COST ESTIMATION METHOD SELECTION: MATCHING USER REQUIREMENTS AND KNOWLEDGE AVAILABILITY TO METHODS

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Abstract

Within the cost estimation literature and in practice within organisations a range of cost estimation methods are used to predict costs prior to activities being undertaken. Estimates generated utilising different estimation methods provide different projections of the anticipated cost. The projected differences in cost could have a significant impact on the overall viability of a project or the selection of the optimum design for a product or process.

As a primary step towards creating a mechanism to select cost estimation methods for given situations this paper attempts to represent the cost estimation domain. Based on the representation and other research an innovative mechanism to select the most appropriate cost estimation methods, given the information available and user requirements is presented.

Keywords: Cost Estimation, Decision Support, Classification

Background

The ability of a company to compete effectively in the increasingly competitive global market is influenced to a large extent by cost [1]. Cost is the expenditure necessary for the attainment of a goal; therefore cost estimation is predicting the cost prior to undertaking the activity. The motivation to estimate costs is to aid with decision making, cost management and budgeting. If costs are higher than the price that organisations can attain for products then the products will make losses and this influences the future viability of organisations. Knowledge of the potential cost before the task is undertaken provides an opportunity to optimise design to minimize costs or to quote a price to customers that would enable a profit to be achieved.

A survey of the literature shows that a number of different methods can be used to estimate costs. However the methods are not consistently categorized. Roy [2] describes the cost estimation domain using only five methods: Traditional, parametric, feature based, case based reasoning and neural networks. Cavalieri et al [3] suggest three main quantitative approaches: Analogy-based techniques, parametric, engineering approaches (detailed) and neural networks as a possible fourth approach. Boehm [4] identified seven major software cost estimation techniques: Algorithmic models; Expert Judgment, Analogy, Parkinson, Price-to-win, Top-down and Bottom-up. The Parkinson principle ("work expands to fill the available volume") and Price-to-win can be differentiated as cost management rather than cost estimation techniques and therefore there are only five serious cost estimation techniques described.

Based on analysis of the literature ten methods to estimate costs have been identified including all the methods that construct the classifications by the authors above and additional methods that have been described by other authors:

1) **Parametric** cost estimates are defined by the Parametric Cost Estimating Handbook [5] as using Cost Estimating Relationships (CERs) and associated mathematical algorithms (or logic) to establish cost estimates.
2) **Neural Networks** learn the impact of the attributes on cost by automatic analysis of a set of historical data.
3) **Expert Judgement** is a process where humans from the domain in which the estimate is being made provide an estimate of the cost.
4) **Function Costing** was proposed as a possible estimation method by French [6]. The concept is that a proposed product or system can be costed directly from a specification of its performance.
5) **Feature Costing** is the integration of CAD/CAM with cost information for cost estimation early in the design process via feature-based modelling as presented by Weirda [7].
6) **Group Technology** estimating is based on the similarity of the product being estimated to the products within the classification.
7) **Case-Based Reasoning** consists of a library of previous cases and retrieves situations similar to the problem at hand and generates a solution based on the previous cases.
8) **Knowledge-Based Systems** attempt to imitate the reasoning of experts to estimate costs.
9) **Generative Costing**- sometimes termed analytical cost estimation is when the cost is predicted by aggregating the processes involved in product creation.
10) **Activity-Based Costing(ABC)** was proposed by Cooper and Kaplan [8] as an alternative to traditional accounting methods, ABC is the same as Generative costing but the overheads are allocated to where they are incurred.

Necessity for the research

The ten methods have all been applied in published literature. The literature highlights how the methods all have limitations and are not universally applicable as summarised in Table 1.

Method	Advantages	Limitations
Parametric	• Makes clear the influence of parameters on cost • Repeatable and objective	• Parameters not included could become important • Simplistic
Neural Network	• Accurate estimates possible because of the detail • Can be updated and retrained	• Logic not visible • Complex • Require a large case base to be effective
Expert Judgement	• Quick to produce • Flexible	• Susceptible to bias • Unstructured • Different experts use different mechanisms
Function Costing	• Allows the integration of requirements and cost estimation • Allows designers to compare cost and functionality	• Need to be able to allocate cost to functions • Does not generate an accurate estimate
Feature Costing	• Enables integration of CAD/CAM with cost information • Could be automated	• No consensus on what features are • Require large resources to implement
Group Technology	• Can propose solutions rapidly • Intuitive- user knows the origin of estimate	• Case base may be bias • Doesn't handle innovative solutions • Require a large case base to be effective
Case-Based Reasoning	• Can propose solutions rapidly • Plays the role of collective	• Need a reliable case base • Doesn't handle innovative solutions

	memory of the enterprise	• Require a large case base to be effective
Knowledge-Based Systems	• Logic is visible • Stores the knowledge of the organisation • Structured	• Knowledge could become obsolete • Doesn't handle innovative solutions
Generative	• Accurate estimates possible because of the detail • Detailed breakdown useful for negotiation	• Time consuming • Detailed data may not be available
Activity Based Costing	• Allocates costs according to where they are incurred • Gives a stronger indication of potential profitability	• Time consuming • Detailed data may not be available • Allocation of overhead is complicated

