UNIVERSITY OF SOUTHAMPTON

RE-ENGINEERING THE CONSTRUCTION PROCUREMENT PROCESS

Thesis submitted for Doctor of Philosophy by

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Abstract

This thesis describes the research carried out to create a new contract procurement strategy called Project Delivery Process, PDP. Project Delivery Process is a new way of selecting and then managing parties to the project that creates an integrated collaborative way of working based on a systems approach. This systems approach uses both hard and soft systems ideas. Research focusing on hard systems only – including IT – is described. Research focusing on soft systems ideas, including culture, trust and team working is reported. Research and case studies are described showing that projects managed using both hard and soft systems approaches produce more successful outcomes than those managed by the use of either hard or soft systems only. It is also shown that a collaborative working relationship produces significant benefits for the project. The proposed new contract procurement strategy called Project Delivery Process, PDP, is described. Case studies of its successful implementation are included.

RE-ENGINEERING THE CONSTRUCTION PROCUREMENT PROCESS

Aims of the Research

The aim of the research is to create an improved project procurement strategy that will enable all parties to work in a collaborative way. This new strategy is called Project Delivery Process, PDP, a new integrated, collaborative way of working based on a systems approach.

This research statement is in three parts: (i) ***background***, to provide a broader view of this research area and provide supporting information to substantiate the author's original conviction, (ii) ***research statement***, to describe how each of the papers contribute to the overall research objective of creating the Project Delivery Process and (iii) ***conclusion***, to summarise the research to date.

Background

The research has been driven by the author's conviction that the traditional adversarial way of procuring construction does not produce optimal results for either the client or the other parties to the project; this was based on the author's experience of working in the construction industry. This conviction led to the theory that the new procurement strategy would be needed to have an holistic systems approach to integrate both hard and soft systems approaches into one single project management tool.

Hard systems are those using quantitative analysis methods and include, for example, operational research, contract documentation, precedence networks and information technology. Soft systems are those using qualitative analysis methods and include, for example, company culture, psychology, team working and trust. The proposed integration of hard and soft systems is recommended by Harrington (1991). The Royal Academy of Engineers (1996) states that there is a general lack of appreciation for this integrated approach within the construction industry. Sanvido's (1992) research to find the critical success factors required for successful projects also found that the integration of hard and soft systems was necessary.

This PDP research also looked for ideas from the advanced management practices developed in the manufacturing sector. These include for example, Business Systems Engineering, Business Process Re-engineering, supply chain management and Business Systems Integration. Literature describing these practices include Hammer and Champy (1993), Parnaby (1994), Towill (1992), Watson (1994), and Womack and Jones (1994).

The potential benefits of transferring advanced manufacturing methodologies into construction was recognised and recommended in Latham (1994), Egan (1998) and the Royal Academy of Engineers (1996).

Research Statement of this Thesis

Project Delivery Process, PDP, is a new integrated, collaborative way of working based on a systems approach. The initial research to create PDP is described in papers 1, 2 and 3 and ws based on the theory that a hard systems approach, only, would enable an integrated way of working. Hard systems are straightforward to implement, manage and control and tend to be more readily acceptable to engineers. At this early stage of the research programme the importance of soft systems was not fully appreciated.

Paper 1 was the outcome of research to design an integrated information system for hospital design. There were two aspects to the research in these papers, one was the information system itself and one was the use of an object based approach to help structure the data in the system. It is interesting to note that CAD was proposed as the user interface; such a hard and inflexible interface would certainly be unacceptable today. This paper reports on some early research into the application of object based approaches in construction and an early definition of a product model for hospital design.

Paper 2 presents further research to model an integrated project information system. Research was carried out to structure the knowledge and product information in way that all parties could use it at an early stage of the project. The structure of the object hierarchy proposed included product and process information for both designer and contractor. Additional background research and the methodology for this paper can be found in a series of papers by Jones and Riley (1994a, 1994b, 1994c).

Paper 3 describes research that integrates two existing and formal management tasks into one; it was expected that such an integrated management tool would be more acceptable to industry. A new concept of linking Quality Assurance and the time based project control system was researched and a multimedia-authoring tool used to demonstrate the ideas in a networked environment. The potential of creating an integrated QA and time management control system was proven.

The hard systems approach described in papers 1, 2 & 3 were project wide because a basic tenet of systems thinking is that whole system should be optimised first before the sub-systems. Ideally project wide information systems would include all those parties that ought to be allowed to contribute to the project and would be used from initial concept to in use facilities management. The research area described in these papers is therefore extensive and complex. In the decade since this hard systems research, industry has started to develop these research ideas into commercial software but their complexity and large scale nature still leaves considerable work to be carried out before any significant commercial benefit is produced.

Not withstanding that optimisation of the whole system is required some research focusing on individual hard sub-systems can be rewarding, examples are described in papers 4 & 5.

Paper 4 involved mapping the procurement process of the maintenance contracts of an SME contractor. This process was re-engineered using Harrington's (1991) Business Process Improvement steps. This is the first reported research application of Harrington's ideas to the SME contractor sector. In addition, a performance index was derived that included safety. The outcome of this research was an efficient computer based procurement control system that was implemented and led to a real reduction in procurement costs.

Paper 5 describes the research to develop a new model for maximising return on investment for the purchase of low cost, small volume items. The new model was developed into a decision support system for day to day use in an SME contractor and led to worthwhile savings. Further background research, including the methodology used, is reported in Business Engineering Group Technical Report 9801 (1998).

However, it is clear that the use of only hard systems, (papers 1-5) is not sufficient to create an integrated multiparty project environment. Research to confirm this is reported in papers 6 & 7. Both Latham (1994) and subsequently Egan (1998) supported this conclusion.

Paper 6 identified and mapped the processes at the client-contractor interface in the petrochem sector and is the first paper to report such a mapping. The problems on site were identified and the contractor based routes for additional costs mapped. The equivalent client routes to increased costs were also mapped. The contact methods for analysing the client-contractor interface were compared and reported. This paper described the early attempts to use a structured analysis approach to define value adding and non value adding tasks in this sector. This paper confirmed the need to address the soft issues in addition to the hard system. Additional detailed research results, including methodologies, are available at CORE Deliverable 1C (1996), CORE Deliverable 2B (1996), CORE Deliverable 4E (1996), CORE Deliverable 5B (1997) and CORE Deliverable 5D (1997).

The case study described in paper 7 was critically important for the PDP research programme. The research showed that certain soft systems management tools have to in place in order to create a partnering or collaborative way of working for one-off construction projects.

Paper 8 analysed the case study of paper 7 in a more generic way using Birchall's co-operative values and principles and focused, in particular, on his sixth principle of co-operation between co-operatives modelled onto inter-organisational structures.

A key finding from papers 7 & 8 is that parties to the project, who genuinely wish to work together in a collaborative way, will pro-actively do so provided that the other parties in the project and the project management strategy permit them to do so. These two papers confirmed the basic theory that a new strategy, Project Delivery Process, PDP, was possible. They also showed the importance of a rigorous party selection process in order to select only those parties who wish to work in collaboration and have the appropriate culture to allow them to naturally work in that way. The selection process had to address (i) what criteria should be used to select the parties and (ii) what sort of culture should successful parties exhibit. Research into these two factors is described in papers 9 & 10.

Paper 9 researched both the hard and soft selection criteria and used the Delphi method and Analytical Hierarchy Process. These criteria were derived from organisations in the UK, Egypt and Kuwait. Paper 10 researched cultural environments across three different industrial sectors in order to understand the impact of culture. Further background research and a detailed description of the methodology of paper 10 is reported in the Business Engineering Group Technical Report 9802 (1998).

A sound understanding of contract strategies is also required in order to create any new relevant and appropriate procurement strategy including, of-course, the Project Delivery Process. Research to understand and develop alternative contract strategies for improvement is described in papers 11 & 12. Additional detailed research is found in CORE Deliverable 3B (1996), CORE Deliverable 4C (1996), CORE Deliverable 4E (1996), CORE Deliverable 4G (1996), CORE Deliverable (1997) and CORE Deliverable 5H (1997).

Papers 7 & 8 highlighted the importance of trust as a soft systems tool. Trust has several dimensions including intra and inter team trust and the trust of technology. Trust research has a direct impact on the research of all hard systems, including the approaches to integration described in papers 1, 2 & 3. Trust is clearly important in creating the integrated hard and soft systems approach of the Project Delivery Process. Paper 13 raises some concerns about the trust placed on large computer based systems that might be developed as a result of the research described in papers 1, 2 & 3.

The research described above has enabled the design of an integrated hard and soft systems project procurement and management strategy called "Project Delivery Process". Papers 14 & 15 describe the new strategy. Paper 14 is the first publication to describe PDP; paper 15 describes its operation in more detail. The detailed research for PDP took place whilst supporting the project processes to construct Gosport Millennium Bridge (Forton Lake Opening Bridge, client Gosport Borough Council). This bridge was given demonstration project status (no 112) by the Movement for Innovation (part of the UK government's support to help the construction industry to become more efficient; details at www.m4i.gov.uk). The success of using PDP on this project can be judged by the project being awarded three nationally prestigious awards:

1. The Institution of Civil Engineers Southern Association Merit Award 2001; for achieving a project with the highest level of excellence in concept, design and construction of any project in its region during the year.
2. The Movement for Innovation Demonstration Project Award 2001; the M4I wishes to acknowledge the invaluable contribution made by the BEG in helping to implement "Rethinking Construction".
3. The Solent Protection Society Environmental Awards 2001: for construction in an environmentally sensitive area; one of only 20 awards given in the last 50years!

Conclusion

This thesis has described the research carried out to develop the new contract procurement strategy "Project Delivery Process", PDP, as an integrated, collaborative way of working based on a systems approach.

