ARCOM

Doctoral Workshop

Simulation and Modelling in Construction

Chairman: Professor Akin Akintoye

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Edited by:
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ARCOM DOCTORAL RESEARCH WORKSHOP

Simulation and Modelling in Construction

School of Civil & Environmental Engineering, University of Edinburgh
Friday 26th October 2001 11.00-16.00

Chairman: Professor Akin Akintoye, Glasgow Caledonian University
Organisers: Dr Andy Dainty, Loughborough University and Dr Simon Smith, University of Edinburgh

10.30 – 11.00	Coffee	
11.00 – 11.05	Welcome and introduction to the day	Andy Dainty, *Loughborough*
11.05 – 11.15	Introduction to Simulation and Modelling	Akin Akintoye, *Glasgow Cal.*
11.15 – 11.35	*MODELLING THE VALUE OF CONSTRUCTION MECHARONICS INVESTMENT OPPORTUNITIES*	Mark Taylor, Napier
11.35 – 11.45	Discussion and questions	
11.45 – 12.05	*THE DEVELOPMENT OF A STRATEGIC EMPLOYEE RESOURCING FRAMEWORK (SERF) FOR CONSTRUCTION*	Ani Raiden, *Loughborough*
12.05 – 12.15	Discussion and questions	
12.15 – 12.35	*THE STRATEGIC DECISION PROCESS - A MODEL IN USE*	Paul Wilson, *Reading*
12.35 – 12.45	Discussion and questions	
12.45 – 13.45	Lunch	
13.45 – 14.05	*VFM AND RISK ALLOCATION MODELS IN CONSTRUCTION PPP PROJECTS*	Bing Li, *Glasgow Cal.*
14.05 – 14.15	Discussion and questions	
14.15 – 14.35	*ASSESSMENT OF SPACE CRITICALITY IN SEQUENCING CONSTRUCTION ACTIVITIES USING VR*	Zaki Mallasi, *Teeside*
14.35 – 14.45	Discussion and questions	
14.45 – 15.05	*A DATA CAPTURE MECHANISM FOR MODELLING CONSTRUCTION PLANT BREAKDOWN AND MAINTENANCE COSTS*	David Oloke, *Wolverhampton*
15.05 – 15.15	Discussion and questions	
15.15 – 15.30	Summary and conclusions	Akin Akintoye, *Glasgow Cal.*
15.30 – 16.00	Tea and Close	

MODELLING THE VALUE OF CONSTRUCTION MECHARONICS INVESTMENT OPPORTUNITIES

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ABSTRACT: Deficiencies in the existing procedures for assessing the financial feasibility of construction automation have manifested themselves that further research is required to reveal the true economic potential of available construction mechatronics systems. The author's PhD research highlights the deficiencies in existing appraisal techniques and develops a more befitting valuation framework. Probabilistic risk analyses are implemented to describe uncertain project cash flows associated with existing and prototype systems. The research examines the possible choice of input probability distribution, the interdependence between input variables and the sensitivity of the decision criterion to the input variables. Furthermore, real option-pricing models are developed to encapsulate the managerial options available to plant-hire organisations and contractors.

Keywords: construction mechatronics, strategic valuation

1. INTRODUCTION

The essence of probabilistic risk analysis is to provide the investment analyst with a means to look ahead at possible future outcomes and evaluate whether the investment should be approved. Projected cash flows are often estimates of quantities whose true values are uncertain because they will be determined in the future. The current-status of construction automation implementation does not facilitate the estimation of uncertain costs and revenues. Vagueness concerning cash flow estimation originates from uncertain ownership and operating expenditures. Non-tangible benefits substantially contribute to the economic value of construction automation. Practical experience with advanced construction automation technology is limited and further implementation is required to generate an appropriate historical database of associated expenditures.

Within the construction sector, risk is largely perceived as financial (Baker, Ponniah & Smith 1999). The risk associated with the introduction of new technology is also regarded as an important area for future research (Edwards & Bowen 1998). Furthermore, as identified by the CRISP Commission, risk and evidence of success were priority issues in reducing the barriers to technological change (CRISP 2000). Exploration of the financial risk associated with automated construction technology is necessary to assist quantification and understanding of investment and utilisation risk. Recent debates have discussed whether investment decision regarding advanced manufacturing technology can be based upon quantitative financial techniques or should be undertaken on strategic grounds. Analysis of financial risk in conjunction with the mapping of construction automation investments as real options may assist in assessing the existing and future strategic value of the technology. An overview of the pertinent research issues concerning the modelling and simulation aspects of the research are introduced. Preliminary results and a selection of conclusions are presented.

2. OBJECTIVES & METHODOLOGY

The research aims to provide a detailed risk assessment and analysis of the possibility of plant hire organisations investing in automated construction technology plant hire for introduction into UK construction and civil engineering operations. The research highlights the deficiencies in existing valuation methodologies and, subsequently, applies real option-pricing theory to assess the value of strategic construction mechatronics investment opportunities.

A series of available systems are utilised as potential investments. Objective data is obtained from the machine manufacturers or designers, where possible, and supplemented with subjective estimates. Subjective cash flow data and real option parameters are modelled and simulated to produce NPV and option value profiles for the selected systems. The valuation techniques and their interaction are outlined in Figure 1. Switching, growth (compound), pioneer and timing options are modelled and recommendations for appropriate implementation strategies are formulated.

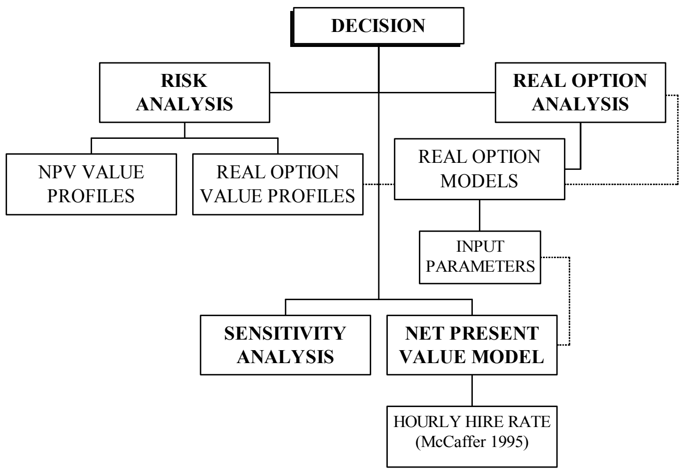

Figure 1 Construction mechatronics investment decision methodology.

3. INVESTMENT SCENARIO

Contractors aim to minimise their fixed capital locked into production by hiring or leasing expensive plant and equipment. The construction industry avoids working practices that demand substantial investment in plant and machinery. Construction contractors sub-contract a substantial proportion of their work and subsequently reduce their commitment to fixed capital. Construction projects are unique and specialist plant with operators is generally only required for limited period. The plant hire industry meets the requirements of contractors and facilitates access to plant and operators without exposure to maintenance and technical difficulties. With regards to civil engineering operations, the work often involves the use of expensive plant, which, to be cost effective, has to be utilised to its utmost. Within the research, it is assumed that a plant hire organisation will purchase construction mechatronics (CM) technology to be hired to construction and civil engineering contractors throughout the UK construction industry.

4. APPROPRIATE PROBABILITY DISTRIBUTIONS

The conducted financial risk analyses requires the estimation of cash flows and the construction of subjective probability distributions. The reviewed literature outlines the difficulties associated with utilising subjective estimations within probabilistic risk analysis.

Objective probabilities are difficult to obtain from the construction industry, where each project is unique. If objective data is not available for determining probability distributions for inputs to a risk analysis model, then subjective data, based upon managerial judgement, may be utilised.

Illogical results follow from the assumption that the input subsystems have a triangular probability density function (Chau 1995). The triangular p.d.f systematically overestimates the probability of exceeding the most likely estimate. The beta distribution, widely used to model construction duration, may not be appropriate for modelling subjective data. Raftery (1994) suggests that risk analysis is not within the realm of repeatable statistical assessment, but of subjective definitions of probability. For reasons of simplicity, Raftery (1994) then recommends that the uniform, triangular, trapezoidal, step-rectangular and discrete distribution for practical use in risk analysis for construction project's. Chau (1995) produced empirical data, which showed that the log-triangular p.d.f provided a better approximation of real construction cost data. Furthermore, neglecting subsystem correlation is erroneous analysis and produces misleading results (Wall 1997).

Probability distributions will also be utilised to describe the real option-pricing valuation parameters. The research investigates the use of the probability distribution functions suggested within the literature. However, without objective data obtained from system users, the appropriateness of the chosen distributions may not be validated.

5. REAL OPTION PRICING

Real option-pricing analysis recognises the additional value that arises from managerial flexibility. Furthermore, it captures management's flexibility to adapt and revise later decisions in response to unexpected market developments. The managerial options available to prospective investors may assist in highlighting the value of existing mechatronics. The Black and Scholes formula (Black & Scholes 1973) can be used to value a European call option. A CM investment timing option may be equated to a European call option. The value of the call option may be calculated by mapping the proposed investment onto the Black & Scholes option parameters.

5.1 Volatility

Within the real option-pricing models, the volatility of the underlying provides an additional source of value, which is not accounted for within traditional NPV valuations. Volatility may be estimated from historical data (FTSE Construction & Building Materials Sector) and then a probability distribution may be constructed to describe the uncertainty surrounding the estimate. Alternatively, once the NPV profiles have been constructed for the financial risk analyses, the standard deviation of the returns (i.e. the underlying) can be used as an estimation of volatility. The different techniques available to describe volatility will be examined within the research.

