Research Design for a Comparative Study of the COCOMO II Model and a Systems Cost Model

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Abstract

This paper argues the need for a comparative study between the COCOMO II model and a systems cost model. It advocates a certain style of system dynamics practice in constructing the model, which affects the research approach chosen. An overview of the research design is provided. This ongoing investigation could support a new direction in algorithmic cost estimation research and provide a new theory on which to base more accurate cost predictions.

1. Introduction

Researchers in cost estimation have pursued the twin goals of accuracy and consistency when constructing algorithmic cost models e.g. COCOMO (Boehm 1995, 1981) and SLIM (Putnam 1978). Bell and Jenkins (1998a) suggest that these goals have not been satisfactorily achieved for estimating large software projects and there have been no significant improvements in the last decade. They contend that a catatonic state has been reached with these types of cost models. Bell et al (1999a) address the question "*Where next in software cost estimation?*" and conjecture that explanatory cost models are the way ahead in algorithmic cost estimation research.

Furthermore, Bell et al (1999a) contend that cost estimation can be divided into two modes, namely, Cost Explanation and Cost Projection. The development of algorithmic models is usually performed in the Explanation Mode, using completed project data sets with full knowledge of the size of the finished product and other cost drivers. The Projection Mode can be viewed as an activity that is associated with high risk, for it attempts to estimate the cost of a new software application rather than explain cost which has already been incurred. Additionally, it is noted that *ex post* analysis and *ex post* systems thinking are two distinctive approaches to producing an algorithmic model in the Cost Explanation Mode.

We have chosen the systems thinking (ST) method (Ackoff 1979) to frame the area of concern, and system dynamics (SD) (Forrester 1961) to explain dynamic behaviour patterns of the identified problems. The combination of ST and SD produces a systems model that is our approach to explanatory cost modelling. Additionally, we intend to explain the cost of a completed software application from the manager's point of view. This style of modelling is linked to Interactive SD practice (Lane 1999), which is associated with Interactionism and Social Action Theory (Burrell and

Morgan 1979). Bell and Jenkins (1998b) have selected frameworks, methodologies, and methods from various disciplines to address specific issues with this identified SD practice in mind. Hence, an interdisciplinary systems approach to explaining software project cost is proposed (Bell forthcoming Ph.D).

We argue that it is important to undertake a comparative study (see Figure 1) between the COCOMO II model, associated with *ex post* analysis, and the project manager's systems cost model, linked with *ex post* systems thinking. We have selected the case study approach (Yin 1984), given the exploratory nature of the investigation.

We believe Yin's (1984) research design for conducting case study investigations is limited as it is aimed at social sciences. We have broadened his research design to meet our requirements for cost modelling research. In Section 7 we describe the components of our case study design for the two hypotheses that are being tested. Finally, we suggest that this work could influence both further explanatory case studies grounded in General Systems Theory (GST) (Boulding 1956), and the construction of a new theory for producing more accurate cost predictions, based on Ackoff's (1979) work on stakeholder participation.