The initial theory was that the use of hard systems only would be sufficient to create a project wide support system for collaborative working. A hard systems approach would have been considerably more acceptable to engineers. However research has shown that the use of hard systems only has not produced the improved results that were anticipated. Research demonstrated that successful projects had management systems that also addressed the soft systems problems.

As a result Project Delivery Process uses both hard systems (multi-criteria decision making tools, concurrent engineering) and soft systems (such as trust, culture, teamworking). The detail of Project Delivery Process, PDP has been described including its successful use on real project.

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LIST OF PAPERS SUBMITTED

THE INTEGRATED INFORMATION SYSTEM FOR AEC PROJECTS

M J Riley and H R S Sabet

Abstract

This paper describes the conceptual design of a common platform that enables its users to exchange information of all types (numerate and non-numerate data, graphical and non-graphical data and knowledge) in a computer-based environment. The successful development of such a platform is one of the key requirements for the future users of information technology in the construction industry. This common platform has been given the name of the Integrated Information System (IIS) in this paper. It is shown that other industries (such as manufacturing) have been more successful in the implementation and integration of Databases, Knowledge Based Engineering, Computer Aided Drawing and Drafting and Object Oriented Databases.

This paper describes an Integrated Information System that provides the users with data and expertise for all stages of the project and for all the professionals involved. This paper describes the architecture and implementation of the system as well as organisational and marketing benefits of using such a system.

Keywords: The Integrated Information System, Building Modeling System, Knowledgebase, Database and Expert System

Introduction

The Architecture, Engineering and Construction (AEC) industry is a very large industry with the building sector accounting for approximately 10-11% of the gross national product of the EC countries and United States. An AEC project develops a considerable amount of information. Projects involve large numbers of people and firms, between whom there is a great need for information interchange. The procedures used by companies to handle this information provides an indication of efficiency, accuracy and the management of the project. This information handling process requires resources in terms of time, workforce and facilities and is one of the keys to successful project management. The accurate and efficient management of this process will lead to increased production with higher quality and lower costs; this is already happening in the manufacturing industries.

The stand-alone use of Computer Aided Design (CAD) is leading to the development of many new ideas for the handling of information during the project lifecycle from pre-design through to maintenance. While the commercial CAD companies have concentrated primarily on drafting programs, those programs are gradually expanding to take on greater and more comprehensive capabilities [Wade 92]. It is interesting to note that most of the earlier work was related to either the initial or the final stages of the project; it was apparently much more difficult to provide solutions for the main design functions.

Independently, the development of databases offered a new technology that could be applied to the integration of different environments. The development of Computer Aided Manufacturing (CAM) was an additional source of inspiration to the professional in the AEC industry attempting to apply the new possibilities that information technology (IT) offered to the AEC industry. "Computer integrated construction is largely fuelled by the success of computer integrated manufacturing (CIM), a similar concept in manufacturing" [Sanvido 92].

The application of artificial intelligence in other engineering disciplines has also led to the development of expert systems within the construction industry, although there is clearly considerable work still to be carried out in this area [Mohan 90].

A system that provides the users with information and expertise in an integrated form, for different functions in an AEC project, is of particular importance to both industry and researchers. The system described in this paper does have the integrated form described above and various researchers have suggested a range of different names to describe their ideas for such a system; this paper uses the name 'Integrated Information System' (IIS).

The Integrated Information System (IIS)

The Integrated Information System is intended to be used by the professionals involved in the project including the architect, structural engineer, HVAC designer, project manager etc. The user communicates with the system through the user interface, which contains CAD software, a database management system and a knowledge base management system. The users are able to change, manipulate and modify data in the CAD drawing and examine its effects on the other elements of the project such as structures, lighting, project's cost, fire safety and interior architecture.

The system has been designed for three different types of user: -

1. Read only access: for non expert users who just require data and information from other design team members in order to help with their decision making.

2. Read and write access: for a specific and defined area of the project information pertaining to their own design responsibility. All such written information will/may impact on other design areas and this will be automatically carried out.

3. As 2 above but with the power to amend or change the criteria used within the expert systems.

The system engineer will control the rights of access given to the various users.

Such a system contributes to integrating not only the different phases of the project but also the different sections of the organisation, such as various departments in the head office as well as the remote site, by implementation of local area networks (LAN) or wide area networks (WAN). The system facilitates the communication between different participants, companies and organisations in the project. The implementation of the IIS will allow concurrent design to take place.

A particular problem, not addressed in this paper, is the security of the data and information held within the system. Confidential information, particularly relating to money, will require restricted access, even for users within a single company. The problem is even more critical when outside companies are linked into the system, which of course they must be in order to achieve the maximum benefits.

The Architecture of the Integrated Information System

Figure 1 shows the architecture of the IIS. The IIS consists of a user interface, which contains a CAD system, plus an object database, which contains all the geometrical objects in time project in hierarchical form. For example, a room is an element that consists of objects such as vertical walls, horizontal beams, columns etc. The CAD system is connected to the knowledge base system through a geometry interpreter. The geometry interpreter's role is to transform any new or modified CAD data into a form that is readable for the knowledge base expert systems. The knowledge base system consists of various expert systems that facilitate different tasks of the project team particularly in the pre-design stage of time project. The system is equipped with databases in order to store, retrieve and modify the files that contain the information resulting from examination of data by experts or expert systems. The expert systems provide expertise in HVAC, structures, lighting, cost, interior decorators fire safety etc. Each expert system may consists of sub-systems e.g. the cost expert system contains painting cost, HVAC cost etc. There are links between different expert systems in order to exchange data between them. If a modification in a CAD drawing leads to changes in the HVAC design, the modified data will be sent to the cost expert system in order to calculate the revised cost of the HVAC system as well as the new overall cost of the project. After all the calculations, the data will be modified and stored in relevant directories in the database. The expert systems have read and write access to the datafiles stored in the databases.

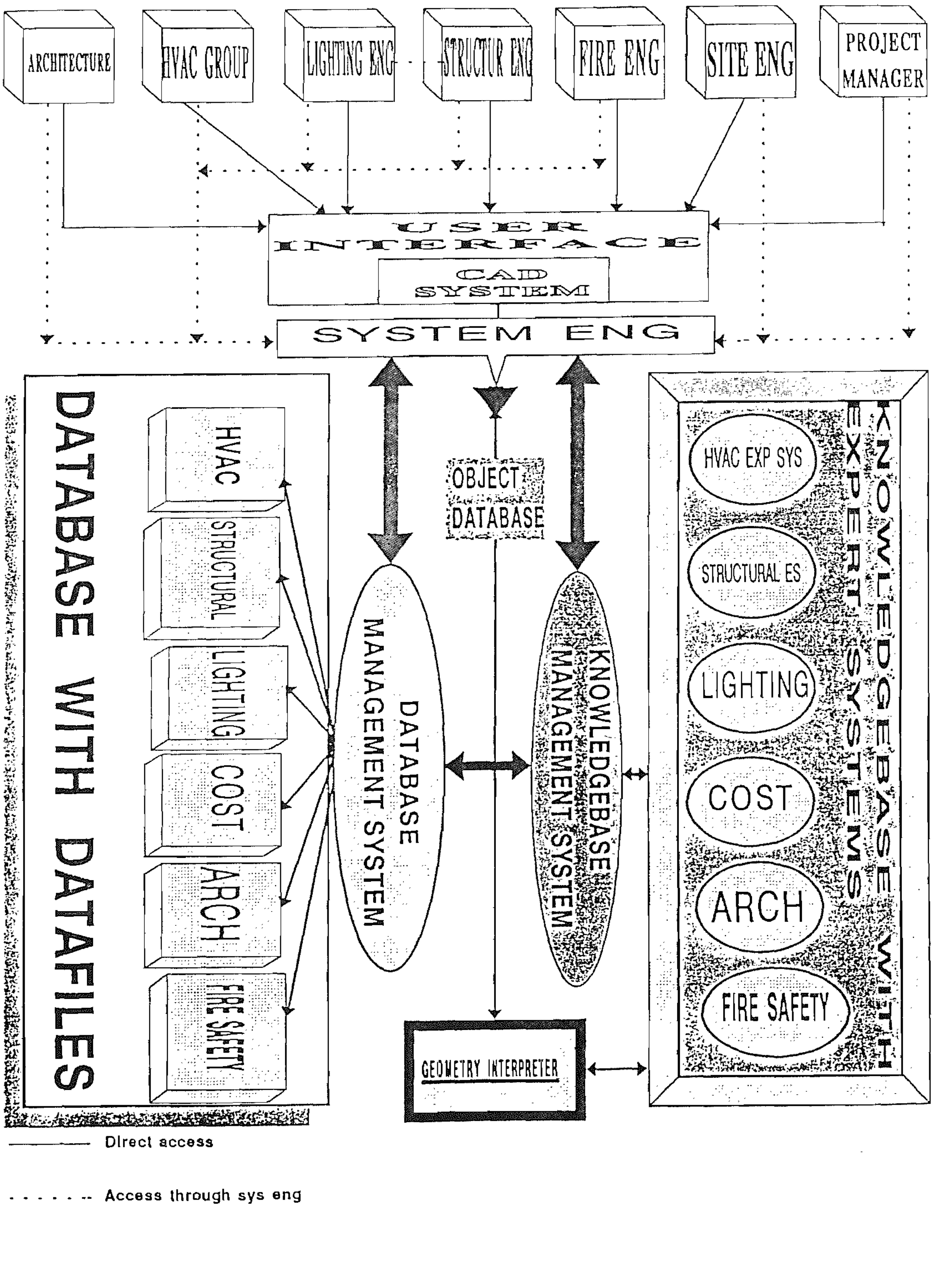

Figure 1 The Architecture of the Integrated Information System

The Hierarchical Structure of Objects

The elements and their attributes are used differently by different users in an AEC project. For example, a wall is considered to be a closing object for the architect whilst the load within the wall or the strength of the columns and beams are of interest to the structural engineer. At the same time, the area of the interior surfaces of the wall is needed by the project manager/expert system in order to calculate the painting costs. Figure 2 shows how the different users/expert systems access the different levels within the object hierarchy of the previously defined superclass-subclass hierarchies.