Table 1. Advantages and Limitations of Cost Estimation Methods

The majority of the literature compares one method to another for a particular case (e.g. [10][3][9]) or shows how a new method can be applied to a case study(e.g. [6][11]). However, some authors have included representations in articles displaying suggestions of when different methods are applicable. Rush and Roy [12] summarise the domain with a matrix (Figure 1) indicating the stages of the product development process where different cost estimation methods are applicable. Discerning which stage of the product development process a product fits within would not necessarily be as simple as the matrix might suggest. The matrix seems to be constructed based on the author's knowledge of the domain and is not justified using research. Additionally, the matrix does not consider the fuzziness of the problem of selecting cost estimation methods by saying either a method can or can't be used.

TOOLS AND PROCESSES					Detailed Cost	Cost Management			
USED WHEN:	PE	NN	CBR	ABC	Estimation	VA	VE	DTC	TC
Concept design phase (innovation)	✓	✗	✓	✗	✗	✗	✓	✗	✗
Concept design (similar products)	✓	✓	✓	✗	✗	✗	✓	✗	✓
Feasibility Studies	✓	✓	✓	✗	✗	✗	✓	✗	✓
Project definition	✓	✓	✓	✗	✗	✗	✓	✓	✓
Full Scale development	✗	✗	✗	✓	✓	✓	✗	✓	✓
Production	✗	✗	✗	✓	✓	✓	✗	✓	✓

Figure 1. Estimating Process Matrix – [12]

Duverlie and Castelain [10] also represented the application of cost estimation methods based on stages of the product development process. However there is also no research presented to backup why the methods can only be used at the stages suggested.

Bode [13], summarised the application requirements for costing methods using a diagram with three dimensions (Figure 2). The three parameters are: size of case base, number of cost drivers and certainty level. Different areas of the diagram are shaded differently to show when different costing methods are applicable. The representation appears to be a two-dimensional depiction of a three-dimensional cube with size of case base, number of cost drivers and certainty level as the three axis. However this is not the case, the paper indicates that only two parameters are considered at one time so Figure 2 could have been represented as three graphs as in Figure 3.

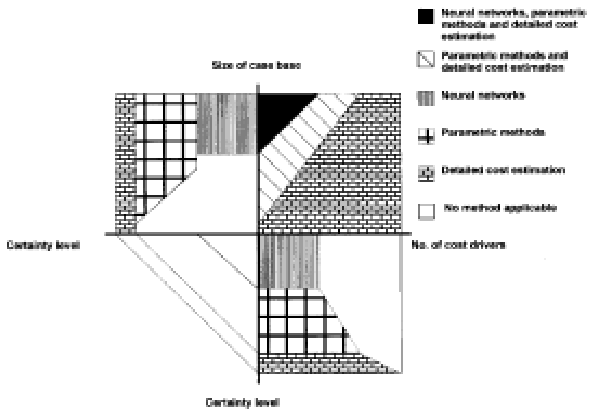

Figure 2. Properties of application domains for different cost estimation methods – [13]

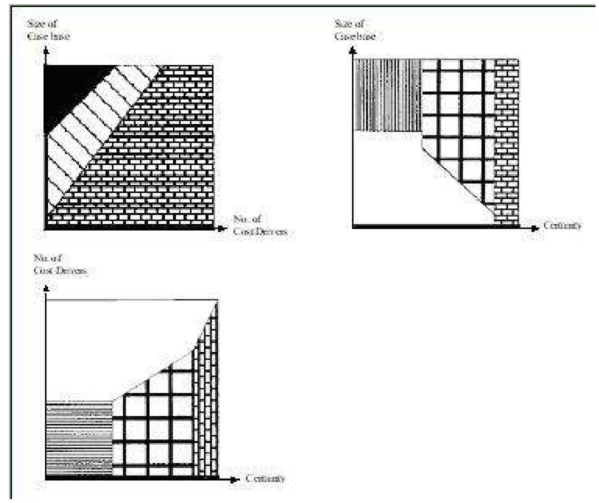

Figure 3. Three graphs based on Bode's representation

This review shows that there are an array of methods that can be used to estimate costs and many articles seek to illustrate how a new method is plausible or how one method gives superior accuracy for a given case. The stage of the product lifecycle is presented as one factor that dictates which estimation methods are applicable. Other factors suggested include the size of the case base and the number of cost drivers. None of the literature presents a model enabling the consideration of multiple criteria to choose the most appropriate cost estimating method.