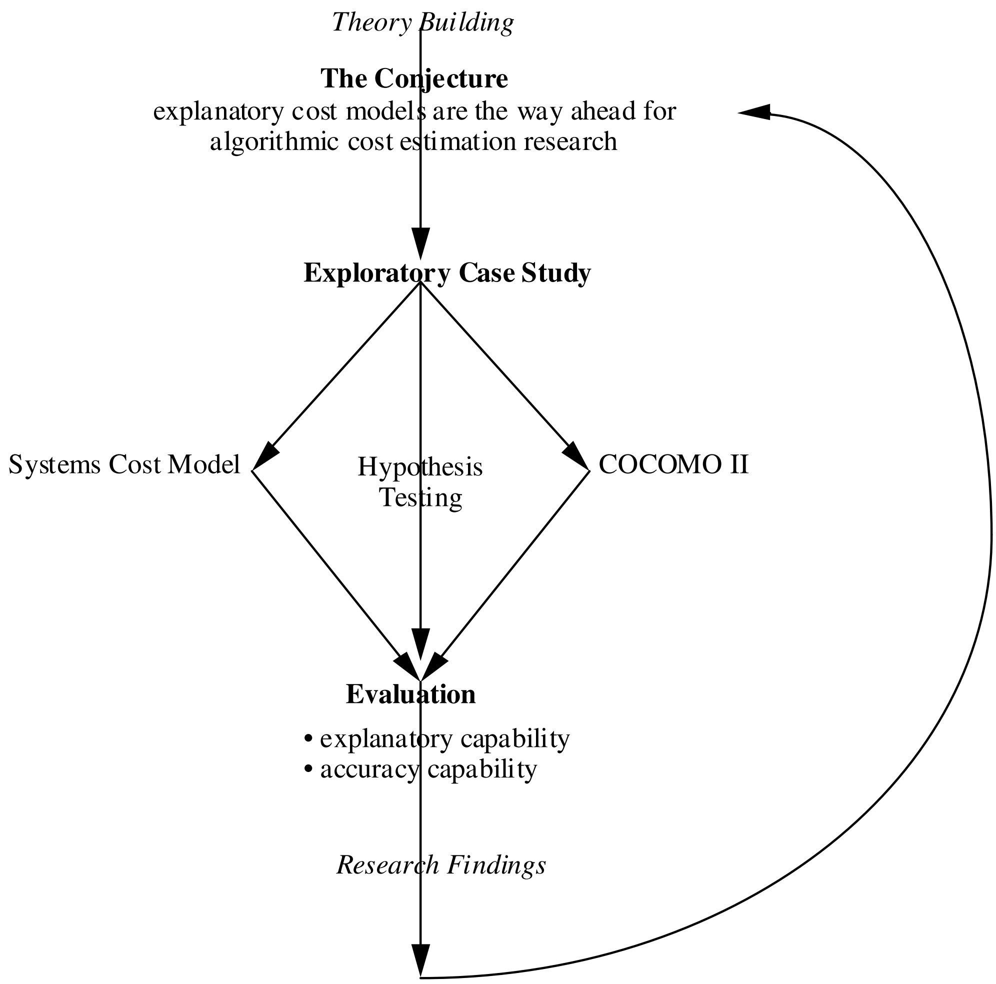

Figure 1: Overview of the comparative study.

2. Software Cost Estimation Research

We have examined several well-known cost models e.g. COCOMO and SLIM, and reviewed empirical work by independent researchers who have investigated these models. Our investigation was concerned with the validation of cost models, cost model comparison using actual project data, and cost model comparison using hypothetical project data. The findings (see Bell and Jenkins, 1998a) indicate that the accuracy and consistency of the identified cost models is poor, and more significantly, that there has been very little improvement in cost estimation research performance in the last decade.

We have suggested that the new goal of cost estimation should be to produce better explanatory cost models. To achieve this goal the model should give a more detailed representation of the development process. This could produce more accurate and consistent estimates within the two cost modes (explanation and projection). Lehman (1997) observes that a software product evolves to meet new requirements from the application domain. Information is essentially fed back from the user to the developer who acts accordingly. Feedback plays an important role in determining the evolution of the software application. Moreover, he views the software development process as a multi-loop feedback system. Hence we have selected SD to assist in developing an explanatory cost model.

3. System Dynamics (SD)

A review of the SD literature has identified several researchers who have applied it to software engineering. Abdel-Hamid (1984) contributed the first SD model of software development management. The goal of his research was to enhance systemic understanding of the general process by which software development is managed. He contends that through improved understanding and insight, real progress towards overcoming persistent software engineering problems is possible. However, Bell et al (1999a) argue that the research methodology selected ensured the model was not owned by the participants. Hence, we have concerns about the findings in respect of the investigations of different project management policies. We contend an important goal of an SD model is to represent a stakeholder's mental model of a situation, which can be used to explore different assumptions through various scenarios.

The verification and validation of SD models can be viewed as a set of confidence tests that must pass the stakeholder's level of satisfaction to ensure model ownership and meaningful outcomes for various strategies (see Equation 1):

$$\begin{aligned}&\text{Verification} + \text{Validation} = \text{Model Confidence}\\&\Rightarrow \text{Model Ownership}\\&\Rightarrow \text{Meaningful strategies/estimates}\end{aligned} \qquad \text{(Equation 1)}$$

In the 1980s there was a significant amount of research into verification and validation, because of implementation difficulties. Innovations in techniques and methods such as causal loop diagrams enable the modeller to work more closely with the stakeholders and through facilitation capture their mental models. This has led to a new type of SD approach labelled Interactive SD practice (Lane 1999).