(Schierer et al 93) suggest a solution by modeling time data in an 'orthogonal model' which consists of:

I. The generalisation /specialisation plane that specifies the "is—a" relationships between sets of similar elements.

2. The composition /decomposition plane that specifies construction, connect joint and "part of" relationships.

3. The localisation plane that specifies topological relationships allowing to determine the connection and location of a particular object in respect to other objects.

The authors believe that this approach will be the most practical solution for modeling the data of different physical elements in a building and will facilitate efficient management of the object database.

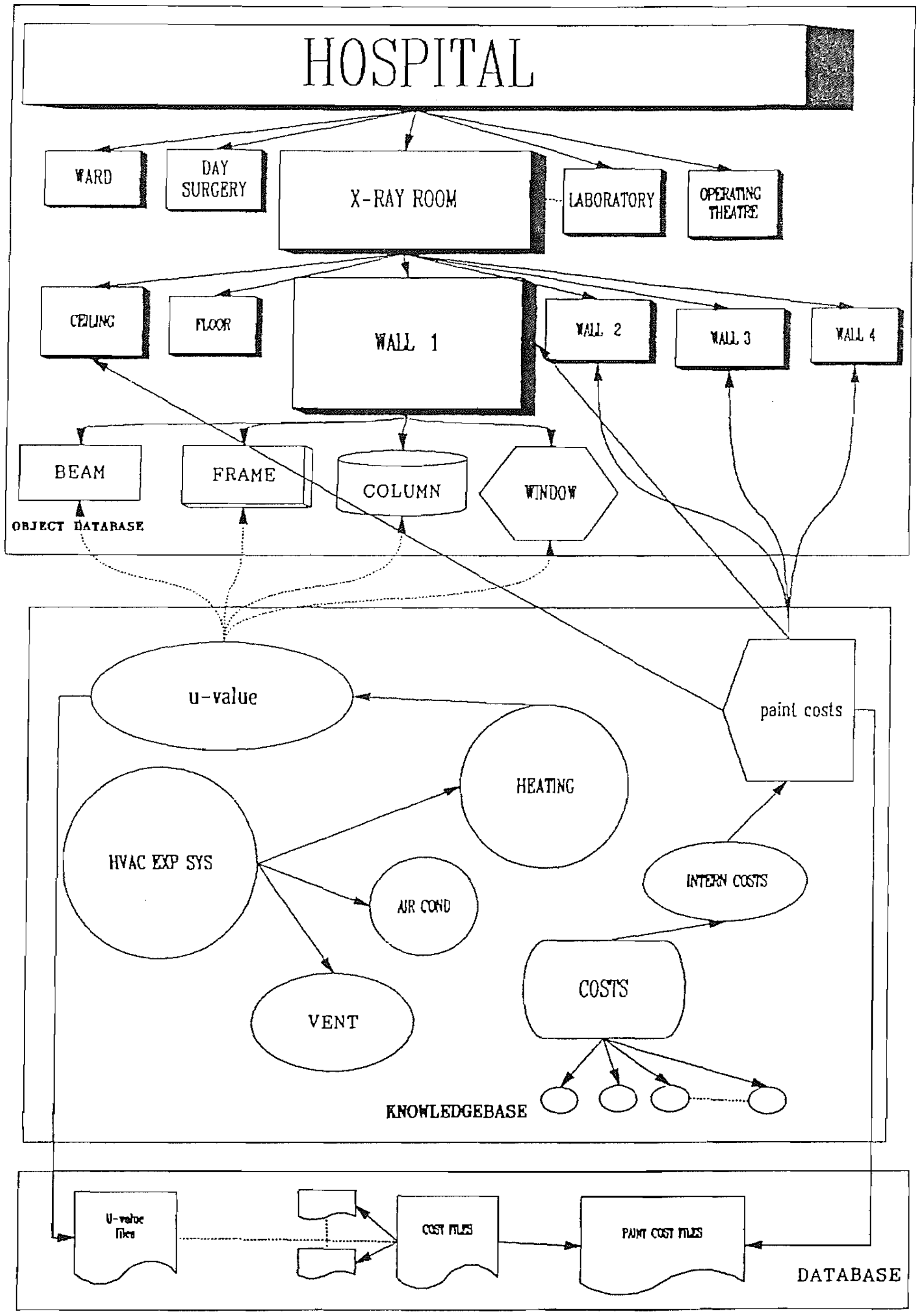

Figure 2 Showing the Different Levels of Building Hierarchy used by Experts/Expert Systems

Implementation of the Integrated Information System

A system such as the IIS is efficient and suitable for large scale projects requiring great amounts of information, having large design teams and involving many external consultants. The IIS also satisfies the project's requirements for the efficient management of the massive and complex internal and external communications links. Examples of such projects include hospitals airports, petrochemical plants, gas or nuclear power plants and waste water treatment plants.

There are two common characteristics of such a project:

1. A large amount of the information in the form of heuristics and experience is not available after project completion.
2. There are many changes in design during a project's life cycle.

The IIS contributes to the solution of the first problem by using expert systems to store the expertise developed during previous projects.

Regarding the dynamic aspects of design, the IIS provides the facility for real-time analysis amid concurrent design throughout the life cycle of the project.

(Aoki et al 93) suggest the goals of an integrated system should be as follows:

I. *Centralised information in a common database.*
2. *Stored company know-how and expert knowledge.*
3. *Easy, high quality communication and data exchange.*
4. *Real—time information processing and visualization.*
5. *On—line management.*

The proposed IIS fulfils these goals.

Displaying and marketing of ideas and products

The IIS also offers the potential for new concepts in marketing which will be advantageous to both client and the professional. The client will be able to view the conceptual design that has been developed using expert systems containing the experiences of previous projects and the AEC professional has the facility to display all aspects of the overall project to the client.

Future development of the IIS

The authors aim to transfer the IIS from the conceptual stage to the physical stage in the near future. The goal will be to implement the system for a large scale project such as a hospital, airport etc. in order to illustrate the strengths and weaknesses of the system and so enabling further research and development to take place. It is likely that the work will involve developments in areas such as Knowledge Based Engineering, Object Oriented Database/ Programming and multi-media systems.

The potential for using Virtual Reality will need to be taken into account with any future work in this area.

Conclusion

This paper highlights the following benefits for time user of the Integrated Information System:

1. Extensive and comprehensive communication facilities within the project team and external to the project.
2. Experience of previous projects will be available to the designers of new projects.
3. Concurrent design will be possible and this will lead to more efficient designs that achieve more closely the client's requirements.
4. Increasing accuracy of the design analysis.
5. Real-time interaction between professionals.
6. Improved decision—making information.
7. The potential for new marketing strategies.

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CONCURRENT CONSTRUCTION INTEGRATED DESIGN

B K Jones and M J Riley

Abstract

This paper explores the possibilities that now exist for construction experts to develop solutions concurrent with architecture and engineering experts. Advances in design technology and research efforts in knowledge based engineering are leading to cultural changes in the whole project environment. This paper proposes that to develop construction professionals who can manage these changes and have enough vision to benefit fully from what is on offer many behavioural, organisational and institutional barriers have to be overcome. The reader is presented with an overview of the components involved in a solution generation conceptual model with references to some of the research in these areas which views, three dimensional computer aided design, databases that allow two-way flow of information between all project participants, a knowledge capture system and a solution generation architecture. A conceptual model framework is proposed that will allow concurrent construction integrated design that draws on knowledge captured from Architect, Engineer and Construction (AEC) experts. The main focus of this paper is directed to the Project Modeling System (PMS) which is the main contractors system that views graphical and non-graphical design output and then builds solutions, regarding major criteria such as construction method, resource requirements, cost engineering implications, time to construct, engineering and technology systems required to construct the facility, construction management organization and control mechanisms. The output from the PMS then forms the basic information used by the management construction team based in the field

Key Words Construction Integrated Design(CID), Computer Integrated Construction (CIC), Project Modeling System (PMS), Knowledge Based Expert Systems(KBES), Knowledge Based Engineering, 3D CAD; Blackboard Architecture, Object - Oriented Programming, Concurrent Modeling.

Introduction

All parties to the project are committed, from the initial stages of conceptualizing the owner's requirements through to the final completed project, to a design and construction process to satisfy the functional, cost and quality parameters the owner perceives. At all points in this procedure decisions are made by human experts that will impact time, cost, quality and value requirements of the project. Many of these decisions set construction goals based on the analysis of data from computer stored information. More efficient portrayal of graphical and non-graphical information, the assistance of knowledge based expert systems (KBES) and the establishment of an effective integrated "Total Project" organization, which allows concurrent discussions, will lead to the generation of complete solutions and provide the client with greater value and eventually reduce project costs.

Traditionally a sequential mode is adopted in the design and construction processes where the output from one stage forms the input to the next. This process has been refined to an acceptable level of integration between the design participants with the minimum of backtracking; however, as the project becomes more complex then concurrent decision making in real time is the goal for optimum solutions.