5.2 The Underlying (NPV of Project Cash Flows)

Within the risk analyses the effect of changing the type of input p.d.f, the number of iterations, altering the coefficient of variation, the estimated mean values; interdependence and the type of simulation are examined. The results from adjusting the coefficient of variation for the input subsystem variables within the risk analysis model are presented as cumulative ascending distribution in Figure.2.

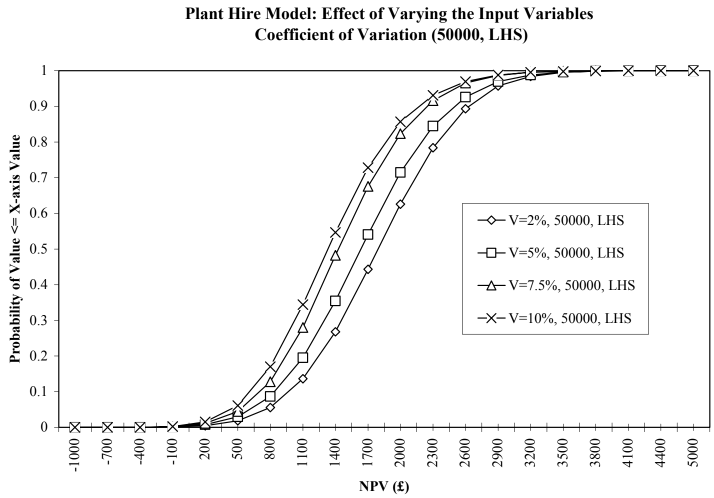

Figure 2 Effect of varying the coefficient of variation for all subsystem input variables.

6. CONCLUSIONS

The main conclusions derived from this study are presented as follows:

1. Probabilistic risk analysis adequately models the financial risk characteristics of CM investment opportunities
2. Varying the coefficient of variation of the subsystem input variables affected the NPV profile for the described investment scenario model.
3. To test whether interdependence exists and the reliability of subjective cash flow data, objective (historical) cash flow data is required.
4. Risk analysis, real option pricing and probabilistic risk analysis may be combined to provide a more accurate description of the value of CM investment opportunities.

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THE DEVELOPMENT OF A STRATEGIC EMPLOYEE RESOURCING FRAMEWORK (SERF) FOR CONSTRUCTION

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The success of a construction organisation is largely dependent upon the quality and morale of its people (The Chartered Institute of Building, 1992; Clough *et al*, 2000). Human resource management (HRM) provides an influential approach to the management of people in many business sectors (Beardwell and Holden, 1997: 3). The construction industry, however, presents a challenging environment for the effective management of human resources due to the dynamic and fast changing organisational, project and skill requirements. This paper reports on the preliminary findings of a research project which aims to develop a strategic employee resourcing framework (SERF) to inform the efficient management of a company's human resources, taking into account competing HRM priorities, project requirements and employee needs and preferences. This process will involve 1) the initial modelling of current HRM practices and the subjective decision-making processes, and 2) the development of a more appropriate framework, SERF. Simulation will be used to test the developed framework.

EMPLOYEE RESOURCING IN CONSTRUCTION

Employee resourcing is an important function of HRM within medium-large construction companies. The major components of this function are staffing, performance and administration (Taylor, 1998: 3). These HRM processes are influenced by several factors internal and external to an organisation. Figure 1 below provides an overall conceptual framework for discussing employee resourcing in this paper, and emphasises the complex interrelationships between the many variables affecting the resourcing process.

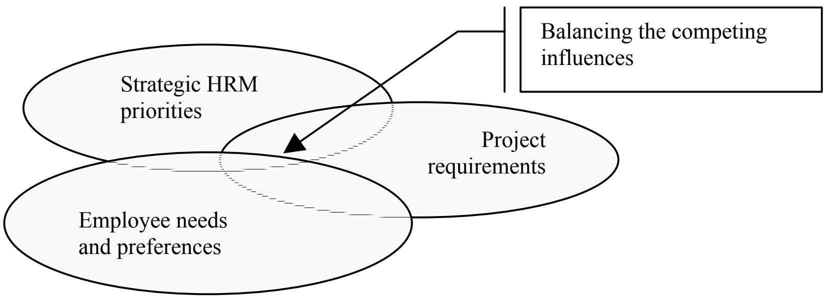

Figure 1. Integrating the competing HRM priorities, project requirements and employee preferences

The main functions of HR administration, staffing and performance management within employee resourcing consist of several distinct, but interrelated management activities. HR administration serves not only the resourcing process but also employee development and relations processes, focusing on the collection, storage and use of employee data (Torrington *et al*, 1991: 22). Information technology is widely used to support this function (see for example Torrington *et al*, 1991; Taylor, 1998; CIPD, 2000), although the ways and levels of practice within construction organisations vary greatly (Raiden *et al*, 2001). The staffing and performance management activities aim to ensure that the right numbers of employees with the right skills and competencies are in the right place at the right time. Key concerns for management in construction organisations are team formation and deployment due to project-based nature of the industry (Hamilton, 1997; Cornick and Maher, 1999). Ideally, management of staffing and performance are simultaneously concerned with ensuring the best possible performance is achieved whilst facilitating employees' career progression and offering them appropriate reward for their efforts.

Each of these interrelated HRM processes can influence the strengths or weaknesses of an organisation. The processes are influenced by several internal and external factors, which in turn provide opportunities and threats to the organisation (Maloney, 1997).

Challenges of managing people in project based environments
The internal factors that influence HRM processes in project based environments include

- *the organisation's strategic choice in terms of HRM* (Iles and Mabey, 1992: 255; Druker and White 1995; Maloney, 1997);
- *organisational structure* (Hamilton, 1997: 99);
- *organisational culture* (Bate, 1992); and
- *factors central to the individual employees within the organisation*.

Ultimately, these factors contribute to the strategic business objectives of employee resourcing: the continuous achievement of organisational goals at a minimum risk whilst maintaining employee commitment. In addition to the factors internal to the organisation influencing the HRM processes, several factors external to the organisation affect the way HRM practices are organised. The challenges include those that apply to construction industry specifically and those, which apply to all business sectors. Common throughout all different business sectors are: 1) technological, legislative and demographic changes; 2) changes in peoples' values and beliefs, quality standards and expectations; and 3) changes in the economic/labour markets. Particular challenges typical for the construction industry include:

- *Unique one-off product* (Chinowsky *et al*, 2000: 1; Clough *et al*, 2000: 2-3);
- *Projects won at short notice* (Hillenbrandt and Canon, 1980);
- *Transient workforce* moving between different work locations (Druker and White, 1995: 77);
- *Client pressures* (Respect for People Working Group, 2000);
- *Male dominated, macho culture/climate* (Maloney, 1997: 53);
- *Short-term teams* form and disband, and are mixed and changing in composition; and
- *Changing skill and competency requirements* (Clough *et al*, 1999).

There is a need to balance these competing external, organisational, project and individual priorities and needs, both at strategic (long-term) and operational (short-term) levels. Current employee resourcing practices often rely on the personal assessments of line management (Druker *et al*, 1996), which have the potential for inconsistencies, poor allocation decisions and hence, disillusioned employees through the violation of the "psychological contract" (Dainty *et al*, 2000). Understanding the psychological contract is vital to understanding employee responses to the employment relationship. Rousseau (1994, cited in Hiltrop, 1996), defined the psychological contract of employment as *"the understanding people have, whether written or unwritten, regarding the commitments made between themselves and their organisation"*. A breach, break or violation of the psychological contract will have negative impacts, such as reduced trust, job satisfaction and commitment to remaining with the organisation (or indeed industry as a whole) and the withdrawal of some types of employee obligation (Robinson and Rousseau, 1994; Hiltrop, 1996; Lester and Kickul, 2001). Thus, to ensure maximum productivity, it is crucial that the individuals' preferences and expectations are taken into account throughout the resourcing process.

Given the highly complex and challenging environment, within which this research project seeks solutions, a preliminary set of interviews was used to establish a focus and direction for future work. These interviews present the main data on which this paper is based.

METHODOLOGY

An interpretative approach forms the overarching research paradigm for the project. A preliminary set of semi-structured interviews was carried out with managers and employees at various levels of an organisation in order to establish 1) current HRM strategy, policy and practice; 2) the skill requirements of the organisation; 3) the individual preferences of employees; and 4) information held on the skills and abilities of staff. As the research focused on collecting in-depth information from the respondents and on establishing a focus for future work, involving a single company was appropriate. Validation studies involving a number of organisations will follow. The research instruments were developed to explore the issues identified within the wider literature and those which emerged from previous interviews. 'Snowball' sampling was used to acquire sufficient number of respondents. The sample profile is shown in Table 1.

In addition to the qualitative interview data, quantitative data were collected via structured questionnaires. Blake and Mouton's (1985) management style questionnaire was used to assess the management style of the managers interviewed and an employee resourcing priority paired comparison test was developed to compare and rank order the employee's individual preferences in relation to their deployment to a project team or organisational division.