Classifying the Cost Estimation Methods

The ten cost estimation methods outlined above were classified using Web Grid III based on a cluster analysis using ten constructs (Figure 4). A construct is a term used in Web Grid to describe the dimensions on which the domain being considered is construed. The ten constructs distinguished all of the methods so that the methods could be classified. The cost estimation methods were allocated a number between one and five depending on which opposing description in the construct the method was best described by. If a method is best described by the right hand side of the construct on the cluster analysis the method was graded five and if the method was best described by the left hand side of the construct the method would be graded one. Grades between one and five were used when the costing methodology did not fit exactly to either opposing term in the construct but fitted somewhere in between.

Web Grid organises the cost estimation methods and constructs so that methods with similar scores against the constructs are grouped together. The numbers within the matrix show the scores against the constructs clustered together. The numbers one to ten around the outside are the numbers allocated to the cost estimation methods and constructs when setting up the analysis and are not indicative of any ranking or score.

The lines in the bottom-right hand part of Figure 4 display a hierarchy where cost estimation methods are sorted based on the cluster analysis into groups of similar methods. The intersections where lines meet were allocated named nodes based on the constructs and this hierarchy formed the basis of the classification in Figure 5. This could be considered a top-down method of classifying as the ten cost estimation methods are distinguished and grouped based on similarities so that more specific classifications are formed further down the tree.

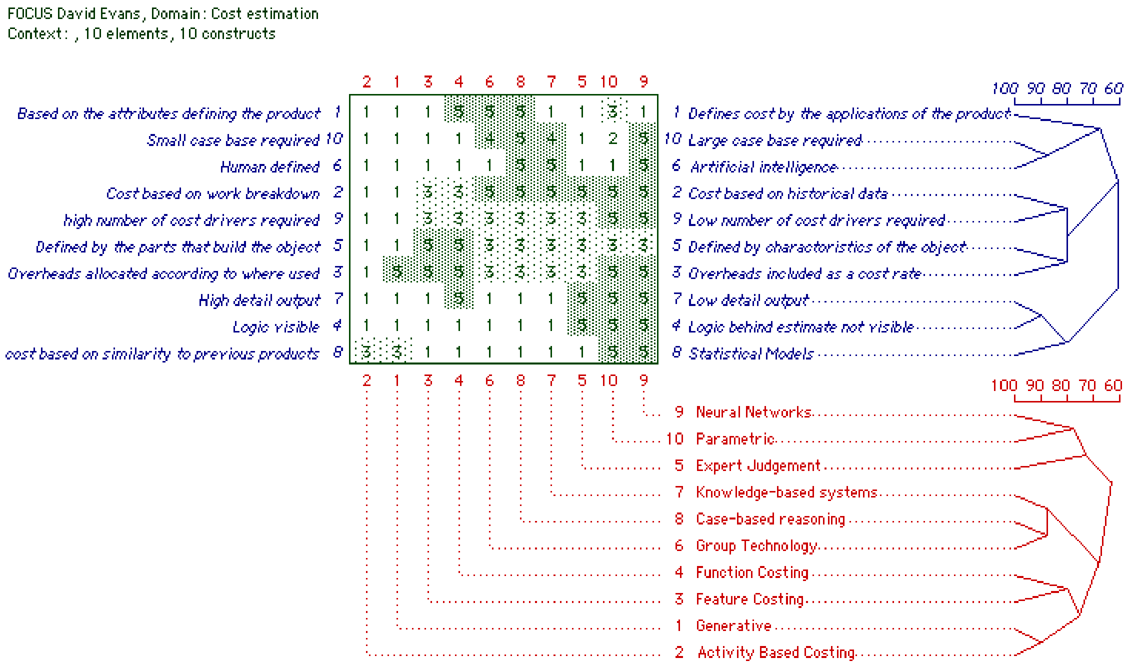

Figure 4. Cluster Analysis from Web Grid III

New Representation

Figure 5 shows the classification of the ten cost estimation methods based on the cluster analysis in figure 4. The highest-level separation in the tree splits the methods into two categories: “Transparent Box” and “Black Box”. Black box is a term often used in the Cost Estimating domain to describe methods where the reasoning for the solution is not apparent or intuitive. The Term “Transparent Box” describes methods where the reasoning for the solution is apparent.