4. Analysis of Cost Modelling Approaches

There are two fundamental approaches to developing a cost model within the Cost Explanation Mode (see Figure 2). The traditional method is called the *ex post* analysis approach, as researchers implicitly view costing as a complex problem, consisting of parts such as effort, size, scheduling, etc. The *ex post* analysis approach is linked to forecasting. A forecast is based on descriptions of the past and aims to produce the "best" solution, *i.e.* "the how", for the issue of concern. For example, examination of data sets from several projects can be used to derive a cost model through regression analysis. However, we contend the explanation, i.e. the why, is limited.

An alternative view is to consider costing as a group of complex problems that are interrelated, dynamic and transient. These complex problems are holistically framed using the systems thinking method, and may be investigated through the use of an SD model. We label this approach *ex post* systems thinking. A cost model constructed through the *ex post* systems thinking approach is linked to prediction. For example, systems thinking provides a framework for capturing the systemic behaviour patterns of various problems (which can be replicated through SD). A prediction is based on explaining the descriptions of the past and attempts to elucidate the best solution, *i.e.* "the why" and "the how," for the problem situation.

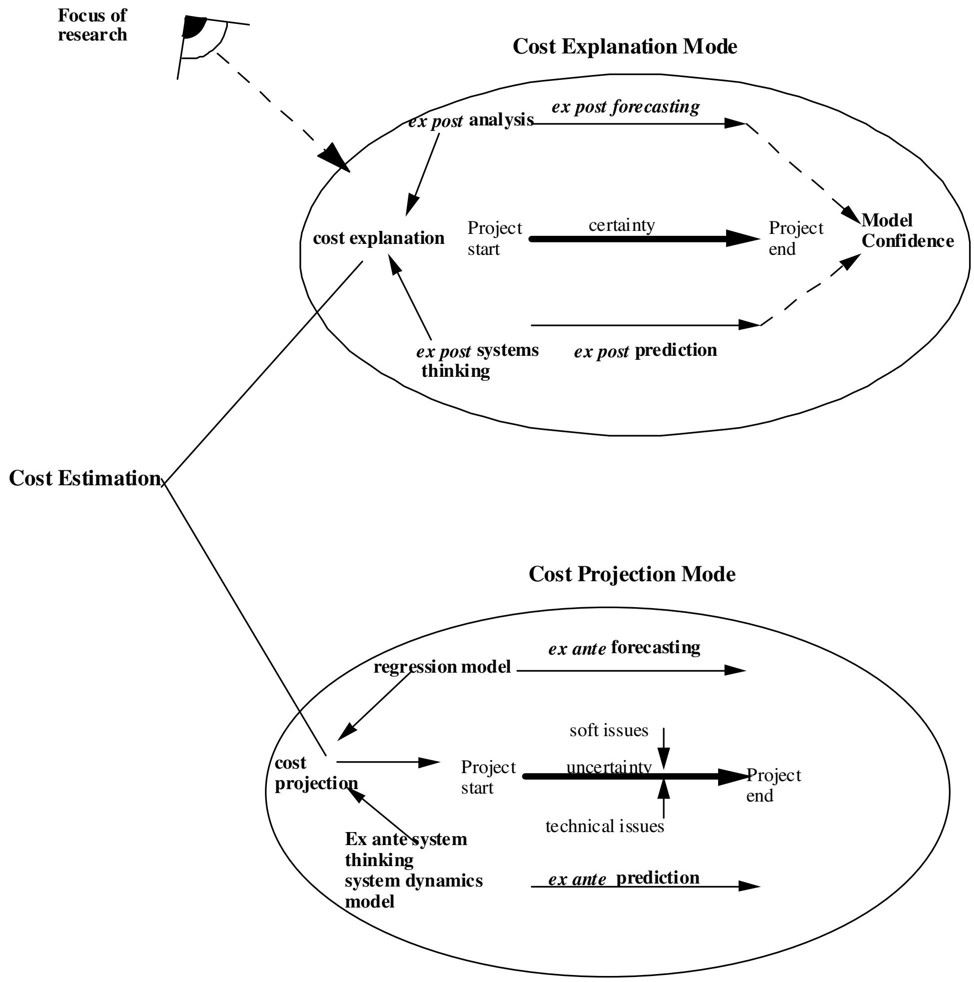

Figure 2. Analysis of Cost Estimation Modes (adapted from Bell et al 1999a).