Table 1. Sample profile breakdown

	Appr.		Sex		Age					Famil. Status		Bas.		Tl.
Role	Semi-strc.	Exploratory	Male	Female	Under 25	25 - 35	36 - 45	46 – 55	55 or over	Parent	No depend.s	Office	Site	
Director	1	2	3	-			1		2	3	-	3	-	3
Contr. Mngr	5	-	5	-			3	2		5	-	5	-	5
Chief Surveyor	1	-	1	-					1	1	-	1	-	1
Chief Estimator	1	-	1	-				1		1	-	1	-	1
HRM Staff	-	4	1	3		2	1	1		3	1	4	-	4
Comm. Mngr	1	-	1	-		1				-	1	1	-	1
Project Mngr	4	-	3	1		1	3			2	2	1	3	4
Site Manager	1	-	1	-					1	1	-	-	1	1
Site Agent	7	-	7	-		4	1		2	5	2	1	6	7
Design Co-ord.	2	-	1	1		2				-	2	-	2	2
Sen. Estimator	1	-	1	-			1			1	-	1	-	1
Senior QS	3	-	3	-		2		1		1	2	1	2	3
QS	2	-	2	-		2				1	1	1	1	2
Ass. QS	2	-	2	-	1	1				1	1	-	2	2
Engineer	4	-	4	-	2	2				-	4	-	4	4
Gen. Foreman	2	-	2	-			1	1		1	1	-	2	2
Work. Foreman	1	-	1	-				1		1	-	-	1	1
TOTAL	38	6	39	5	3	17	11	7	6	27	17	20	24	44

PRELIMINARY RESULTS: The compatibility and conflicts of employee and organisational needs

Several issues concerning the compatibility and conflicts between employee and organisational needs were highlighted within the interviews. The most common ***external influence*** on HRM practices mentioned by the respondents was client demands. Several managerial respondents also referred to difficulties in recruitment. The industry's poor image was said to affect young peoples' career decisions leading them to work for IT/law firms rather than 'traditional' construction organisations. The current labour market presented managers with further difficulties together with employment legislation impacting upon HRM.

With regard to ***internal influences***, it was identified that the company's strategic choice was to devolve HR responsibilities to line management. However, the company's structure was strictly hierarchical despite the dynamic nature of the industry. The organisational culture on the other hand was described as *"open and family orientated"* with two-way communications at the heart of the operations by both, managers and employees. Although some employees referred to the existence of an internal *"old school and boy's network"*. Rather mixed messages were received with regard to employee preferences. Managerial respondents stated that they attempted to accommodate employee needs and preferences, especially with regard to work location. However, employee responses varied; some strongly believed managers took their opinions into account, whilst others felt their needs and preferences were continuously ignored.

Surprisingly, ***employee relations*** issues were not considered important by the interview respondents. However, ***employee development*** on the other hand, was one of the key topics discussed within many of the interviews. Both managerial and operative respondents felt the company promoted training and strongly encouraged continuous development. Overall, however, despite management efforts in investing in future through management and graduate development, employee development appeared reactive rather than proactive in meeting organisational needs.

In examining the company's ***employee resourcing*** practices and processes, *HR administration* was found to be a complex process. Several computerised systems and manual filing mechanisms were in use. *Staffing* responsibilities seemed to have been devolved completely to line management with no input from HRM staff. As there were no records of employees' performance, their skills and/or competencies, nor their qualifications or personal preferences, deployment decisions were based on the subjective assessment by line managers. The employees' views on the company's staffing practices confirmed the managerial responses. The formal aspects of *performance management* culminated in an annual appraisal system, which served mainly as a tool for developing a training plan for each individual employee and organisational division. The management style questionnaires supported these findings revealing that managers placed considerable emphasis on the shorter-term operational issues. The employee resourcing priority paired comparison test further revealed that employee needs were varied and differed according to each individual's circumstances. This suggests a need for a flexible system that would allow for the various and differing individual preferences be taken into account in the resourcing decision-making.

CONCLUSIONS

In conclusion, it is clear that one of the company's strengths, in terms of HRM, lies in the managerial aim for good people management practice. Although employees do not feel this is always realised, this forms a positive foundation for opening future opportunities through the development of more organised HRM practices. Strategic planning, effective administration and communication (Smithers and Walker, 2000) together with effective knowledge management, can contribute to minimise risk, whilst also carefully incorporating the employee voice into the decision-making. This, in turn, should contribute to the continuous achievement of organisational goals through competent, committed and satisfied workforce with fulfilled psychological contracts. A critical in-depth analysis of the company's HRM practices will follow this preliminary evaluation. It will include modelling the current HRM practices and subjective decision-making processes. When complete, the analysis will be used to support the development of a strategic employee resourcing framework and an associated human resource information tool. Virtual resourcing will be used to simulate realistic projects and test the framework's practicality once finished.

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STRATEGIC DECISION-MAKING IN A PROFESSIONAL SERVICE FIRM

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Mintzberg *et al.*'s (1976) general model of the strategic decision process is applied to the decision to 'restructure' a cost and project management consultancy. The study focuses upon the activities to reach the initial decision to 'restructure' and not the implementation of the decision itself. The research is a pilot study in the first year of a part-time PhD and was carried out in an inductive and ethnographical manner, in order to develop a greater understanding of professional service firms (PSFs) for future hypothesis generation and testing within the PhD. Conceptual modelling of the decision is achieved but the model is considered to lack identification of critical implicit activities in the process. It is suggested that the model confuses reaching a decision with implementing a decision and that the identification of the numerous subsequent interrelated decisions becomes difficult. It is also suggested that a top-down strategy within a PSF is not acceptable. The diagnosis of the problem was considered too vague and consequently it became difficult to see what the real driver for change was at all. Future research questions for the development of the PhD are proposed together with observations on the PhD process from a part-time student perspective. This paper is drawn from Wilson (2001).

Keywords: Professional service firm, strategic decision-making

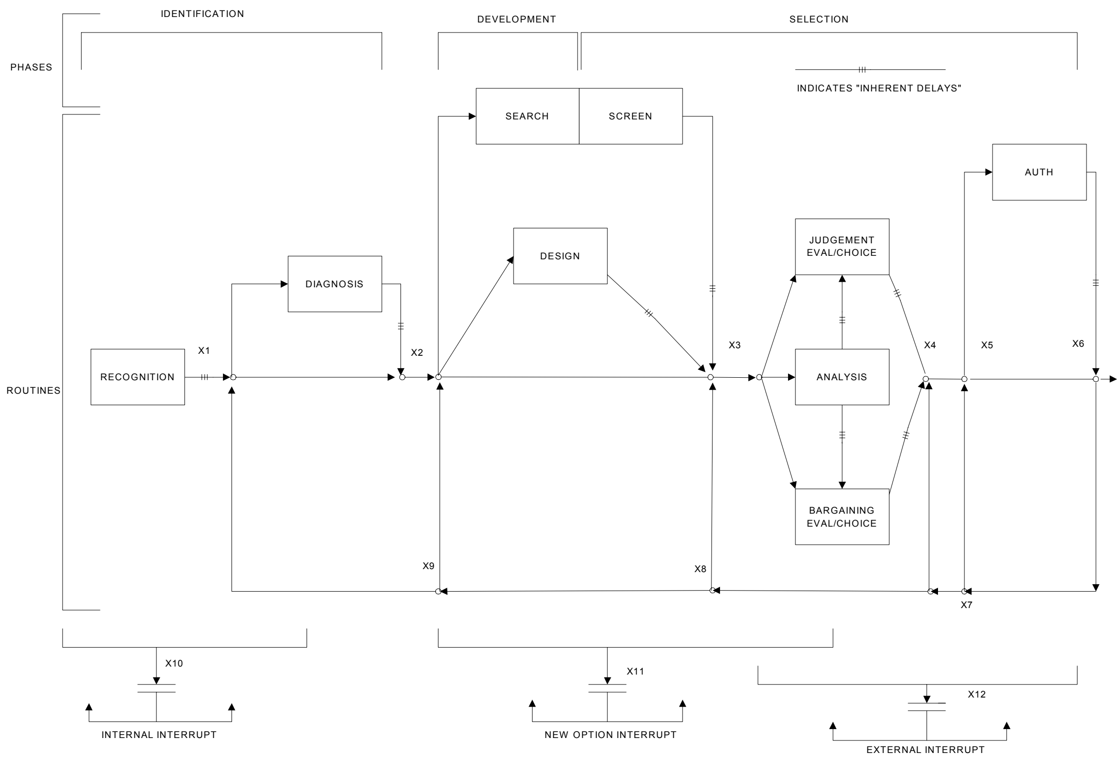
INTRODUCTION

This research applies a general model of the strategic decision process (Mintzberg *et al.*, 1976) to investigate a strategic decision within a PSF. The author of this paper is a manager within the PSF and the approach adopted is 'inductive' and 'ethnographic'. Given the limited research into the field of strategic management in PSFs, this research offers an insight into strategic decision-making in a large cost and project management consultancy and is a step in developing a greater understanding of PSFs for future hypothesis generation and testing. The research investigated the decision to 'restructure' the company in organisational and legal form.

MINTZBERG'S GENERAL MODEL OF THE STRATEGIC DECISION PROCESS

In their paper *The structure of "unstructured" decision processes* (Mintzberg *et al.*, 1976), Mintzberg *et al.* define the characteristics of strategic decisions as novel, complex and open ended with decisions not so much made under uncertainty but within a continuous state of ambiguity, where almost nothing is given or easily determined. Mintzberg's *et al.*'s (1976) field study of twenty-five 'strategic decision processes' across a range of organizations suggests that there is a basic structure underlying these ‘unstructured’ processes. A general model of the strategic decision process was constructed, see Figure 1, which tries to show that whilst strategic decisions are immensely complex and dynamic, it is possible to give them conceptual structuring. Mintzberg *et al.* find that the structure can be described by twelve elements comprising three ‘central phases’ (‘identification’, ‘development’ and ‘selection’), three sets of ‘supporting routines’ (‘decision control’’, ‘decision communication’ and ‘political’) and six sets of ‘dynamic factors’ (‘interrupt’, ‘scheduling delays’, ‘timing delays and speedups’, ‘feedback delays’, ‘comprehension cycles’ and ‘failure recycles’). The general model describes the interrelationships among them and the decision processes studied are shown to fall into seven types of ‘path configurations’. Three decision stimuli sit in a continuum, namely ‘opportunities’ at one end (voluntary decisions to improve a secure position), ‘crises’ at the other (decision responses to intense pressures) and ‘problems’ in the middle; each capable of integrating or moving along the continuum.