Construction Decision Making

Design systems that are flexible and allow rapid construction analysis of time, cost, assembly method, constructability and achievable quality are required to maximise design decision effectiveness. Traditionally it is the construction experts in this system who determine a method of assembly that so influences the final construction costs and time to build, but the major criteria, which affect the project's quality, cost and time parameters are imposed mainly by the architectural design team. Once determined, the design often imposes a system of building and methodology that has little room for open discussion or innovation of alternatives. Construction companies need to be moving to a position of devising fast concurrent systems for analyzing projects at a screening/feasibility stage that will establish a more construction cost efficient design. However for these efficiencies to bring maximum benefit, the owners and design teams must fully integrate and share their decision criteria and expert knowledge with the Project Modelling System (PMS) of the main contractor. The PMS has been defined as that system which views graphical and non-graphical design output and then builds solutions, regarding major criteria such as construction method, resource requirements, cost engineering implications, time to construct, engineering and technology systems required to construct the facility, construction management organization and control mechanisms. The output from the PMS then forms the basic information used by the management construction team based in the field

The direction in which computer integration is developing

If the present capability of computer tools to support concurrent multi - disciplinary design are considered, then most achievements to date are based on initiatives that link together a disjointed range of software packages (e.g. scheduling packages, estimating packages, MRP, CAD, structural design packages, etc). Those companies, whether construction, engineering, design or CAD software houses that lead in providing complete integrating solutions across all AEC experts, will enhance their competitive position when negotiating for new work. It may be that strategic alliances have to be formed before companies can convince clients that they offer unique solutions that are cost effective and efficient. But the computer technology is in place, what is now required is the closest collaboration between researchers, construction experts and design experts [Ref 1].

Vertical and Horizontal Fragmentation

It is understood that the architecture, engineering and construction industries have large inefficiencies due to their inability to solve concurrent problems that affect the design and construction of a project. Within the relatively short time framework of a major project, the vertical fragmentation between project stages (e.g. conceptual design, detailed design, PMS, construction, operations, facility management) and the horizontal fragmentation between expert participants (e.g. architect, planning authority, engineers, estimators, construction managers) is unparalleled in any other manufacturing industry. This is often accentuated because of the professional demarcations which are defined by the professional institutions. The present computer environment now offers the scope to improve considerably our understanding of the work and associated intricate problems of our colleagues, who represent a common allegiance to the client.

Definition of Integration

The definitions of integration which suggest what is desirable to achieve are: [Ref 2] that defines integration as that which provides a common database to be accessed, used and updated by multiple applications or users. The information in this integrated system is organized in a logical way and demonstrates a centralized behaviour with consistent and non-redundant data. Whereas [Ref 3] states that the goal of computer-integrated design and construction is the vertical integration of data, design decisions and knowledge through all phases of facility development leading to improvements in the efficiency and quality of design and construction. At the same time, enhanced integration and automation of decision making in all phases of the process can create a machine-readable and machine-usable knowledge environment in which automation of the physical construction processes can proceed more easily.

These definitions suggest that the centralized sharing of data, which is in a form each user expert requires, is one of the major priorities of integration. Once this is achieved, the participant can enhance this data with the addition of knowledge based expert systems thereby giving the ability to reason from such data in order to derive solutions.

Solution Development and Optimization

The previous sections focused on integration which is seen as desirable within and across the design, engineering and construction professions. To operate effectively these professionals all require to input and retrieve information. The communication system within the information model can range from direct discussions with human experts to gaining access of machine captured data, knowledge or information. Whatever, 'success' can only be efficiently assured if there is an information management system that provides the information, in a form best suited for the experts decision making processes and then allows rapid analysis for solution optimization.

Decision making processes in Design and Construction

The designer or constructor needs to understand fully, and question, the decision making processes that presently occur in the design and construction domains. If decision making within the design process is considered, Levitt [Ref 4] viewed this process as three tasks performed iteratively in increasing detail.

Firstly a designer synthesizes one or more candidate solutions aimed at meeting a set of design specifications. Secondly the designer analyses and reasons each candidate solution to determine its behaviour in terms of important dimensions of the system's performance. Thirdly, the designer evaluates the performance of each candidate solution that determines whether, and how well, they meet the design specifications. If a solution is deemed unsatisfactory, the dimensions of performance needing improvement are used to guide the next round of synthesis for an improved solution and so on.

Reflecting on these observations in considering solution development within the PMS it is proposed that, firstly, the construction experts analyse the graphical and non-graphical information produced in the design process; secondly they determine the criteria to be satisfied; thirdly they use their personal knowledge and judgement supported by company defined data to develop solutions and finally they optimise to arrive at one solution that best meets the challenge presented from design.

Detailed understanding of what is being achieved in these processes is the key to developing computer analysis systems that provide the solutions within a minimum time-framework and with maximum viewing across other professional's criteria. Interpreting the product through the many stages of architectural design, engineering design and construction, the initial client's brief can become very distorted from what was first envisaged. By modelling these processes concurrently then a better chance exists to produce a structure that truly reflects what the client wants, within the parameters first considered. Therefore a complete computer developed analysis of the product for the clients approval at very early stages of project anticipation would expedite effective solution development.

Solution generation within a Blackboard Architecture

A formalised framework for solution development in the AEC project team problem solving domain is required as part of the complete model. Blackboard architecture has become widely accepted as an extremely general and flexible framework for problem solving, when information sharing is required [Ref 5]. This problem solving tool has formed the basis of a number of research initiatives to develop computer based models [Ref 7, Ref 8, Ref 9]. A blackboard environment would be suited for making construction decisions where a multi-discipline team of experts is represented and a number of alternative solutions are to be reasoned about. Within this solution generation environment the expert participants, called knowledge sources (KS), are faced with a problem that can be described on the blackboard (BB) for analysis. None of the KS's can solve the entire problem on their own, but each of them may be able to contribute problem-solving steps that, when combined in reasonable sequence, lead to a solution. By looking at the BB, KS know when it is appropriate for them to focus their attention and they know when it is proper to propose taking action. The only way for KS to communicate with each other is by making changes on the blackboard. In each step towards the solution, one and only one, KS executes its proposed action by changing the BB. The cycle then repeats. It is through a moderator in the meeting who, at each cycle, listens to the KS and selects the best, which then gets executed by changing the BB [Ref 6]. This media of communication presents an electronic environment where construction solutions can be arrived at concurrently with other AEC experts.

Cad Design Environment Using Knowledge Based Tools

In the past few years Computer Aided Design and Drafting (CAD) tools have evolved to provide the first cohort of design synthesis possibilities through the technology of linking CAD to real time engineering analysis, graphics and databases. This provides the framework for concurrent design in real-time. Placing CAD alongside Information Technology Systems with appropriate Information Management Systems and it is possible to create an electronic integrated AEC project modelling environment that has great scope for innovative use from the various expert contributors. In particular, it gives the potential not only to change the way designers define the building but also the form architectural, engineering and construction information is provided.

Many possibilities exist to use CAD in the modelling of the construction processes to determine method, constructability, resource analysis and cost planning, etc. A number of these possibilities are listed in appendix 1. While structures are being designed, construction engineering decisions often have to be grappled with. Proposals need to be forthcoming on such matters as formwork fabrication and use, temporary support, work access, health and safety implications, material and resource work flows patterns. The construction process is about the assembly of individual or composite products with the effective selection of resources against a background of a whole host of constraints, most which are design imposed. The designer, assisted by computers with associated databases, arranges those products into the designed structure. This generates much information associated with the object the user draws and the relationship existing between those objects. Viewing the facility as the combination of product objects manipulated by process objects gives us the scope to represent these objects in a structured way and then manipulate them to develop computer generated solutions with minimum interference from the human expert. Much of the construction engineering analysis work could be carried out in real time while the design is taking shape on the computer screen.

CAD data interchange and knowledge based support

There are many benefits in the AEC industry that are achieved by developing data exchange systems which can exchange non-graphical as well as graphical information. The databases linked to CAD systems can be linked to other databases to provide for integrated analysis of various construction criteria. Several kinds of reasoning using standard Knowledge Based Expert System (KBES) techniques [Ref 10] are possible. It then allows logical queries to be made that link both geometry and object data e.g. where are all the columns over a certain height which therefore require concrete pouring in more than one stage. This type of recognition allows the CAD/CAE database to be used for a wide variety of downstream functions in the architectural, engineering or construction domains. Levitt [Ref 4] suggests the following grouping of knowledge and date: physical properties of the materials of which the component is made for use by structural, heat flow, etc.; analysis programs; technical specifications for manufacturing; assembling; testing or operating the components of the engineered system; administration information needed in the manufacturing process e.g. vendor name, contact number, payment provision; analysis information e.g. member or connection forces and moments computed by structural analysis packages. This data is available in the CAD system and can be quickly generated to support multi-discipline decision making.

Linking a CAD system to databases enhanced with knowledge based expert systems and using the facility of blackboard architecture to assist in solving problems, gives the construction expert, with other design experts, the opportunities to generate solutions in a concurrent framework. This can all be represented on the computer display in a multi-media fashion with full audio and visual links for the various participants sitting in their respective offices or site based.

Modelling with Object Databases

Object-oriented modelling has gained much attention in computer aided design in recent years; it offers many advantages over the traditional relational data model. Object-oriented systems help the user in managing related data having complex structure by combining them into objects. The use of objects permits manipulation of the data at a higher level of abstraction. For instance objects can be formed to represent the building's components/elements (e.g. beams, columns, windows); their properties (e.g. depth, width, weight, area); the activities to construct the components would also be represented as would the resources to perform the activities. Building the model in this way gives the opportunity to construct systems that offer greater flexibility, higher intelligence and better integration. There is a need to eventually establish an agreed industry data or object model standard, that offers insight into what the fundamental information elements of the project management process are [Ref 17].