Moreover, *ex post* forecasts and predictions and *ex ante* forecasts and predictions are linked, respectively, to Cost Explanation Mode and Cost Projection Mode. Hence, the two types of forecasts and predictions have different purposes. *Ex post* estimates are compared with data sets of completed projects in order to evaluate the accuracy of the cost model. *Ex ante* estimates attempt to estimate the cost of future software applications.

The traditional *ex post* analysis approach was adopted by Conte et al (1986). They identify a major factor (team size) whose significance was not fully analysed, and construct a new cost model -- COPMO. The accuracy of the *ex post* forecasts of COPMO were then compared with past cost models using the same project data sets to highlight a small estimation improvement. The evaluation process increased confidence in the use of COPMO enabling it to be applied in the Cost Projection Mode. However, COPMO did not find widespread commercial success. Again, we argue that the goals of accuracy and consistency have not been satisfactorily achieved.

Our study will be undertaken in the Cost Explanation Mode and will examine the capabilities of the two cost models in terms of explanation and accuracy. Our planned evaluation will compare the *ex post* forecasts of the COCOMO II model with the *ex post* predictions of the manager's systems model. Bell et al (1999a) suggest there are significant characteristic variations in developing cost models, for example, in issues such as the role of the modeller. This is a consequence of the underpinning meta-theoretical assumptions related to both philosophy of science and theory of society.

5. The Meta-Theoretical Assumptions Underpinning Algorithmic Cost Models

Burrell and Morgan (1979) provide an intellectual map for exploring social theories and their relationships with different approaches to studying organisations. A number of researchers, *e.g.* Checkland (1981) and Lane (1999), have applied the intellectual map to link certain methodologies/practices from their own disciplines with various social theories to clarify the theoretical assumptions underpinning them. Bell et al (1999a) derive a one-dimensional analytical scheme based on Burrell and Morgan's work. This shows relevant investigations chronologically in order to guide the positioning of certain archetypal cost models. Our goal is to clarify the underpinning meta-theoretical assumptions of identified cost models, highlighting the similarities and differences, which may lead to more innovative approaches to producing new cost models.

COCOMO II, SLIM and their derivatives are underpinned by the doctrine of Reductionism. Additionally, the modellers isolate themselves from the situation of concern to produce the cost model. We argue that cost models associated with *ex post* analysis are linked with Objectivism, which is the most extreme category of thought within the Functionalist paradigm. Objectivists take a rigid realist position and their views of human nature reflect an extreme form of Determinism. Their investigations are the archetype of Positivism. In addition, they favour analytical approaches as used in the natural sciences, e.g. laboratory experiments, to test hypotheses with scientific rigour in a highly nomothetic methodology.

Abdel-Hamid (1984) contributed the first SD model in software engineering. We believe his work is linked to Broad SD practice (Lane 1999), and is thus associated with Integrative Theory, with meta-theoretical assumptions in the middle of the Functionalist paradigm. Researchers from this category of thought are fundamentally Systems Theorists first, and then Interactionists. We argue that their models tend to be black boxes, with researchers seeking common structures that are independent of individual mental models, though actors may discuss specific aspects of their mental model with experts. The research approach is reflected in the type of nomothetic method selected within the Functionalist paradigm.

Our approach in developing a cost model is linked to the Interactive Planning methodology and Interactive SD practices. However, we contend that SD models should reflect the subjective views of the stakeholder to ensure model ownership. Therefore, the frame of reference of the modeller changes from teacher to facilitator to ensure understanding of the stakeholder's mental model. Our cost model takes a top-down approach, which reflects the outlook of an expert who has managed the software project and collected the appropriate data. Comparisons between the collected data and the *ex post* predictions are undertaken using agreed validation techniques. We contend that our approach is firmly linked to Interactionism and Social Action Theory. This is an intermediate position on our analytical scheme, merging Idealist and Positivist approaches to investigating social situations. When investigating a social situation Interactive modellers refer to previous experiences, and the type of mathematical techniques they use suggest an Holistic Positivist epistemological perspective. Moreover, this suggests that they select research approaches, e.g. case studies, which can assist in the identification of regularities and laws. However, it should be noted that as social situations tend to be unique, capturing the subjective view of the stakeholder is important. This implies a Nominalist ontological perspective and a Voluntarist view concerning human nature.