Figure 1 A general model of the strategic decision process



Source: Adapted from Mintzberg, H., Raisinghani D. and Théorêt, A. (1976). “The structure of "unstructured" decision processes.” *Administrative Science Quarterly*, **21**, 246 – 275.

RESEARCH METHOD

This research was undertaken as a pilot study in the first year of a part-time PhD. The author is a manager within the research target and the opportunity arose to investigate a strategic management decision that had been made by the owners of the company (note that the author is not an owner in the firm). The timing of this opportunity did not allow the scientific method to be adopted, such as the literature review in the field, generation of hypothesis and testing (Silverman, 2000). Instead, the decision was taken to use a general model of the strategic decision process and to 'get on and investigate' the decision in an inductive and ethnographical manner. It is accepted that the research will not satisfy the hypothetical-deductive requirements of the scientific method of research, but nonetheless it will offer the first step into developing a greater understanding of PSFs for future hypothesis generation and testing within the PhD.

The first part of the research was a semi-structured interview with the current MD of the practice in order to develop an understanding of the past, present and future context of the practice and to gain an insight into the implicit parts of the decision. Following the interview, the MD passed copies of five strategic management documents that were the formal records of reports, minutes and debate of the decision to 'restructure'. These documents were offered by the MD and not selected by the researcher, and as a result cannot be relied upon as the only relevant information. It is acknowledged that these are unlikely to represent the informal modes of communication in the process such as conversation, but alongside the semi-structured interview offer a satisfactory representation of the process for the purpose of a pilot study. The five documents were analysed, using a matrix as a checklist to find examples of the components of the model within the text.

RESULTS AND DISCUSSION

Results of the document analysis

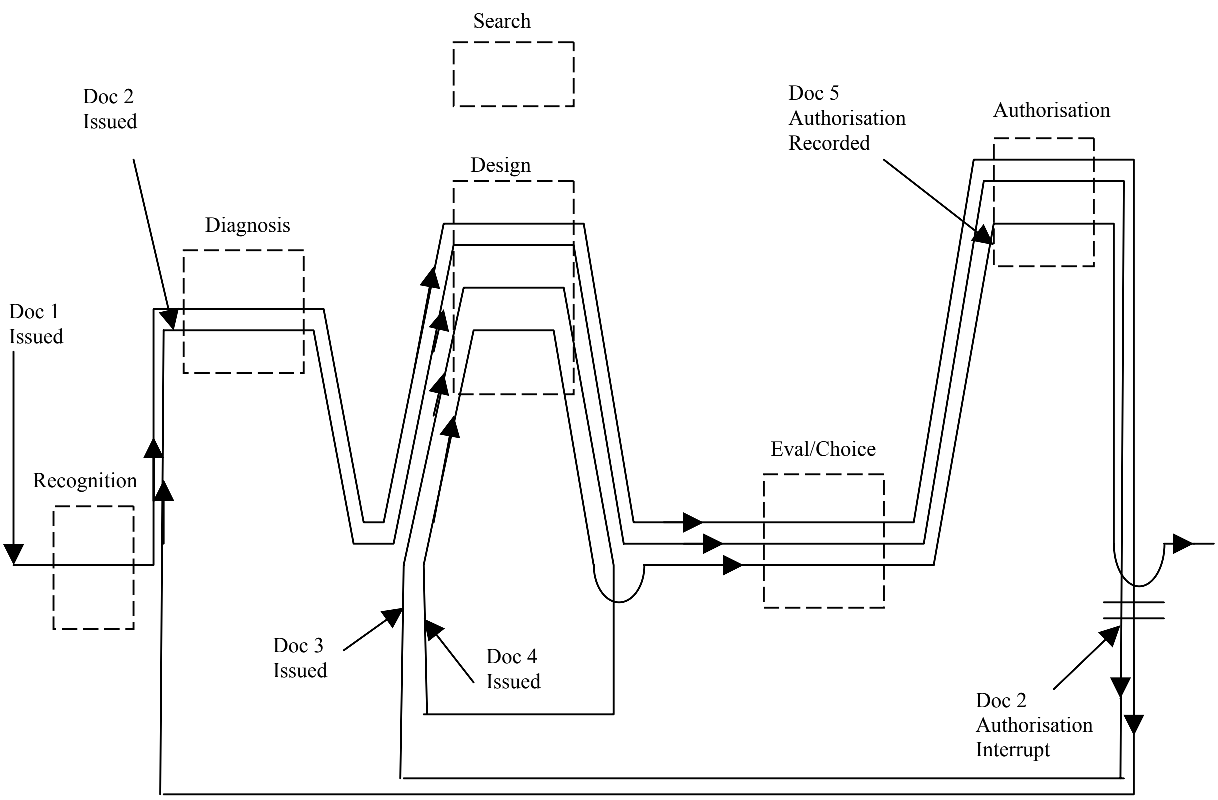
The study has revealed four significant issues for discussion. Firstly, it has been possible to conceptually model the decision to 'restructure' and the decision may be seen to fit with a 'path configuration' of a Type 2: Political design decision process (Figure 2). As such the model gives the impression of a relatively straightforward, iterative and systematic decision. Nonetheless, it is considered that the complexity of the decision process is not well represented. The model in itself does not explicitly identify 'dynamic factors' or the 'supporting routines' that in the case of this decision were critical implicit issues and as such requires further development.

Secondly, a Type 2 'path configuration' suggests that the strategic decision is less complex than a decision to build a new facility (Type 7). It is suggested that the Mintzberg *et al.* (1976) model confuses the process of making and implementing the decision. As a result it becomes difficult to identify the numerous subsequent interrelated decisions. For example, the decision to 'restructure' the practice led to twelve points of diagnosis, that led to a further twenty-three points of diagnosis. Taking Mintzberg *et al.*'s (1976) definition of strategic as 'important' each one of these decisions could in themselves be construed as strategic.

The third issue relates to the apparent top-down approach to strategy within the PSF. This is evidenced by the dominance, or arguably leadership, of the joint senior partner in the original diagnosis, the control of the decision process itself and the manner and philosophy of the discussions. The final document may suggest that top-down strategies are not acceptable within a PSF. Dictating the decision process, greater in-depth knowledge, the use of an independent facilitator and political manoeuvring did not ensure the decision was accepted.

The final finding was that the diagnosis of the problem appears to be too vague. It is overly simplistic and arguably irrefutable; the need for change in order to survive. Consequently it became difficult to see what the real driver for change was at all. It may be analogised with a doctor saying that a patient is ill. Although correct it does not in itself constitute a diagnosis.

Figure 2 A political design decision process – the decision to 'restructure a professional service firm



FUTURE RESEARCH

This pilot study has provided groundwork for the future development of the PhD. It has identified a number of questions that may be developed in the future as hypothesis for testing as part of the PhD:

1. Can a strategic decision be adequately conceptualised without investigation of the implementation phase?
2. How many interrelated decisions follow a strategic decision?
3. Can group decision theory offer greater insight into strategic decision-making within a PSF?
4. How does the quality of the diagnosis relate to the success of the implementation of a strategic decision?

The next phase of the research will develop a critical awareness of the existing strategic decision-making literature. Given the tentative criticisms of Mintzberg *et al*'s (1976) model, it is proposed that the PhD be developed as research of a 'testing out' nature

(Phillips and Pugh, 1994) by applying the model to the entire duration of the decision to 'restructure' this particular PSF. In so doing, it will test and develop the generalizations of existing theory.

Observations of the PhD process

Two observations on the PhD process are offered from the perspective of being a part-time student. Firstly, difficulties have been encountered from the outset with the traditional approach to the PhD process, typically literature review, research and then writing-up. Due to the ethnographical nature of the research it has been difficult to consider theory without constant reflection against current practice. Advice from the tutor to "get on with some research" has proven invaluable. In so doing it has forced rigorous review of the theoretical model and behaviour in practice, thereby proving the value of research to provide new insights.

Finally, getting on and doing some interim research has led to departmental seminars, MSc teaching and presenting a paper at the ARCOM conference (Wilson, 2001). These are all considered to be a positive step in the PhD process in 'learning the trade'. Future activities are hoped to include 'notes' in construction journals on sections of the literature review to encourage early feedback.

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VFM and Risk Allocation Models in Construction PPP Projects

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A conceptual process model of risk allocation in 'Public Private Partnership' (PPP) projects is presented, as part of an on-going PhD study. Through an extensive literature review, risk factors in PPP projects have been identified. Primary data have also been collected through a questionnaire survey, and the analysis is in progress. Two key findings that have emerged from the analysis are presented. Eighteen measures that can enhance the achievement of 'Value for Money' (VFM) in PPP projects were subjected to a factor analysis, which grouped them into four categories: "project efficiency", "project sustainability", "multi-benefit objective" and "public effective procurement". The second analysis discussed in this paper, concerns qualitative risk allocation, and is summarised in a tabular form. This later analysis illustrates that a majority of risks in PPP projects are "allocated to the private sector". However, there are a few risks, where their unitary allocation is not obvious.

Introduction

Some preliminary results of an on-going PhD research are presented. The overall aim of the research is to develop a risk management model specifically for PPP construction projects. Several milestones have been achieved in the study, including the investigation of critical success factors of PPP construction projects, and assessment of approaches to risk management. Primary data have been collected through a detailed and structured questionnaire survey, and are currently being analysed. The paper thus reports on the two aspects of the analysis, which have been completed: measures that enhance the achievement of VFM in PPP projects, and risk allocation between the project parties.

