable of

Among all the commercial systems shown in Table 5, the most dominant ones in the market are considered to be SEER from Galorath (2007), and PRICE from PriceSystems (2007). These two software systems provide useful tools for cost estimating and use historical data to assist in the decision making process. In particular they provide accurate costing data for frequent/similar products at the detailed design level. They include the hardware costs but provide little detail on the non-recurring costs and through-life-costs. The through life costs they have examined tend towards disassembly, re-use of products and the costs associated with this. In general these tools are effective for repeated products that build on a base product model with incremental design changes where much of the detail is available.

4. CONCLUSIONS

In this paper, a review has been carried out based on the research conducted by academia. In particular the paper has given a comprehensive overview of cost estimation, showing the key impact of different cost elements in the product development process. This paper has also summarised the findings of a range of commercial systems for cost estimation. The survey and evaluation process was based on a set of key requirements. The information of these requirements was obtained through the software providers' websites.

The application of costing techniques and methodologies are inter-dependent of the type of products and industry. For example, product requirements in the aerospace and defence industries are usually considered to be more complex. Construction and building industries are focused on forecasting of a complete project and preparing sufficient information for a bidding process. Manufacturing industries are focused on product design and redesign to accurately estimate the costs associated with a new product. Electronic industries on the other hand are concerned with keeping costs down and to reduce the duration of the development cycle for its products.

The fundamental aspect of this review paper was to provide readers with an understanding of the basic principles of cost estimation techniques and the advances of current academic research and commercial cost estimation software. This paper is presented as part of the joint research being undertaken by the Universities of Bath and the West of England on the investigation of "Cost Estimating for Low Volume Long Life Products in Electronic Defence Systems".

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