6. Selection of the Case Study Approach

We believe the understanding of research approaches in SD investigations is poor compared to more mature disciplines. We have reviewed literature from the Information Systems (IS) discipline, where there has been extensive discourse on this topic (Mumford et al 1985; Nissen et al 1991; Galliers 1991).

Galliers (1991) has produced a taxonomy of approaches for IS research (see Table 1) highlighting their strengths and weaknesses

Scientific Approaches	**Interpretivist Approaches**
Laboratory Experiments	Subjective/Argumentative
Field Experiments	Reviews
Surveys	Action Research
Case Studies	Descriptive
Theorem Proof	
Forecasting	Futures Research
Simulation	Role / Game Playing

Table 1. Identified approaches for IS research (Galliers 1991, p332).

He advocates the use of the word ‘approach’ rather than ‘method’, where an approach is ‘a way of conducting research’ which may embody a particular style and employ various methodologies, methods and techniques. He argues that no research approach has universal applicability. The taxonomy highlights situations in which an individual approach seems best suited to the research goal, the context of the investigation and the process of theory development and extension in the specific topic area.

We have previously stated our arguments for the conjecture that explanatory cost models are the way ahead in algorithmic cost estimation research. Additionally, we have attempted to highlight the style of SD modelling practice and propose a comparative study. After examining Galliers’ work, we have chosen the case study approach. The important features, strengths and weaknesses of the case study approach are reproduced below (see Table 2). Our fundamental reason for selecting the approach is that a case study enables an investigation to retain the holistic and meaningful characteristics of real-world situation.

Approach	**Key Feature**	**Strength**	**Weakness**
Case Studies	An attempt at describing the relationships which exist in reality, usually within a single organisation or organisational group.	Capturing ‘reality’ in greater detail and analysing more variables.	Restriction to a single event/organisation. Difficulty in generalising, given problems of acquiring similar data from a statistically meaningful number of cases. Lack of control of variables. Different interrelations of events by individual researcher/stakeholders.

Table 2. A summary of key features, strengths and weaknesses of the case study approach (Galliers 1991, p337).

Yin (1984, p.21) argues that there are many examples of sloppy case study investigations, and consequently, there have been numerous criticisms of the approach. He has attempted to introduce a more rigorous framework for conducting case study research. He states that a research design is far more than a workplan, though it may be thought of as a blueprint for research:

“The main purpose of the design is to help avoid the situation in which the evidence does not address the initial research questions. In this sense, a research design deals with a logical problem, not a logistical problem”

(Yin 1984, p.29)

He contends that a good research design has five important components (see Table 3). These components demand the development of a preliminary theory related to the topic of study. This is intended to improve the quality of the research design and become the main vehicle for generalising the results of the case study.

Component Number	Component	Description of component
1	A study's question	Clarity and precision of the study question influences the nature of the research.
2	Its proposition, if any	A proposition directs attention to the phenomena for study.
3	Its unit(s) of analysis	The definition of the unit of analysis is influenced by the proposition. Additionally, the unit of analysis should be similar to previous investigations to enable the findings to be compared.
4	The logic linking the data to the proposition	The data analysis steps in case study research.
5	The criteria for interpreting the findings	There is no precise way of setting the criteria for interpreting findings apart from perhaps comparing at least two rival propositions.

Table 3. Five Components of a research design for a case study (Yin 1984).

7. The Exploratory Case Study – Research Design

The SD model under development aims to explain the cost of a completed software application from the manager's point of view. We are working very closely with a project manager, who has several years' experience of software production in a telecommunications organisation. An interdisciplinary systems approach to constructing the model is being used with the aim of achieving model ownership. To achieve model ownership, it must pass verification and validation tests to the satisfaction of the manager. A comparative study between the COCOMO II model and a project manager's explanatory cost model is proposed to test our conjecture. The exploratory case study will confirm, refine or refute our conjecture. Yin's research design requires enhancement with respect to the characteristics of our proposed case study (see Table 4). We next outline each component of our design.

Component Number	Proposed Components	Yin's Components
1	Research Question	A study's question
2	Proposition	Its proposition, if any
3	Selected Software Metrics	Its unit(s) of analysis
4	Calibration of COSTAR Tool	
5	Systems Cost Model Construction	
6	Evaluation	The logic linking the data to the proposition
7	Interpretation of findings	The criteria for interpreting the findings

Table 4. Components of a research design for a comparative study.