Public Private Partnership (PPP) in construction concerns "a long-term contractual arrangement between a public sector agency and a private sector concern, whereby resources and risk are shared for the purpose of developing or refurbishing a public facility" (Norment, 2000). At the moment, PPP is prominently used in public project procurement in many countries. In the UK, the number of PFI projects has increased steadily since 1997 when the Labour Government came into power (HM, 2000).

Typical PPP project risks have been highlighted in PFI guidelines (HM, 1995; Gallimore et al, 1997; Lam, 1999). Some of these risks have been widely associated with political and legal conditions (Stager, 1996; Gupta and Sravat, 1998), economic conditions (Gupta and Sravat, 1998; Duffield, 1998), social conditions (Kopp, 1997) and relationships (Reijiners, 1994, Kopp, 1997). The various risks in PPP projects vary with the development process, i.e. from the planning stage through the design, construction and operation stages (Reijiners, 1994). The objective of risk analysis is to capture all feasible options and to analyse the various outcomes of any decision concerning their treatment (Flanagan and Norman, 1993).

It has been argued that the contractual misallocation of risks is the leading cause of construction disputes in the USA (Megens, 1997). The UK government guideline on PPP/PFI procurement recommended the assignment of risks to the party best able to manage them (HM, 2000). Thus, a model which will help PPP parties to allocate risks between themselves more quickly is worthwhile.

Conceptual model

A three-level risk factor classification and checklist was proposed for risks associated with PPP projects (Li, et al, 2001). The three tiers in this classification concerned 'macro' (ecological, political, economic, social, natural environment etc) risks, 'meso' (project-engineering) risks and 'soft' (micro level) risks. The conceptual model is based on this classification.

In the proposed model, the public sector is expected, in conjunction with the private sector to identify potential risks, which will arise throughout the life of a PPP project. The private sector evaluates its ability to deal with these risks, using the two dimensions of severity and frequency to measure the risk impact. The private sector also prices the risks in its tender, which is submitted to the public sector client. If the cost of the risks is acceptable to the public sector, a contract will be easily awarded. If however, the private sector's charge is considered to be excessive, the

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public sector would go into negotiation with the private sector. The negotiations would consider whether the public sector should either accept the high risk cost, share the risks with the public sector, or retain the risk in the public sector.

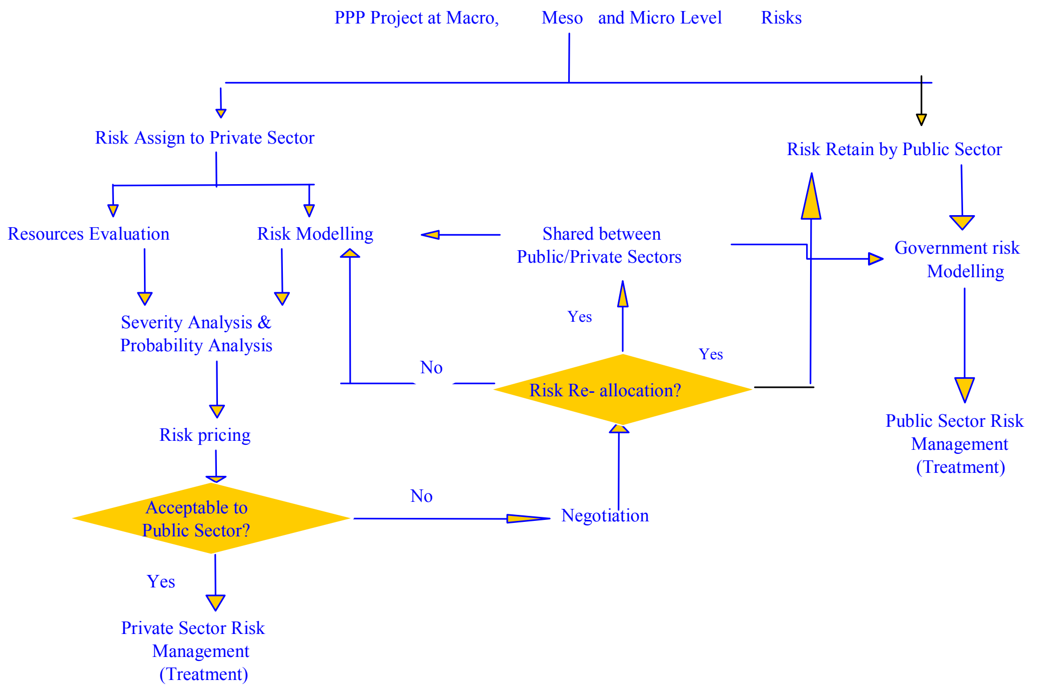

Figure 1: Process of risk analysis and allocation in PPP projects (Li, et al, 2001)

Current research

The research was started in 1999. Literatures were reviewed to inform the preparation of a questionnaire, which consisted of two parts: the first dealing with general questions, while the second covered project specific questions. The issues covered in the questionnaire included:

1. Attractive factors for adopting PPP, instead of traditional procurement.
2. Negative factors associated with PPP.
3. Critical factors for adopting PPP in project delivery.
4. Measures enhancing the achievement of VFM in PPP projects.
5. Critical success factors in PPP projects.
6. Criticality of risk factors.
7. Expected risk allocation framework.
8. Risk allocation preferences.
9. Risk treatment measures.

Items 1-5 will allow an understanding of PPP in the UK. While items 6-9 will be used to inform the various elements of the conceptual model. The postal questionnaire survey was carried out between June and August 2001. 500 questionnaires were sent out; 61 responses were received in which, 53 respondents fully answered the first section, and 44 responded to the second section.

Preliminary Results

There are two elements of the analysis discussed in this paper: 1) factors enhancing VFM in PPP projects, and 2) perception of respondents on risk allocation in PPP projects.

Factor enhancing VFM in PPP projects

Analysis of the rating of several factors by the respondents shows that "efficient risk allocation", "output based specification", and "long-term nature of contracts" are reckoned by both the public and private sectors to be the top three VFM measures in PPP projects. This result is similar with that reported by Arthur Andersen and Enterprise

LSE (2000). In an attempt to achieve more interpretable results and to establish clear benefits between the VFM measures, a factor analysis was undertaken.

Factor analysis is a statistical technique used to identify a relatively small number of factors that can be used to represent relationships among a set of many interrelated variables (Kleinbaum, et al, 1988; Norusis, 1992). The eighteen variables identified as enhancing the achievement of VFM were rated by the respondents, and their ratings were evaluated through factor analysis. The correlation matrix showed that all the variables have a significant correlation at the 5% level. The value of the KMO statistic was 0.804, which according to Kaiser, is satisfactory (Norusis, 1992). Principal component analysis was also undertaken, which produced a four-factor solution, with eigenvalues greater than 1.00, thus explaining 63.45% of the variance. After varimax rotation, the loading exceeds over 0.50 is shown in Table 1, in which it can be noticed that the variable of "off the public sector balance sheet" received no representation by the components.

The four major factors derived are interpreted as:

1. Factor 1: for project efficiency,
2. Factor 2: as sustainability,
3. Factor 3: for multi-benefit consideration, and
4. Factor 4: for public effective procurement measures.

Table 1: Rotated factor matrix (loading) of enhancing VFM in PPP/PFI projects

Factors	Variables	Component			
		Factor 1	Factor 2	Factor 3	Factor 4
Project efficiency	Low project life cycle cost	0.7567			
	Optimal use of asset/facility and project efficiency	0.7010			
	Improved and additional facilities to the public sector	0.6779			
	Private sector technical innovation	0.6739			
	Early project service delivery	0.6708			
	Private management skill	0.6283			
	Low shadow tariffs/tolls	0.5543			
Sustainability	Reduction in disputes, claims and litigation		0.8984		
	Nature of financial innovation		0.6574		
	Long-term nature of contracts		0.5350		
	Output based specification		0.5046		
	"Off the public sector balance sheet" treatment				
Multi-benefit Consideration	Risk transfer			0.8077	
	Environmental consideration			0.6779	
	Level of tangible and intangible benefits to the users			0.6265	
	Profitability to the private sector			0.5558	
Public effective Procurement measures	Competitive tender				0.7629
	Efficient risk allocation				0.7216
Eigenvalues		4.0651	3.0711	2.5743	1.7113
Percentage of variance		22.6	17.1	14.3	9.5

Kaiser-Meyer-Olkin Measure (KMO) of Sampling Adequacy:		0.804
Bartlett's Test of Sphericity:	Approx. chi-square	442.851
	df	153.00
	Sig.	0.000

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 16 iterations

Factor 1 includes the issues of low project life cycle cost, optimal use of asset/facility, improved and additional facilities, private sector technical innovation, early project service delivery, private management skill and low shadow tariffs/tolls. All these seven variables are associated with measures that enhance project efficiency.

Factor 2 is associated with the sustainability of project and services. A successful project must be established on the basis of reduction in disputes, claims and litigation. The other measures, which help the public sector to achieve project sustainability, include the use of long-term contracts, output based specifications, and financial innovation.

Factor 3 is associated with multi-benefits. The project itself should bring to the end-users great benefits, along with some environment considerations.

Factor 4 emphasises that public sector procurement must rely on competitive tendering and efficient risk allocation.

Risk Allocation by Parties

There are two dimensions of risk allocation: the first is qualitative, i.e. what type of risk is allocated and to whom? The second is quantitative i.e. how much of the risk is allocated. The second aspect can involve sophisticated mathematical solutions, an example of which had been proposed by Yamaguchi, et al (2001). Several scenarios of risk allocation have been studied by, for example, Arndt (1998) and Hartman, *et al.* (1998). In order not to duplicate such studies, the present analysis focused on the first issue, by investigating the types of risks allocated to different parties in PPP.