There are three methods on the “Black Box” side of the tree: Expert Judgement; Neural Networks; and Parametric Methods. The reasoning is not transparent with Expert Judgement because the mechanism that creates the estimate is undertaken within the mind of the expert based on the expert’s experience. Neural Networks and Parametric methods are distinguished from Expert Judgement, as the estimates are formed based on statistical analysis of historic data.

The remaining seven methods and classified as “Transparent Box” as the methods propose a solution in a manner that makes reasoning for the solution apparent. These seven methods are separated into Analogical methods and Detailed methods. The Analogical Methods are: Knowledge-based systems; Case-based reasoning; and Group Technology. These methods are considered analogical because the cost is estimated based on the new case’s similarity to previously encountered cases.

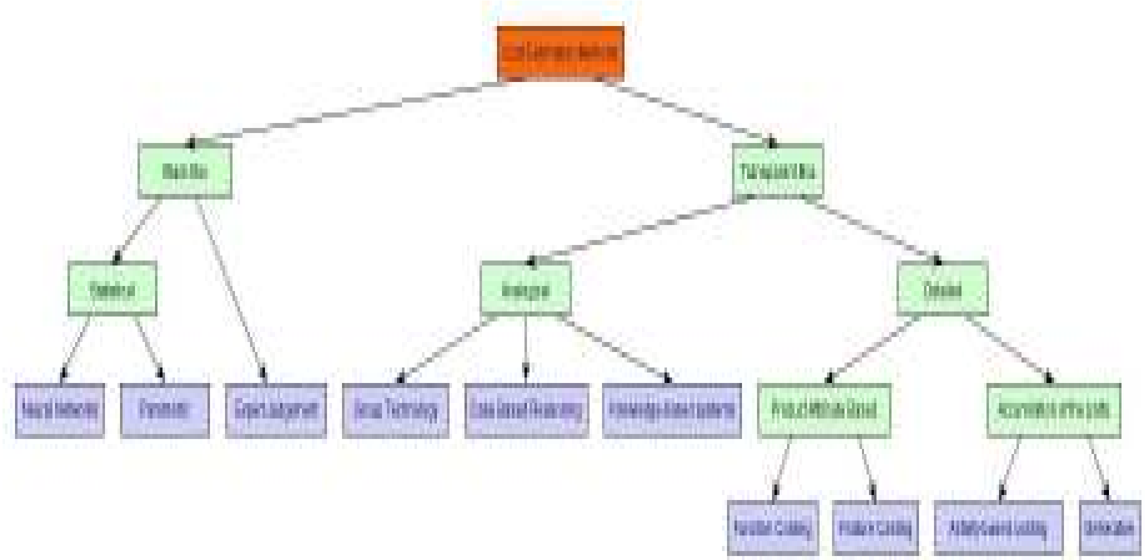

Figure 5. Classification of Cost Estimation Methods

The last four methods are considered “Detailed” methods; “Detailed” denoting that the methods calculate the costs based on the summation of all the elements that form the whole case that is being estimated. These four methods are divided into methods that “Product Attribute Based” and Methods that are based on the “Accumulation of the Parts”.

Function costing and Feature costing are classified as “Product Attribute Based” because these methods estimate the cost by summation two different kinds of attributes of the product: Features are characteristics of the element being estimated, whereas functions are tasks that the element can be utilised for.

Activity-based costing and Generative costing both estimate costs summation of estimates of all the parts that form the whole element being estimated. The two methods are distinguished from each other by the manner in which the overheads are allocated to the cost of the individual elements.

Method Selection

Based on the literature review and the classification a simple set of rules have been established and embedded into a crisp decision tree model called DESCEM (DEcision support for the Selection of Cost Estimation Methods) using Decision Pro (http://www.vanguardsw.com). Decision Pro provided the functionality required to develop a rule based model and also gives an intuitive presentation of the analysis. Therefore it is possible to rapidly understand why the model generated the output. Figure 6 shows the structure of the decision tree and figure 7 shows the inputs and outputs from the model. For this initial model the inputs are fairly simple, mostly Boolean true or false values. However, the design stage has been separated into five categories: concept; feasibility; project definition; full scale development; and production and the output required has been broken down into three levels: single output; partial breakdown of costs; and detailed output.