Component 1
An extensive survey of archetype cost models and the theoretical arguments for an explanatory cost model have assisted in deriving the research question:

> *Is an interdisciplinary systems model the way ahead for algorithmic cost estimation research?*

Component 2
The comparative study will be undertaken in the Cost Explanation Mode. Two hypotheses have been identified. These are related to the explanatory and accuracy capabilities of the cost models.

Hypothesis 1

> *An interdisciplinary systems model improves the explanation of software cost*

Hypothesis 2

> *An interdisciplinary systems model produces more accurate results than a traditional cost model*

Component 3
The telecommunications organisation that we are working with has informally assessed itself at level 2 of the Capability Maturity Model (Paulk et al 1993). Specific software metrics must be collected at this level of maturity. We are currently examining the organisation's data set to ensure it can be used for the comparative study.

Component 4
We are using the COSTAR tool (Liggett 1998) which is based on the COCOMO II model. The data collected from the telecommunications company has been used to calibrate this tool in preparation for the comparative study.

Component 5
We have been developing an "in house" systems cost model. This work is classed as a preparatory activity, undertaken before working with the experienced project manager in the style of SD practice that we advocate. We are using some methods highlighted by Taank (1998) to assist in verification, and a number of validation techniques identified by Barlas (1989) and Sterman (1984) to ensure model ownership is achieved.

Component 6
We intend to evaluate the explanatory and accuracy capabilities of the cost models used in the comparative study.

Evaluation of Explanatory Capability
A preliminary questionnaire has been constructed to enable the manager to express any views concerning the explanatory capabilities of the two cost models. It consists of both open and closed questions of the interval scale type which facilitates the use of descriptive statistical techniques e.g. bar charts.

Evaluation of Accuracy Capability

Our literature review indicates that the magnitude of the relative error (MRE), mean magnitude of the relative error ($\overline{MRE}$) and Predictor level (Pred(l)) are the best indicators of accuracy and consistency of cost models (Conte et al 1986). We will use these indicators in evaluating the accuracy capabilities of the two cost models.

Component 7

The evaluation of the explanatory and accuracy capabilities of the two cost models will allow us to test the two hypotheses. Additionally, we will attempt to answer the research question through interpreting the investigation findings. Finally, this may lead to confirmation, refinement or refutation of the conjecture.

8. Conclusion

Our ongoing investigation is being conducted in the Cost Explanation Mode using data from completed software applications. The objective of the exploratory case study is to answer the question: *"Is an interdisciplinary systems model the way ahead for algorithmic cost estimation research?"* through evaluation of the explanatory and accuracy capabilities of the two cost models. Further case studies may be needed to refine our interdisciplinary approach. Additionally, common systems and feedback loops may be discovered given certain project criteria. The search for regularities in Interactionism and Social Action Theory may be linked to GST. However, GST is grounded in cybernetics, so we may require some refinements and clarifications as SD is linked to a servo-mechanistic perspective.

An important area for future research is in properly capturing the views of key project staff for inclusion in the systems model. We propose the use of the Holon Methodology (Bell et al 1999b), an informal approach to process improvement, which aims to capture "the whats" in a problem situation. Furthermore, "the whats" may be grounded in a systems cost model which emphasises "the how" and the "the why," which are important for accurate prediction. Our views are influenced by Ackoff's belief that:

"The future depends at least as much on what we and others do between now and then as it does on what has already happened. Therefore, we can affect it, and by collaboration with others -- expanding the system to be controlled -- we can increase our chances of "making it happen". The wider the collaboration, the more closely we can approximate the future we have jointly designed."

(Ackoff 1979, p101)

We believe that this thinking will form the basis for an expanded view of cost estimation, leading to the development of a new theory in which stakeholder viewpoints are continuously assessed and incorporated as required.

9. References

Ackoff, R.L. (1979) "The Future of Operational Research is Past", Journal of Operational Research Society, vol. 30, pp 93-104.

Abdel-Hamid, T.K. (1984) "The Dynamics of Software Development Project Management: an Integrative System Dynamics Perspective", Ph.D. Thesis, Sloan School of Management, MIT, Cambridge, MA, USA.