The survey results are listed in Table 2, in which the preferable risk allocation choices are represented in percentage. Most respondents agree that a risk should be allocated "to whom is best able to manage, control, or bear it".

There are five risks that are preferable retained by the public sector (i.e. those with percentage scores below 50%). Except for "site availability", the other four risks in this group can be classified as political factors. The analysis shows that, political risks tend to be allocated to the public sector, similar to situations in developing countries (Zhang, *et al*, 1998; Vega, 1997).

A majorities of the risks were allocated to the private sector (i.e. those with percentage scores over 50%). The analysis shows that out of forty-six key risks, thirty-two (70%) were preferably assigned to the private sector. These thirty-two risks fall into two sub-groups: those assigned "primarily to the private sector" and those assigned "solely to the private sector".

The sub-group of risks assigned solely to the private sector are twenty-one in number risk. With most of them scoring around 0% to the public sector, these are mainly engineering factors, except for "organisation and co-ordination risk" which has a little bit of "soft" characteristics. It thus seems that PPP procurement relieves the public sector of the burden of bearing responsibility for engineering risks, which are meso level risks.

There are five risk factors that are shared between the public and private sectors. Three of them are soft elements: 'lack of commitment from partner', 'responsibilities and risk distribution' and 'authority distribution between partnerships'. The other two are "force majeure" and "changes in legislation".

There are several risks that are difficult to include into a single category. These are "level of public support", "project approval and permit", "contract variation" and "lack of experience". From the responses received, these risks were neither related to project type, project value, procurement method, nor revenue resource. Thus, there is no significant clue on the allocation of these risks to one of the parties.

Conclusion

Based on a questionnaire survey in the UK, VFM criteria and qualitative risk allocation were analysed upon which models have been developed. The VFM model is based on factor analysis. The suggestion is that project participants should adopt any measures associated with "project efficiency", "sustainability", "multi-benefit consideration" and "effective procurement arrangement" in order to fully achieve VFM in construction PPP projects.

The risk allocation model is based on methods of allocating risks, to the public and private sectors, as well as sharing between them. The risk allocation analysis/model suggests that macro level risks should be retained by the public sector; meso level risks should be transferred to the private sector; while, micro level risks should be shared between the two sectors.

In VFM model, the four factors only contribute 63.5% to overall VFM; and, in the risk allocation model, there are several exceptions on how a risk should be allocated, depending on the nature of the project. However, the frameworks provided in this study are straightforward and focused. They should help the public and private sectors reduce time spent in allocating and negotiating risks, and thus help then achieve optimal VFM in PPP projects.

Table 2: Risk Allocation in PPP projects

	Public	Private	Shared	Preferred Risk Allocation
Nationalisation/expropriation	79.4%	8.8%	11.8%	Public Sector
Poor political decision-making process	69.0%	6.9%	24.1%	
Political opposition	62.5%	21.9%	15.6%	
Site availability	60.6%	12.1%	27.3%	
Government stability	58.3%	25.0%	16.7%	
Level of public support	45.8%	41.7%	12.5%	Strongly Depending
Project approval and permit	35.1%	32.4%	32.4%	
Contract variation	33.3%	25.6%	41.0%	
Lack of experiences in PPP arrangement	13.3%	43.3%	43.3%	
Lack of commitment from public/private partner	24.1%	10.3%	65.5%	Shared
Force majeure	18.4%	13.2%	68.4%	
Legislation change	17.1%	22.0%	61.0%	
Responsibilities and risk distribution	0.0%	22.6%	77.4%	
Authority distribution between partnerships	4.0%	28.0%	68.0%	
Tax regulation change	17.9%	51.3%	30.8%	Primarily to Private Sector
Late design changes	26.3%	52.6%	21.1%	
Residual risk	22.6%	54.8%	22.6%	
Inflation	7.3%	56.1%	36.6%	
Tradition of private provision of public service	27.3%	59.1%	13.6%	
Staff crisis	6.7%	60.0%	33.3%	
Third party tort liability	3.3%	60.0%	36.7%	
Influential economic events	8.3%	69.4%	22.2%	
Financial attraction of project	3.0%	69.7%	27.3%	
Level of demanding project	7.7%	73.1%	19.2%	
Different working methods	0.0%	73.3%	26.7%	
Industrial regulatory change	0.0%	75.0%	25.0%	Solely to Private Sector
High financing cost	3.0%	75.8%	21.2%	
Interest rate	2.4%	78.0%	19.5%	
Organisation and coordination risk	0.0%	80.6%	19.4%	
Weather	0.0%	82.1%	17.9%	
Environment	0.0%	84.2%	15.8%	
Availability of finance	0.0%	85.3%	14.7%	
Ground condition	5.1%	87.2%	7.7%	
Operational revenue below par	2.7%	89.2%	8.1%	
Financial market	0.0%	89.5%	10.5%	
Quality of workmanship	2.5%	92.5%	5.0%	
Construction cost overrun	0.0%	92.5%	7.5%	
Frequency of maintenance	0.0%	92.5%	7.5%	
Availability of labour/material	0.0%	94.4%	5.6%	
Insolvency of subcontractors/suppliers	0.0%	94.7%	5.3%	
Low operating productivity	0.0%	94.9%	5.1%	
Design deficiency	0.0%	95.0%	5.0%	
Unproven engineering techniques	0.0%	97.0%	3.0%	
Operation cost overrun	0.0%	97.5%	2.5%	
Higher maintenance cost	0.0%	97.5%	2.5%	
Construction time delay	0.0%	97.6%	2.4%	

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Assessing Space Criticality in Sequencing and Identifying Execution Patterns for Construction Activities Using VR Visualisations

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Abstract:

Current practises of construction project planning involve a number of methodologies/techniques that model dependencies and sequencing of project activities. Among these techniques are the bar charts, network diagrams, and time-chainage diagrams. None of these techniques has the capabilities to model and visualise both sequencing and execution pattern of activities.
It has been recognised from CAD applications in manufacturing that simulation of sequencing production activities using 3D models integrated with schedules prior to execution could lead to better understanding and evaluation of production processes before site operations commence. Therefore, the construction industry needs to implement new approaches to planning on-site project activities and for better judgement and communications of schedules among project teams. The purpose of this paper is to discuss the development of a methodology to achieve the objectives of the research and in particular 4D space planning and structuring CAD project information for the purpose of integration and visualisation.

Keywords: 4D CAD, construction activities, space modelling.

Research Background:

The construction of a building is a process that requires many individual activities to be planned and managed. Traditional techniques for planning these activities have involved text description and a number of 2D technologies including bar charts and network diagrams [Morris, 1994; Woodward, 1975]. Based on CAD application in manufacturing, there is recognition that simulation of sequencing and identifying execution patterns of activities in construction projects using 3D models prior to execution could strengthen the management of construction projects.

Although project managers consider workspace in their planning resources, it is defined as in the form of offices, accommodation and stage spaces for materials, i.e. a static space [Armstrong-Wright, 1969]. A spatial analysis of a pilot case study was performed on a £6 million construction site at the University of Teesside indicated that there is about 30% of non-productive time on site due to the lack of detailed and space planning. It was concluded that the lack of space planning of activities resulted in space conflicts, long journey paths, unavailability of access to rooms, inefficient utilisation of time [Dawood et. al., 2000]. Virtual Reality (VR) visualisations and analysis allows the exploration of 'what-if' scenarios and could identify problems of space configuration in the early stages of project planning.

Research Problem:

A number of authors have referred to the phenomenon of 4D (3D + time) space planning and have proposed methodologies for linking 3D models with time [Retik and Adjei-Kumi, 2000; Fischer et. al., 1996, 1997; Morad and Beliveau, 1991]. Many of the 4D-CAD systems proposed by these authors are being developed with the purpose of examining constructability, buildability, and scheduling. All of these systems are based on linking finished products to time elements and they do not offer the industry any assistance in examining and rehearsing the product development processes. Riley and Sanvido [1995] and [Riley, 1998] described various patterns of construction workspace that underpinned some space properties such as paths, operators, access points, storage/unloading areas, and so on, which interfere with tasks in-progress. In this context, the purpose of our study focuses on the inclusion of such dynamic spatial attributes of construction activities while rehearsing the sequence to execute these activities. Therefore, the objective is to re-produce construction schedules with least spatial clashes between work-packages and to include space as a resource in a similar representation to Work Breakdown Structure (WBS) [Pilcher, 1992].

Research Aim:
The aim of this research is to develop a methodology and a tool that allows construction planners to sequence and assess execution patterns of construction activities and identifies spatial conflicts using visualisation and analytical tools. It is intended to assist those professionals responsible for the planning of a construction project by improving their skills in sequencing project activities. The study will include a survey of the current techniques and project planning methods and the development and verification of the tools.

The main objectives of the research are:

1) A thorough review of the previous and current state-of-art research to identify problems with space planning and space-time conflicts on construction sites.
2) Study different construction execution patterns to extract space related information.
3) Identify the WBS for activities and establish the best-interconnected hierarchy between CAD model components and its spatial attributes in relation to work progress to rehearse construction work patterns.
4) Develop a computerised model using 2D and/or 3D model of a building space that analyses space utilisation and investigates activity interference/clashes in a workspace, and to identify conflict-evidence in the work.
5) To evaluate the developed model in construction practice and direct future strategies for general applications.

Research Methodology:
Research methodology of this research project is as follow:

a) Revision of state-of-the-art literature in the area of 4D-CAD models.
b) Site observation to determine the relationships between the spatial configurations of work being carried out on-site and work activities.
c) Data capture and collection of project resources including CAD drawings, schedules method statement, as-built programme and therefore constructing a detailed analysis of activity-space relationships.
d) Identification and mapping of specification and processes of the proposed tool. In particular establishing dynamic relationships between resources and building objects.
e) Investigation of suitable software, programming language and tools for the research.
f) The development of the prototype 4D simulation model according to building components and spatial attributes through the utilisation of VIRCON database (project database being developed as part of an EPSRC research project). This will enable planners to explore different execution patterns while planning project activities.

g) Testing and validation of the prototype on other case studies and recommend further modifications.