Research in Object-Oriented Models

Several researchers are attempting to develop object - oriented product models. [Ref 18]. The Technical Research Centre of Finland, through its Information and Automation Systems Research in Construction, has made progress on an object - oriented building product data model (RATAS). The prototypes developed during the project were (i) a PC based relational database prototype of a typical office-building storey, (ii) a hypermedia demonstration of the building product data model structure and (iii) a relational database prototype with flexible user interlaces, built in a Macintosh environment and tested with several case buildings and (iv) a hybrid CAD-system and relational database prototype covering quantity data management. At MIT Professor Robert Logcher's work on an object - oriented CAD system (BUILDER) which generates a symbolic model as the graphics are created on a LISP [Ref 19]. At California State Polytechnic at San Luis Obispo, a design system termed Intelligent CAD (ICAD) has extended the scope of a CAD system by adding intelligence that aids the designer. The research being carried out at Centre for Integrated Facilities Engineering at University of Stamford, California is to develop an Object Oriented

Project Model for AEC Process termed PMAP [Ref 10]. This work produces an unrestricted model that can cover many aspects in the AEC process. Initially the model was used as a vehicle to share product information for a mid-rise building project between a CAD system and two expert planning systems. AutoCad is the CAD system interface with PMAP. The two separate knowledge - based construction planning systems used are OARPLAN [Ref 8]; this is a prototype knowledge - based construction planning system based on the notion that activities in a construction project plan can be viewed as intersections of objects, actions and resources at different levels of abstraction and SIPEC [Ref 20], which is a prototype knowledge - based construction planning system using System for Interactive Planning and Execution developed by SRI International [Ref 21]. The work on PMAP was extended to work entitled An Object Oriented Project Model Supporting Multiple Views (PMAPM), this work is summarized in [Ref 22]. The major difference between PMAPM and PMAP is the inclusion of the view definition for each participant in the AEC process.

Identification of Construction Objects

The identification of construction objects should be based on a study of the user requirements and then the objects can be designed, implemented, validated and tested to reflect the actual objects. When building a conceptual object model for project management applications it is suggested that the library elements be adopted which are proposed as follows [Ref 17]:

(A) general construction objects composed of (i) resource types (labour, equipment etc), (ii) component types (the physical elements), (iii) action types, (install, cast, assemble), and (iv) method types; that identify method and match appropriate resources and actions on specific components.

(B) specific project objects these include the projects specific physical components, the resources used and the specific activities involved; this information would be used dependant on a hierarchy work breakdown structure similar to that used in the various planning/programming stages.

(C) project management applications involving objects that generate, refine, or utilise the basic project elements (e.g. the estimating system procedures might be used to generate the project elements). This in turn would lead to the automatic generation of components, activities and resources as well as the automatic calculation of the items costs.

Expert Knowledge Capture

Considering the total life of major projects and the decisions that are generated by the many professionals, then an intricate time/people/decision process emerges. Within this project framework expert knowledge contributes to the completion and operation of the finished product. This project-specific knowledge often has to be recalled, re-analysed and re-justified. If this intelligence is captured and ways developed that efficiently access this data, then it would save time in future decision analysis. Because of the dynamic nature of a construction project, often the originators of those decisions with their respective knowledge skills have left to join other project teams and therefore only sketchy memory details exist of their decisions. So questions must be asked how to capture, effectively screen and efficiently use this expert knowledge. The layered knowledge is illustrated in Figure A.

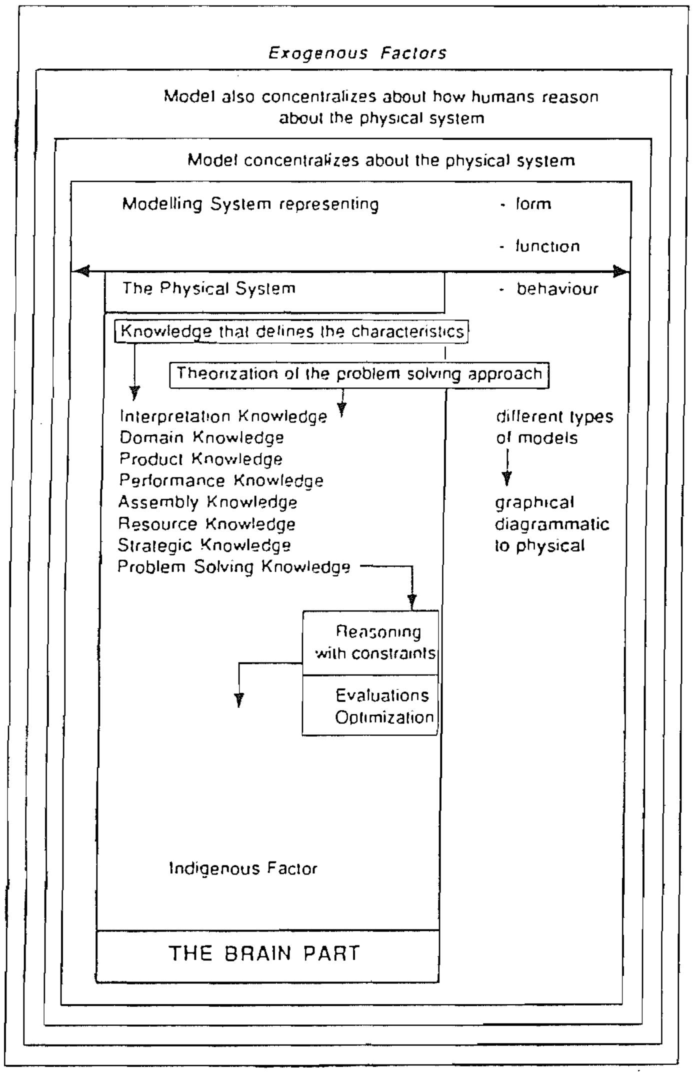

Figure A The knowledge layered model

Knowledge Acquisition

Knowledge acquisition from experts is generally be considered to be the major problem in knowledge based engineering. Research studies include the investigation of knowledge representation schemes and languages that help case knowledge acquisition, the development of efficient maintenance tools for a knowledge base and the exploration of automatic acquisition tools and implementation of effective interview methods with experts [Ref 14].

A number of strategies have been developed to observe a sequence of actions performed by the expert. The WATCH system [Ref 11], was designed to be a knowledge acquisition tool. This saved knowledge is the necessary background information for the learning process. It allows an expert to define all the background domain knowledge and then automatically learn control information by observing and tracing the experts problem solving behaviour processes. The intended control strategy is then established by induction. This is achieved through placing a copy of the observed action sequence on the blackboard system environment and then by examination, globalisation and elimination, the best strategy can be determined.

Project data is accumulated from those initial design decisions that link elements of basic data, design data, project specification, domain knowledge and general knowledge to explain the design. [Ref 12] discusses the range of data and knowledge whose elements have to be captured in an engineered system. This knowledge ranges from very specific defined details (Basic data) to very abstract, common principles (General knowledge); the areas between are considered to give us greatest problems of capture.

Structural Engineering and Construction Knowledge

It is interesting to contrast knowledge for a structural system with the classification of knowledge in the construction project modelling system.

For a structural system the classification proposed by Jam 1990 [Ref 15] can be referenced. This defines System Knowledge; Behaviour Knowledge; Performance Knowledge; Product Knowledge; Concept Knowledge; Strategy Knowledge.

Classification of knowledge used within the PMS is proposed as follows:

Interpretation knowledge: the ability of the construction expert to read design information, determine criteria and constraints. It also includes the ability to reproduce data and decisions into a form consistent with construction management.

Domain knowledge: is the constraints and heuristics that belong to a construction professional. This knowledge is often recorded in process manuals, textbooks, records from past projects, expertise of software packages. The quality of this knowledge is often dependant on the experience of previous projects. Domain knowledge also includes the ability of construction experts to view across multiple domains.

Product Knowledge: knowledge about specific products that can be used for construction is classified under this category e.g. properties of concrete strength related tests, timber visual classification tests, or knowledge about the availability of certain products.

Performance Knowledge: Relating to the construction experts understanding of the performance and behaviour of a whole structure under construction or individual component parts.

Concepts or Assembly Knowledge: a broad knowledge appertaining to economic sequencing, buildability and constructability issues.

Resource Knowledge: refers to an understanding of the resources used to construct a facility and how resources can be combined to achieve maximum efficiency. A knowledge of the cost implications is implicit in this understanding.

Strategic Knowledge: a large proportion of generic domain knowledge is contained in the previous points but such base-level knowledge alone is not sufficient for solving construction problems. To effectively solve the challenges laid down by a designed facility the construction expert must sometimes rely on informed or sometimes un-informed intuition. A certain amount of creativity or strategy comes into play. This knowledge reflects the human thought process that emulates the human techniques in approaching the problem.

The knowledge of the structural expert or the construction expert requires an understanding of the products used in the building or civil engineering project. Both should understand the performance of that product and what is required to transfer the individual product objects to a composite structure. Both should be aware of cost and quality implications in selecting those product objects to be included in the completed structure. It should not be necessary to arrive at "construction' criteria only when the final structure is designed when designers can safely communicate this information through a traditional paper system. This is all too late. Knowledge from both should be introduced and used within thePMS, for solution optimisation at a much earlier time.

It must be emphasised that having this knowledge is not always sufficient to ensure that greatest efficiency is achieved. Managers rely on certain skills that can be built on from an intuitive base; these include such things as negotiation skills, communication skills, technical skills and leadership skills.

Capturing Construction Managers Knowledge

There are particular problems in capturing knowledge from construction management experts since this management expertise is generally decentralized among many managers in various positions. There are further problems in that most users of a management knowledge based system are not novices; they generally have some level of management/decision making expertise. Therefore when using the expert system the answers often become too limited and predictable. This is because expert systems use strict inference mechanisms whereas human managers do not reason by inference mechanisms. Rather they use much looser knowledge associations drawing from a broader, more diverse, knowledge network in a less anticipated way. Managers often want to share experiences of other managers therefore knowledge sharing through knowledge bases is an important consideration. Retrieval of knowledge from shared data bases also presents certain problems because that knowledge is not captured in words that can be accessed like a thesaurus or dictionary; it is generally expressed in clauses, phrases, or sentences [Ref 16].