Barlas, Y. (1989) "Multiple Tests for Validation of System Dynamics Type of Simulation Models", European Journal of Operations Research, vol.42 (1) pp.59-87.

Bell, G.A. (forthcoming) "An Interdisciplinary Approach to Software Project Cost Explanation", Ph.D. Thesis, Department of Computing, City University, London, UK.

Bell, G.A., Cooper, M.A, and Jenkins, J.O. (1999a) "Software Cost Estimation: Where Next?", in Proceedings of the United Kingdom Academy for Information Systems (UKAIS '99), pp. 575-587, York University, UK.

Bell, G.A., Cooper, M.A, Jenkins, J.O., Minocha, S., and Weetman, J. (1999b) "SSM + GQM = The Holon Methodology: A Case Study", in Proceedings of 10th European Software Control and Metrics Conference (ESCOM '99), pp.123-135, Herstmonceux, UK.

Bell, G.A. and Jenkins, J.O. (1998a) "The Need to Broaden the Scope of Cost Estimation Research", In Proceedings of 9th European Software Control and Metrics Conference (ESCOM '98), Rome, Italy.

Bell, G.A. and Jenkins, J.O. (1998b) "Methodologies and Methods Chosen to Explain Software Project Cost", International System Dynamics Conference CD, Quebec, Canada.

Boehm, B.W. (1995) "Tutorial: COCOMO, Ada-COCOMO and COCOMO 2.0", Proceedings of the 10th COCOMO Users Group Meeting, Carnegie Mellon University, Software Engineering Institute, Pittsburgh, PA, USA.

Boehm, B.W. (1981) Software Engineering Economics, Prentice-Hall, Englewood Cliffs, New Jersey, USA.

Boulding, K.E. (1956) "General Systems Theory -- the Skeleton of Science", Management Science, Vol. 2, pp. 197-208.

Burrell, G., and Morgan, G. (1979) Sociological Paradigms and Organisational Analysis, Gower, Aldershot, UK.

Checkland, P.B. (1981) Systems Thinking, Systems Practice, John Wiley and Sons, Chichester, UK.

Conte, S.D., Dunsmore, H.E., and Shen, V.Y. (1986) Software Engineering Metrics and Models, Benjamin/Cummings, Menlo Park, CA, USA.

Forrester, J.W. (1961) Industrial Dynamics, Productivity Press, Cambridge, MA, USA.

Galliers, R.D. (1991) "Choosing Appropriate Information Systems Research Approaches" in Nissen et al (Eds) (1991) pp. 327-345.

Lane, D. C. (1999) “Social Theory and System Dynamics Practice”, European Journal of Operational Research, vol. 113(3), pp. 501-527.

Liggett, D. (1998) COSTAR Tool, P.O. Box 1360, Amherst, NH, USA.

Lehman, M.M. (1997) “Process Modelling: Where Next”, Proceedings of the 12th International Conference on Software Engineering 1997, Boston, IEEE Computer Society Press, Los Alamitos, CA, USA.

Mumford, E., Hirschheim, R., Fitzgerald, G., and Wood-Harper, A.T. (1985) Research Methods in Information Systems, North-Holland, Amsterdam, Netherlands.

Nissen, H.E., Klein, H.K., and Hirschheim, R. (Eds) (1991) Information Systems Research: Contemporary Approaches and Emergent Traditions, North-Holland, Amsterdam, Netherlands.

Paulk, M.C., Curtis, B., Chrissis, M.B. and Weber, C.V. (1993) Capability Maturity Model for Software, Version 1.1, SEI Technical Report SEI-CMU-93-TR-24, Software Engineering Institute, Pittsburgh, PA, 15213-3890.

Putnam, L.H. (1978) “A General Empirical Solution to the Macro Software Sizing and Estimating Problem”, IEEE Transactions on Software Engineering, Vol. 1, pp. 345-361.

Sterman, J.D. (1984) “Appropriate Summary Statistics for Evaluating the Historical Fit of System Dynamics Models”, Dynamica, Vol. 10(2), pp 51-66.

Taank, M. (1998) “Investigating Ways to Enhance Verification of System Dynamics Models”, BSc. Report, Department of Business Computing, City University London, UK.

Yin, R.K. (1984) Case Study Research: Design and Methods, Sage Publications, London, UK.