Findings related to space-time conflict characteristics:
The research has been able to point out at particular reasons of space-time conflicts that might occur on construction sites:

- The project planning applications currently in use in the construction industry do not model spatial properties of construction activities. As a result, construction activities might share work areas in the same timing and that produces insufficient free space to work.

- A number of issues should be considered while producing a construction schedule. These are the execution pattern of work packages, the allowable amount of overlapping between these patterns, and the workflow direction within locations of work execution (zones).

- Spatial dynamics of activities lead to complex spatial problems and should be a major part/issue of the 4D model. Such addition of dynamic space requirements (i.e. activity process and resources) in the 4D simulation should enhance the process of rehearsing project sequence.

Work development to date:

- A review of the existing project planning strategies, relevant published documents, and state-of-art- 4D tools in relation with improvements of spatial issues in construction sites was undertaken. The study revealed that there is a substantial need for improvements in the area of space analysis on construction sites. We were able from the literature review to decide on the proper simulation model approach and methodology. The full review of current state of the 4D modelling has been achieved and we were able to formalise the construction knowledge required for structuring the 3D CAD model.

- A pilot case study was performed on a construction project. It explored spatial configuration on a construction site, the relationships between the executed work and improving productivity and performance.

- Significant progress was achieved in populating the graphical (3D CAD model) information into the VIRCON project database. The space requirements for the studied project activities have been captured from the CAD drawings, project schedule, and therefore constructing a detailed analysis of activity/space relationships was established. The geometrical properties of all CAD components in the project's drawing was extracted and stored in a database (see figure 1). The developed technique uses Visual Basic for Applications macros to read related space information from the CAD building components to be used for future manipulation. This VBA routine enables the representation of CAD graphical components in terms of object location and object size. Therefore, the geometrical representation of building spaces was automated and linked to its non-graphical information (MS Project schedule and resources) in the database.

- Major development from this research was in structuring the components of the 4D model in a standard layering convention. Our layering methodology is compatible with the British Standards 1192-5 for structuring the CAD information. Moreover, the research has implemented a hierarchical arrangement of 3D CAD components and the layers in such a way to harmonise with Project Breakdown Structure (PBS) and Work Breakdown Structure (WBS) of a building project. We called this central concept as *Space Breakdown Structure* (SBS), which will benefit the 4D visualisations in later stages in.

- The research developed a concept for creating 3D objects automatically by defining specific rules. This reduces the tedious process in modelling some of the support activity components (e.g. form work, excavation, construction areas, zones, and workmen freedom range). We present three developed types of CAD objects as follows:

  1) Rule one allows the automatic generation of an *Approximation Envelope* (AE) CAD component that has a ratio relationship to the related building component. For example, a surrounding box (or AE) component is generated automatically to occupy the area required for the formwork or steelwork around a pad foundation.

  2) Rule two incorporates resources like workman size, tools, equipment, and then an activity component is displayed and included in the visualisation. For example, the extra workman area object for pad foundation is displayed by extending the pad foundation component area plus the workman area.

  3) Rule three utilises space takeoff or extraction routine and subsequently visualises the occupied spaces by both finished activities and activities in progress.

Conclusion:

This paper has presented the methodology for developing a tool to assist project planner in sequencing project activities. The research included an in-depth literature review of the state-of-art in 4D visualisations, construction management planning strategies, approaches, methods, and technologies. We were able from our literature review to decide on the proper approach for the visualisation model. Not only we illustrated the logic and techniques behind constructing the 3D model, but also we described the level of detail required in order to match with the project schedule. Hence, a week-by-week model was constructed and project activities were linked with its 3D CAD model components.

Although the industry utilises its own convention of organising information in CAD layers, this research ensured that CAD layering corresponds with the British Standards 1192-5. The layering system has been integrated with the processes in MS Project.

The current CAD model has been simplified for our specific 4D visualisations. Three important features were considered in the developed model that could help reducing modelling efforts: one is the use of a unified method for drawing building components as in closed polylines; two is to arrange 3D building product in a hierarchical relationships; three is the inclusion of rule-generated CAD components.

Finally, a trial 4D simulator has been produced and developed by Visual Basic for Applications routines. The simulator is integrated with the VIRCON relational core database [Dawood et. al., 2000]. The computerised simulator is responsive to the space needs for project activities. When entirely automated and visualised in VR, it is believed to enhance communication between the project team and to develop space-planning methods in sequencing construction tasks.

Future work:
Future work will involve the development of scheduling strategies using the above graphical interface to rehearse different project plans. The research will investigate the possibilities of visualising the 3D model in virtual reality technologies. For example, viewing the 3D model in VR desktop and other immersive VR technologies like CAVE, and hemispherium environments.

We envisage expanding our scope about space verticality and horizontality. This task requires expanding the research strategy to include the horizontal and vertical activity spaces in the simulation model. It is believed that it would have a direct correlation with space takeoff analysis and further simulation of the construction execution patterns.

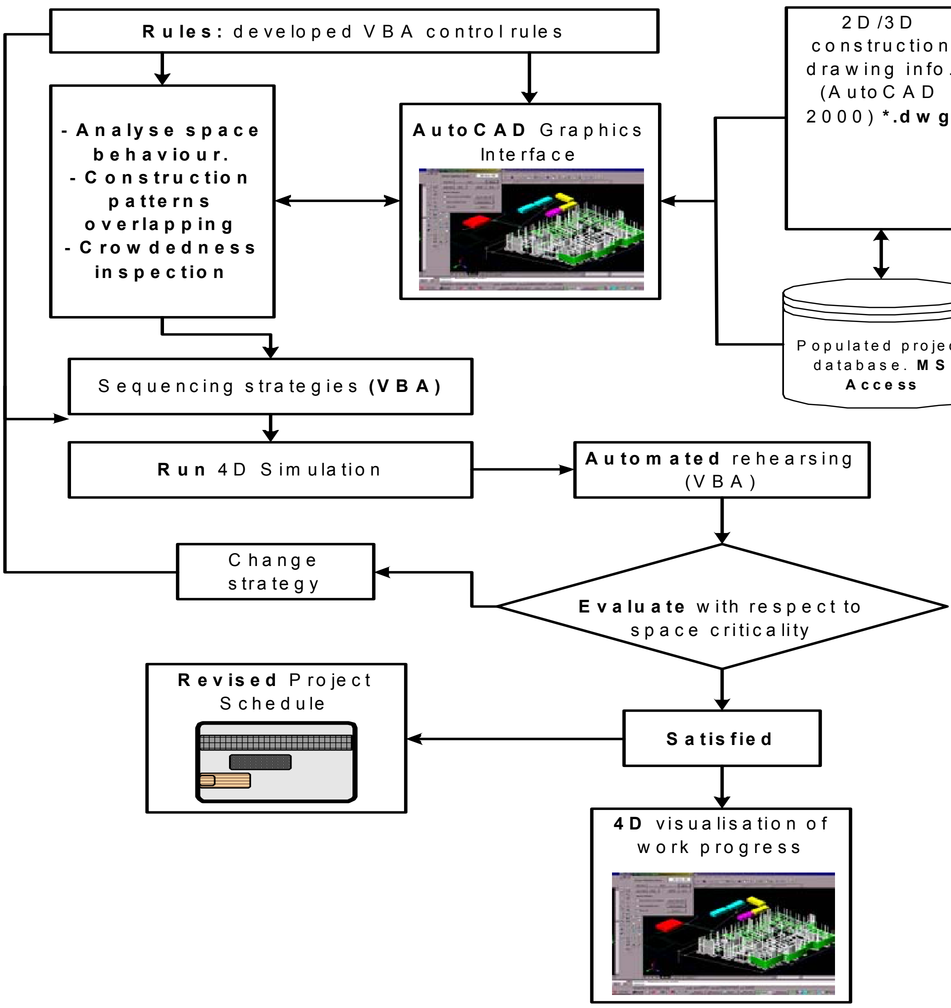

Figure 1: Flow chart of the visualisation environment for the space model

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A DATA CAPTURE MECHANISM FOR MODELLING CONSTRUCTION PLANT BREAKDOWN AND MAINTENANCE COSTS

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INTRODUCTION

Construction plant has an instrumental role in the industry's quest for increased productivity. However, plant breakdown and associated maintenance costs continue to affect the optimisation of plant utilisation throughout the construction sector. Plant breakdown relates to the state in which a plant item is temporarily, or permanently, unusable (Canter, 1993). During breakdown, project progress can be hampered significantly unless, adequate contingency plans have been made (Harris and McCaffer, 1991). Maintenance costs on the other hand, refer to cost incurred as a result of plant operation, fixed-time-to service and repair (in the event of breakdowns) (Edwards, 1999). Maintenance and breakdown events therefore share a symbiotic relationship since maintenance is conducted to reduce breakdown occurrence and thus improve machine performance.

Annexed to these aforementioned events is the need to record plant history in order to monitor and control expenditure and ensue operational efficiency. Unfortunately, current 'plant history' documentation formats do not automatically enable plant breakdown incidence and maintenance costs prediction (Nunnally, 2000; Oloke *et al*, 2001). Rather, they enable management to visually monitor trends and use subjective interpretation based upon such; this approach gives limited assurance that predictions made are accurate and robust.