Modelling for Construction Solutions

In this paper, the uses of conceptual models to arrive at complete solutions that assist the domain construction expert are proposed. It is worth comparing the mechanisms of a model to generate solutions rather than the human expert.

In solving problems the human expert quickly focuses on likely solutions; stays there unless there is good reason to move; initially they use use non-rational or unconscious mental processes (implicit); is not exhaustive in search; has a vast experience base which affects the solution process even if not an expert and is slow on numerical computation. Therefore humans use experience to compensate. The conceptual model on the other hand only eliminate possibilities if there is good reason to do so; has no initial bias; explicit mechanism of exclusion and score; is exhaustive but has a limited knowledge base; has fast supporting numerics that are used to make up for the lack of domain knowledge. It must be stressed that experts are experts because of their knowledge, not because of their inference capabilities; human experts use heuristics to focus and be efficient. Therefore a combination of the human expert with support from model based machine experts seems the most expeditious solution.

Model based reasoning ---- developing knowledge systems

Developing a knowledge system for performing an engineering task is, in many respects, analogous to developing a scientific theory; one identifies underlying knowledge that defines the characteristics of the physical system being reasoned about and one must also theorize the problem-solving approach of a given class of professionals in the domain of interest [Ref 24]. Model based reasoning has emerged as useful for solving problems in diverse application areas [Ref 25 & 26]. In order to reason about a system in this approach one represents the form, function and behaviour of the system being modelled. The representation of form, function and behaviour of the construction system can be used in conjunction with the representation of problem solving knowledge, thereby forming a layered reasoning system modelling two distinct conceptual entities:

(a) the physical system and

(b) the human being reasoning about the physical system. (Ref 15].

What must be achieved is a reliable means to predict the most effective method of construction with the technology, resources and knowledge available to the dedicated project team, this should be done concurrent with multi-discipline experts.

A possible knowledge system for design and manufacturing

An Enterprise Knowledge System that builds on and unifies two technologies is envisaged by Tenenbaum [Ref 27]. This uses a common symbolic model of the enterprise to facilitate information exchange with the use of intelligent agents to create a co-operative man-machine environment. The knowledge base is a complete symbolic model of the enterprise: its physical resources such as product inventories; facilities;

equipment and raw materials; its human and capital resources: and its information resources including product designs. design and manufacturing processes and organizational structure, responsibilities and operating procedures are all represented. Interaction with this model is mediated by the agents. For example people will each be given a customised view of the model containing the information needed for their jobs. Whenever anyone changes something in the model, all affected agents are immediately notified to re-display so that everyone sees the change simultaneously from their own viewpoint. Tool kits enable individuals to customize further their agents, transferring the knowledge and expertise needed to take over routine job functions. This paper goes on to explain that to minimize contention problems, the centralized knowledge service can be computationally distributed. Specifically, the knowledge base is partitioned and custody of each piece given to the agent or group of agents most directly concerned with that knowledge. For example, knowledge associated with product designs could be placed in the custody of the agent over-seeing the design engineering group, while knowledge about manufacturing processes would reside with the agent over-seeing the manufacturing group. This Manufacturing Knowledge System (MKS) consists of a centralized, semantically structured model and numerous modules that interact with that model via a knowledge service. The framework as described from the Tenenbaum research could form the type of integrating mechanism necessary for a well structured AEC environment.

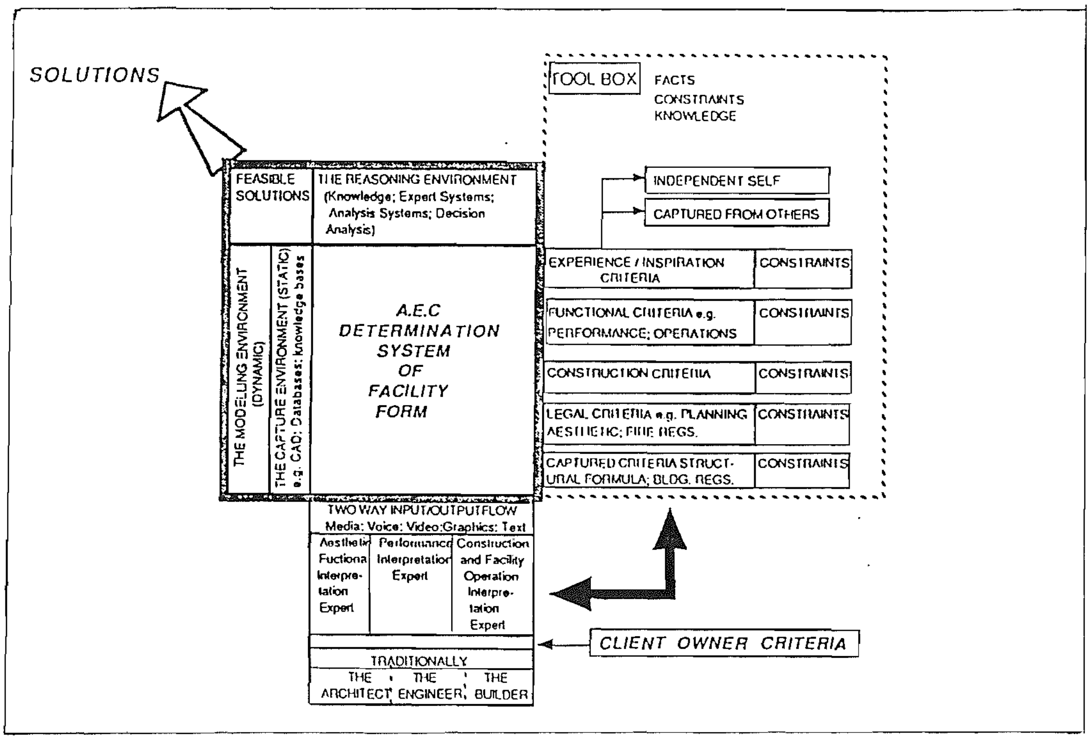

Figure B Proposed Model Environment

Models therefore have a part to play in generating alternatives based on the experts perceived criteria, however at the end of the day the final decision still rests with the human manager. This paper envisage a model environment of the form proposed in [Fig B] as being a suitable framework for making decisions on a wide variety of design/construction considerations.

Integration of AEC Experts

It is clear that the scope exists to innovate using electronic devices and their software to assess the impact on construction of a designed structure at earlier stages in the design sequence. This assessment can draw together design and construction experts into efficient multi-disciplined teams that have real decision making impact on the pertinent issues of project cost and value.

A specific example of the direction present technology is moving can be deduced from [Ref 23], where a Building Services Engineering (BSE) design software program that was developed to achieve an integrated building development and operating system for Skidmore, Owings and Merrill in Chicago is described. The programs where developed to operate on a common platform that includes three-dimensional graphics; windows for multiple simultaneous views of a graphical model; windows to enter, review, revise and retrieve information from databases; menus for easier interaction with the system; commands for specific and global editing; user-defined synonyms for frequently used instructions; and user-created command program files to execute repeated groups of commands and to define repeated command logic sequences. This gives the platform features to allow engineers extensive use of library databases to define system layouts with interactive product selection. The BSE system described is dependent on other design systems, including the architectural and structural systems. This dependency is particularly relevant where 3D graphics play an important part. The design system lays the groundwork for systems in other segments of the building industry which include financial planning and costing, equipment manufacturing, project construction and operational maintenance. The success of this type of development points to system integration being a very effective method of increasing the efficiency of the entire project development and operation cycle.

The Direction of Construction Solutions integrated with Design

This paper has emphasised the importance of evaluating construction decisions concurrent with the many and various design processes. A conceptual frame work for achieving this is discussed and the overview for a complete model is shown. [Fig C]. The remainder of this paper summarizes some of the possibilities that now exist to analyse construction within the model, or components of the model proposed. It must be remembered that when considering the issues regarding how knowledge-based systems and conceptual models are emerging they should be discussed from the point of view of the user. Therefore, when it comes to reviewing the Project Modelling System (PMS) problem solving domain it should be established what are the problems face by the users and how the users solve the problems. This then establishes the issues and allows us to focus on the purpose of the PMS. It is then possible to analyse and develop our model. This will identify particular parts of the system and how those parts can be best represented.