The outputs from DESCEM are also simple true or false values. The outputs show which methods are applicable given the scenario described by the inputs. For example, Smith and

Mason [15] compare parametric and neural network methods for estimating the cost of pressure vessels. The requirements used in the article are: logic not visible; single figure estimate required; concept life cycle stage; not new innovation outside the current product set; there is an historical case base available; a long time required to build the model and the required solution is reusable. DESCEM suggests for the scenario set out in Smith and Mason that both neural network and parametric models are applicable. However, DESCEM suggests that only a parametric model is applicable if the product being estimated had been a new innovation outside the current product set (this rule is based on the matrix in figure 1 from [12]).

A case from the literature where DESCEM does not recommend the method that was actually used in the article is Giachetti and Arango [16] applying an ABC model to the fabrication of Printed Circuit Board (PCB) at the conceptual design stage. Figure 1 suggests that ABC models are not applicable at this early design stage and this has been reflected in DESCEM. DESCEM may need an additional rule to reflect the situation modelled by [16] suggesting that detailed methods can be used at the conceptual design stage if enough knowledge exists about the product or if the product is relatively simple. Conversely the model suggests that knowledge-based systems may be applicable for the case outlined. Although [16] defines the model as an ABC system it may be considered a knowledge- based system within DESCEM as the cost is being estimated based on an inferred product configuration established from previous experience.

Summary

The literature review identifies a number of methods that have been used to estimate costs and gives examples of how the methods have been categorised and represented. A classification of the methods has then been presented showing a possible view of the domain. The review and classification lead to the first basic version of the DESCEM model which demonstrates how a simple rule base can be used to suggest suitable cost estimation methods based on a situation inferred from a group of basic inputs.

Future Work

The next step for this research is to gather evidence as the basis for the construction of a broader rules set for potential inputs and outputs of DESCEM. Using this evidence research will be undertaken to determine the viability of using a metric of suitability so that rather than the model simply giving a Boolean result saying either a method is or isn't applicable the methods can be ranked from most suitable to least suitable and recommendations of what is required to make methods more applicable can be offered.

Inputs:

design stage	true
logic visible	false
innovation	false
Reusable	true
Long time to build model	true
historical cost data	true
detailed output	false

Outputs:

parametric	true
neural net	true
generative	false
Expert Judgement	false
knowledge based systems	false
casebasedreasoning	false
group_technology	false
function_costing	false
feature_costing	false
activity_based_costing	false

Figure 6. Inputs and outputs table from DESCEM

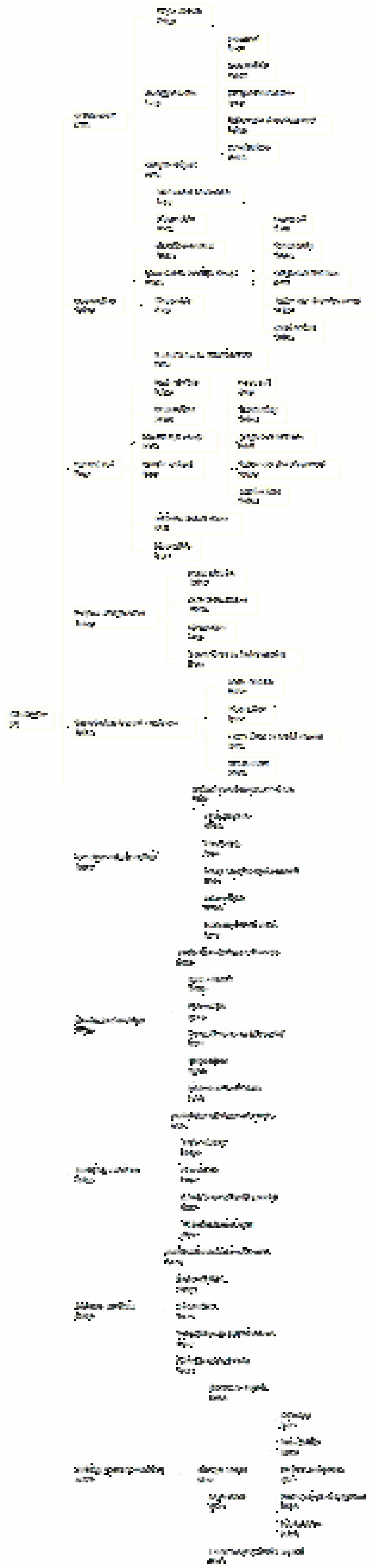

Figure 7. The full DESCEM decision tree

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