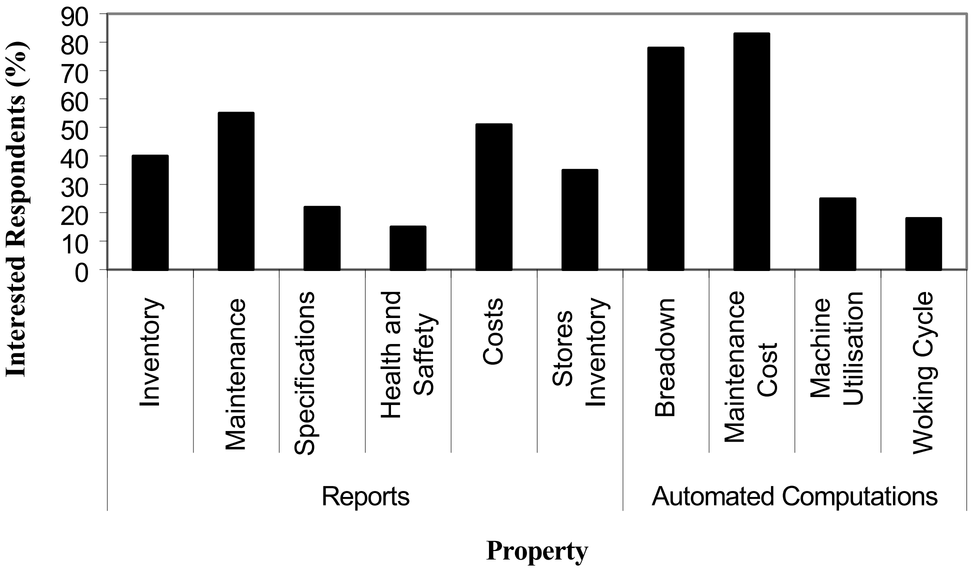
This research aims to resolve this management dilemma via the development of an intelligent system that can capture plant history data and automate the prediction of plant breakdown and maintenance costs. Specifically, a conceptual design of the data capture mechanism (within the proposed intelligent information management system) is hereby presented. The following objectives will be realised in pursuing this aim: i) to review plant history data formats produced by industry practitioners; ii) to select appropriate entities for data capture; and iii) to design an entity relationship model.

METHODOLOGY

The research methodology commenced with a pilot survey of existing plant information management techniques, utilised throughout industry. Numerous textbooks, journals, proceedings, Internet resources, etc. were also meticulously reviewed in order to ascertain the status of research and development in this field. The literature review revealed that existing plant information management techniques are either paper-based or of an electronic format. Furthermore, any deterministic forecasts made are based on a range of individualistic 'ad-hoc' statistical models that are generated from lengthy manual manipulation of the historical records within a database. A major drawback of this approach is that the models themselves are static and do not lend themselves to the dynamism of predictor variables (Edwards, 1999).

Pilot study field visits, conducted earlier this year (2001), interviewed plant practitioners regards their individual information management needs. The majority (over 75 per cent) of practitioners indicated that they would appreciate a system, which could automate the prediction of plant breakdown and maintenance costs based on each plant item's history file. In addition, practitioners sought a system that was capable of producing reports of inventories, maintenance records, specifications and plant historical costs. A detailed result of the field survey is presented in Figure 1.

Figure 1: Field Survey Results



The study revealed that the design of the plant information management system would be intricate. Amongst other things, the system must be user friendly and should permit ease of data update due to the dynamic nature of plant records.

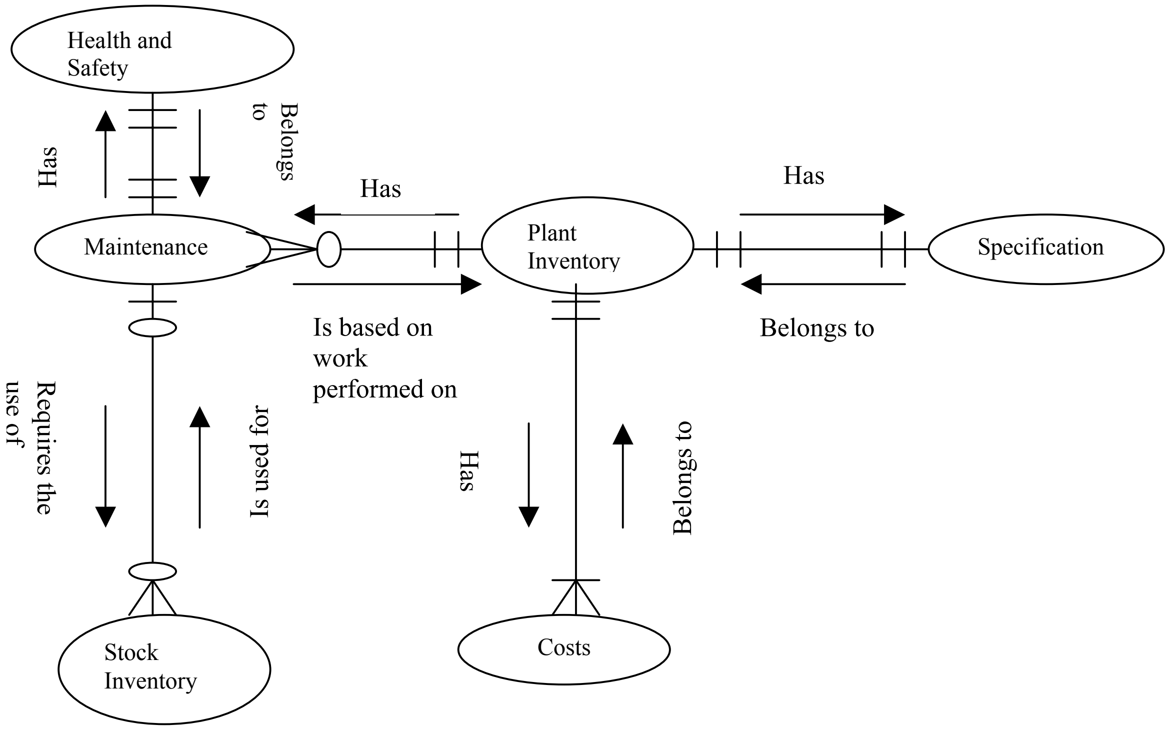
Design of the Database System

When considering a broad range of alternatives, a Relational Database Management System (RDBMS) was identified as a viable and credible solution to industry needs. This is due to its advantages over alternative systems available, for example, hierarchical and network database systems (Boyd, 1995; Zhang, 1999). Consequently, the RDBMS was thus designed to ensure that plant operations data was captured and managed most effectively. That is, plant documentation collected is 'filed' in an appropriate section within the overall database structure. It also permits the development of queries that will enable the generation of up-to-date reports based on plant history information contained on the database.

Entity-Relationship (ER) Modelling

The entity modelling technique was employed to produce an initial design of the RDBMS. This procedure involved the definition of entity types for storing historical records. Thereafter, the ER model was developed based on the relationship between the entity types. Attribute lists were then drawn up, after which, a normalisation of the data sets was also carried out. The database schema was subsequently formed from the documentation set consisting of the entity model and attribute list results. The schematic ER model is shown in Figure 2. Model design followed all RDBMS prerequisite rules of: creating attributes lists; defining the primary, secondary and component keys; and normalising the data sets.

Figure 2: Entity-Relationship Model for the Construction Plant RDBMS



The ER model represented above was then used to design the RDBMS in Microsoft Access 2000.

CURRENT STATUS OF RESEARCH AND FUTURE WORK

Having designed database forms and reports the system will soon be exposed to practitioner scrutiny and thus, validation. Similarly, the design of the Graphical User Interface (GUI) is in progress and will require further testing and debugging before presentation to practitioners. Several queries (over 30) have been coded into the programme using Structured Query Language (SQL). These enable the instantaneous real-time reporting of plant history such as cumulative hours worked, number of breakdowns, maintenance costs, parts replaced, etc. The overall RDBMS is to be programmed in Microsoft Visual Basic 6 software.

Data, in the form of history records is also being assembled from collaborating plant practitioners and with the assistance of the UK Ministry of Defence, Scottish Plant Owners Association and the Contractors Mechanical Plant Engineers. To date over 5,000 records relating to plant breakdown, utilisation and maintenance have been collected for 40 different types of plant operating on open cast mining and major earthworks projects. This data will enable various deterministic modelling techniques to be employed such as time series analysis, artificial neural networks (ANN) and other multivariate techniques. Algorithms and models produced from these analyses will form the basis of a dynamic model base management system for automating plant breakdown and maintenance cost prediction. Already, exploratory analysis using univariate time series techniques illustrated that plant history data are quite suitable for predictive modelling (Edwards, 1999; Oloke et al., 2001).

Future work entails the development of a knowledge base management sub-system that will facilitate decision support for plant breakdown and maintenance costs management. The final phase of the research involves the process of web-enabling the database to allow for ease of accessibility across geographical boundaries. The proposed web database will be secured within a walled-garden such that only those collaborators using the website can access their commercially sensitive data.

CONCLUSION

The methodology for designing a data capture system for modelling construction plant parameters has been described. Field surveys revealed that breakdown and maintenance costs are of significant interest to practitioners and that any system proposed must be user friendly and should permit ease of data update.

A RDBMS was selected and designed using an entity modelling technique. The database forms and reports have been designed whilst the design of the GUI is also in progress. At present, the programme contains over 30 queries that can generate real time plant history reports. The development of the model base management system is also in progress and preliminary results indicate that the series satisfy the prerequisite requirements of deterministic modelling techniques.

An intelligent plant management system will eventually emerge from this embryonic research. In addition to the RDBMS, the system will contain a model management and knowledge management sub-system. Ultimately, the system developed will be web-enabled to facilitate easy accessibility to plant users.

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