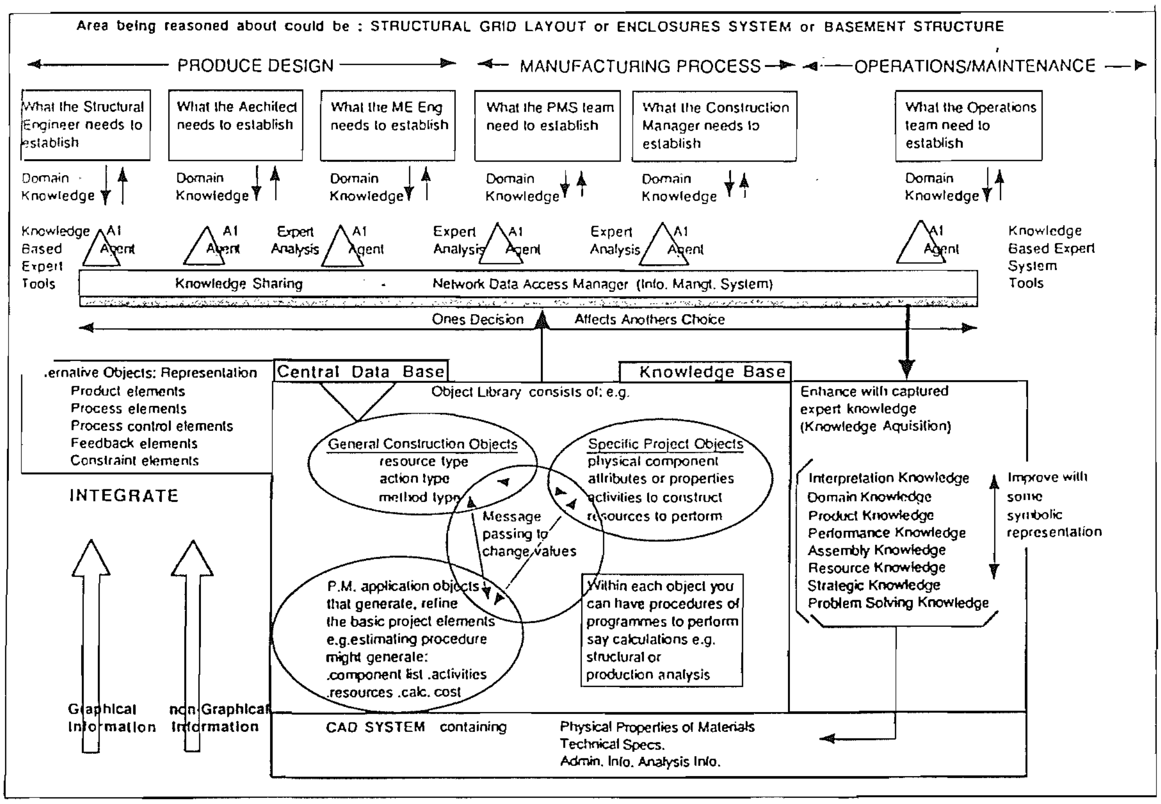

Figure C The conceptual frame work for concurrent construction decisions making

Constructability

An area of solution definition that has major implications for project success is constructability. This can be defined as the use of construction knowledge and experience during all phases of a project to meet overall objectives. [Ref 28]. A further report [Ref 29] discussed the benefits of constructability through the development of a concepts file which describe specific ways to use construction knowledge. As outlined computer tools are progressing to a point of providing the necessary databases and knowledge bases that can capture constructability knowledge and support integration [Ref 30]. Vanegas [Ref 31] notes the importance of identifying constructability knowledge requirements for the preliminary design of buildings. Three aspects were identified:

[i] increased understanding of vertical integration: the horizontal and vertical inter-dependencies between all components of an integrated project are complex. Furthermore, decisions made during the initial phases of design have a larger impact on the project than decisions made later in the process.

[ii] Assistance in overcoming prior limits of constructibility research: prior constructability research studies reached a limit because of a lack of understanding of knowledge requirements. An initial structure of constructability knowledge requirements allows better matching of construction personnel and this type of construction input to the different design phases. In addition, understanding these requirements helps capture useful and relevant post-construction information for future projects.

[iii] A structure for constructability input that benefits all phases of the project: a fundamental structure for construction knowledge was needed.

Another limitation of previous efforts to study constructability is the fragmentation of the overall process and the fact that construction input commonly is the result of specific project needs and problems. Understanding the structure and characteristics of construction knowledge supports planning for appropriate mechanisms of construction input. This integration will eliminate fragmentation by incorporating construction as an integral part of design. Early involvement not only allows better initial decisions, but also helps anticipate problems during construction, which allows preventive rather than corrective action.

Summary and Conclusion

This paper has emphasised that to continue the advances being made to integrate the design professions and provide design solutions concurrently then the construction profession must be drawn into our modelling processes. For too long design groups have not fully considered the implications of their designs regarding construction until it is too late. Often large cost and time overruns have resulted. The technology is available to work within a construction integrated design environment. But what is clearly needed is an open innovative mind to explore this computer technology and have the vision of the AEC project industry to propose change. Cultural changes are required across the whole industry.

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Appendix 1

Construction criteria analysis possibilities within Computer Aided Design and Drafting environment

It is helpful to record what is possible now in design technology and then speculate what might be possible in the future once full research has been applied.

(a) Accurate 3D models can be built in real time, thereby always generating the latest revision. Once selected a menu interface could also array a hierarchy of information related to the plan detail requested. Drawing can be reproduced on command by instruction of what it should contain (eg scale, position, information it should contain, angle and direction of perspective viewing).

(b) Dynamic movement through highly realistic and accurate 3D computer screen models allows analysis of mechanical equipment routes or identifies resource movement routes, etc.

(c) Designers can layer designs.

(d) 'Fly-throughs" of a prototype can be output direct to video.

(e) Photo-realistic images complete with lighting, shadows, surface textures, such as brick or marble and glazing effects are produced fast.

(f) Whole geographic areas can be modelled, this then allows you to determine the impact of the new structure on surrounding infra-structures.

(g) Quality analysis and tracking could be performed.

(h) Design elements can be accessed from the master library of products and design tools.

(h) Information is held in a totally unified object-orientated, 20 and 3D project database that allows discriminatory selection; the CAD model will be intelligent enough to recognize component need and offer choice, with associated resource, cost and time analysis.

(i) True 3D systems allow intelligent dynamic links to be formed (parametric elements) so that whatever change/addition you do to plan, elevation, section or perspective it will affect other views. (design changes are carried through to all drawings and project databases).

(j) Design models that have expert systems attached to perform calculations, optimise solutions, select operations suitable for various resources including robots.

(k) Should one element clash with another, as often occurs with highly serviced and complex structures, then the system will alarm by flashing the obstructing element in red and sounding a warning-interference, checking is considerably improved. Some analysis system could be appended.

(l) Coordinating problems are solved since window technology will allow multiple viewing of plan, section, elevation and perspective together. Multi-media displays then link experts in their offices or in the field by means of visual and audio systems.

(m) Schedules and reports can be generated from the database that can have information attached such as dimensions, descriptions, quantities and costs.

(n) A record can be kept of the completion status at various stages in the project execution; this can be reproduced in the 3D model for subsequent analysis on first instance claim checking.

(o) Plan the layout of offices and retail spaces through 3D walk through facility, some systems would have the intelligence to generate automatically the 'best fit' solution.

(p) Use the stored design for preventative maintenance once the building is in operation.

(q) Link oracle/dBase databases to record a variety of appended operational information.

(r) Intelligent boxes that calculates energy requirements for rooms then interacts with the designer to size and layout supply system.

AN AUTOMATED SYSTEM FOR Decision SUPPORT IN THE CONSTRUCTION INDUSTRY

M. J. Riley and C. J. Pickering

Abstract

This paper describes a collaborative project to research and develop a computer based decision support system for the construction industry. The system is intended primarily for use during the construction phase of a project. The first steps towards producing a system which links Project Management (PM) with Quality Assurance (QA) using a hypermedia-based computer application called Microcosm [1] are described. The new system is designed to replace any paper based QA system and, in addition, open they way to producing new analyses of performance hitherto considered either impossible or impractical.

Introduction

In the Construction Industry complete responsibility for a project, as well as all the resources needed for its accomplishment, is usually assigned to a Project Manager (PM). More than most managers, the project manager lives in a world characterised by conflict. In order to optimise the flow of resources and personnel, the Project Manager needs to plan, schedule and control a project and have good access to accurate and well-ordered information from a variety of sources. In this way decisions can be made in an optimal way during the course of a construction project.

In the past several decades, formal PM techniques have made a significant contribution to the practice of managing civil engineering projects. Today, there are a wide range of techniques available to the Project Manager to assist in the process of planning, scheduling and control [2].

Indeed, these tools are now widely available on computer. In general however, PM tools tend to focus on resource and personnel flow and are not integrated with the information systems which are required for complete support of the decision making process.

In the last decade or so, there has been a rapid growth of Information Technology (IT) and a corresponding growth in the Information market. For the Project Manager in the Construction Industry information used effectively represents an essential component in the decision making process. The challenge is, therefore, to integrate existing PM tools with the various information services that are available to the Project Manager. It is at this point that the ideas behind Quality Assurance (QA) have a part to play.

QA is principally concerned with performing tasks correctly the first time. Whilst it embodies a number of organisational issues within a company, for a QA system to operate effectively, information must flow along well-defined channels and records of it's movement must be kept so that the QA system can be audited. QA, therefore, represents a way of formally linking a system for the management of resources (PM) with a system that manages the flow of information. By integrating QA with PM tools on a computer based system, it will be possible to significantly improve the Project Managers chances of making the correct decision, first time.

In this paper we present the results of the first phase of a project to research and develop a computer based system which integrates project management and quality assurance for use during construction [3,4]. In order to achieve this goal within a two year research programme, it has been proposed that the computer system is based, where possible, on existing proven software packages. It has also been proposed that it should implemented on an accessible and affordable industry standard platform, i.e. a Personal Computer running applications in a Windows environment. To date, therefore, work has progressed with the following objectives:

AWARENESS - to evaluate awareness and usage of formal PM, QA and IT techniques within the UK construction industry.

THEORY - to develop a theory for the flow of information and resources in a construction project thus permitting analysis and optimisation of the PM process.

SOFTWARE SELECTION - to select existing commercial PM and QA software packages.

We shall consider first the issue of awareness of PM, QA and IT methods within the UK construction industry.

Awareness of the UK Construction Industry

The issue of current awareness in PM, QA and IT has been assessed for the purposes of this work by collecting data and results from existing recent surveys on the subject. Within the time scale of the programme, it was not possible to conduct a new survey of industry. The main sources of information have been Claypole (PM) [5], Oliver (QA) [6] and Ashby et al. (IT) [7]. The reader is referred to these publications for detailed discussion. In summary, the majority of managers in industry are aware of the 'jargon' associated with the technological areas of PM, QA and IT and, perhaps, the British, American and European Standards which relate to them. In larger companies, it is usual that there is a section or department devoted to each of the functions or, at least, a manager assigned to the function. In these cases, awareness is high and the technologies are implemented in a planned manner with good understanding of the underlying principles.

In smaller and medium sized enterprises (SME's -having <500 employees) there is a common awareness problem. Employees are aware of the terminology but often ignorant of the underlying methodology and potential cost/benefit of employing the technology.

It is proposed that an integrated PM/QA system intended for use on a Personal Computer is likely to be accepted by Project Managers within the SME community. In essence therefore, by tackling the technical problem at grass roots level, it is hoped that the longer term strategic changes which will need to take place within some sections of the construction industry will be met with enthusiasm by managers who have already seen some of the benefits of this approach.

Before going on to discuss the way in which it is proposed that the system be implemented, it is necessary to consider the underlying theoretical principles behind the proposed decision support system.

Initial Theoretical Approach

Organisational theory and management practice have undergone substantial changes in recent years. Traditional theory has been modified by informational input from both management and behavioural science. These research inputs have sometimes led to divergent findings. During the past decade or so, however, an approach has emerged which brings these ideas together, the systems approach, which can be used as a framework for the integration of modern organisational theory [8]. The systems approach and systems thinking in general has led to the development of a variety of techniques for modelling an organisation. At the time of writing, it is not clear which of the various models is most appropriate for the purposes of the project. Upon reviewing the literature, it would appear that some of the features of a number of models will be useful in developing a sound theoretical background for the work. This problem has been noted by other researchers in the field [9].

What is required is a systematic approach to the selection of models which best describe the process of construction. The authors therefore plan to use the approach suggested by Flood and Jackson [9] known as Total Systems Intervention (TSI). TSI views organisational problems using different systematic 'metaphors'. It admits that any organisation is too complex to understand using just one model and points out that it is the failure to admit this fact that often causes difficulties for traditional management thinking. Using TSI, the researcher forms a generalised conception of a system which represents the organisation under investigation. Using this description, it is then possible to apply the different systematic metaphors and decide which are appropriate in the development of a model for that organisation. At this stage of the project, therefore, we are interested in forming a generalised conception of the system that describes a construction project.

In order to achieve this, we have turned to a technique that has been developed in the UK specifically for the computerisation of a particular project, the Structured Systems

Analysis and Design Method (SSADM) [10]. It is well documented and has been in use since 1980. It is the standard method for IT projects in UK Central Government and is becoming widely used in the private sector. Again, a full description of the technique is outside the scope of this paper and the reader is referred to Longworth [10) for further information.

An important aspect of SSADM is that it involves the end user right from the start of the project. In order to satisfy this requirement, it has been necessary to work together with a local medium sized Civil Engineering Construction Company. At the time of writing, we are working with the company to establish a system description of the process of construction. With this description, it will be possible to use the ideas of Flood and Jackson to develop a system model of the process and, in principle, produce an integrated PM/QA system that reflects the results of this work.

In parallel with this work, a software selection procedure has been conducted to assess the current state of the art in PM and QA. The objectives have been to identify suitable 'off the shelf' solutions which are based on sound theoretical models and which can be integrated into an automated decision making tool.

Software Selection

As mentioned in the introduction, it is assumed that the PM/QA system will operate from a PC running Windows applications. This assumption is now briefly justified.

Windows is a 'Multitasking graphical-based user interface windowing environment'. All windows applications have a consistent appearance and command structure, giving all programs the same fundamental look and feel, therefore making them easier to learn and use. Windows programs run in the same way on a variety of hardware configurations. The programs do not directly access the display hardware (screen or printer) but instead windows includes a Graphics Device Interface (GDI) thus eliminating the need for development of specific device drivers.

The availability of multitasking allows several windows programs to be displayed and running at the same time. Continuing the theme of easy learning and use, a desktop metaphor is used for the display of multiple programs. A deciding factor in choosing an environment for the development of the PM/QA system is the multitasking option available in the windows and the inter-process communication support that windows provides, the most useful of which is Dynamic Data Exchange (DDE).

DDE is based on the messaging system built into Windows. Two Windows programs (known as the 'client' and the 'server') carry on a DDE 'conversation' by posting messages to each other. The server is the program that has access to data that may be useful to other windows programs and the client is the program that obtains this data from the server.

The proposed integration of the two separate management systems of Quality Assurance and Project Management makes both multitasking and DDE essential to our system for even the most basic of linking methods. Given this, it is now possible to narrow the range of appropriate software tools for the project. It is necessary first, however, to overview the underlying technology associated with the disciplines. In this way, it is possible to assess the suitability of a given product to the task.

Project Management

Project Management involves the co-ordination of a group activity by a Project Manager who plans, schedules and controls in order to achieve a contracts objectives within time, cost and quality constraints.

The use of the term 'project' in this context distinguishes the 'unique' nature of the construction process from the typically repetitive processes usually found in manufacturing industry. When managing projects, there are a variety of techniques which may be employed to aid the decision making process and these are based on the principal of 'network planning'. Having developed a network plan, it is possible to represent and/or analyse the plan before, during and after construction using techniques such as, the Gantt bar chart, PERT analysis, Critical Path Method, etc.

The activities defined within the PM network follow a hierarchical structure of detail levels for different management requirements. At the lowest possible level (contractors' weekly work programs for individual work gangs) the sub-activities are sufficiently small and detailed that it is possible to link each of them to their relevant QA procedure, and this is the simple linking mechanism proposed.

The following products have been identified as satisfying the PM and Windows needs of the project and are currently being evaluated: Computer Associates SuperProject for Windows, Primavera Project Planner for Windows and Microsoft Project.

Quality Assurance

Today, quality is regarded as a factor which 'cannot be inspected but must be built in'. To this end, the British Standards Institute have produced a standard (B55750) that defines the way in which a purchaser may seek to employ companies which may be assured of delivering a quality product or service and the ways in which a supplier may operate his business in order to prove to the purchaser that he is able to achieve this.

The development of a quality system involves essentially twelve steps as shown in figure 1. It is the last five steps which will be tackled by the integrated computer system. The first step however, following a review of current documentation, is to implement the quality procedures as an integral part of the PM tools which will be used on-site. In terms of software on the market today, there is virtually none. The QA Forms and Procedures required by B55750 are easily stored within a word-processor. It is therefore necessary to link a word-processor package with a PM package in the Windows Environment. This will require an effective tool capable of utilising the communications features of MS-Windows. A suitable tool for this, Microcosm, has been developed within the University which has the added advantage of being designed to link objects from multi-media sources - ideal for training. Microcosm will now be considered in a little more detail.

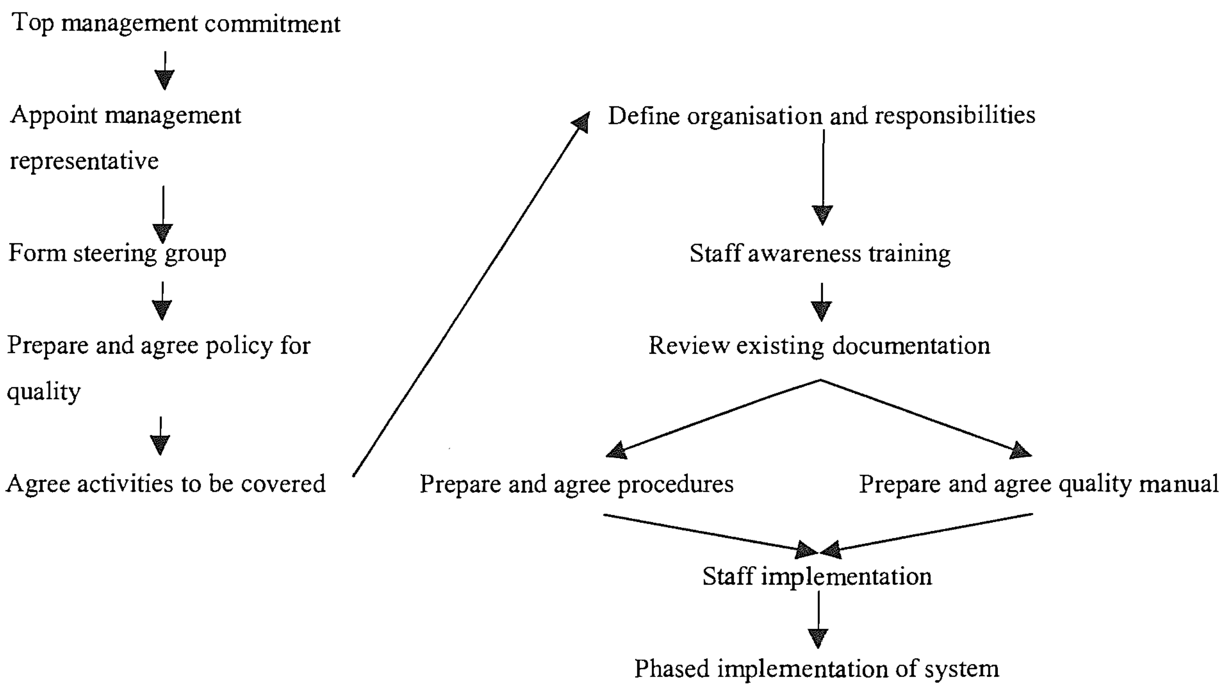

Figure 1. The twelve steps in Quality System Development

Linking PM and QA with Microcosm

Microcosm is a distributed, open hyper-media system, designed to support the integration of many different applications. It uses the DDE protocol which is available in the windows environment. The most prominent feature of the Microcosm model is that the link information is stored in a 'linkbase' separate from the data. Link following is resolved by a look-up file based on the item selected providing easy, reliable system navigation, and allowing identification of all links in the database on the specified item of information. Use of DDE means the links may extend to any application. With the use of the DDE, Microcosm will provide the automatic intelligent links to the Quality Assurance system, and in fact permit seamless access from the Project Management system to any associated multimedia information.

Conclusions

The initial phases of a project to integrate Project Management and Quality Assurance and produce an automated system for decision support in the construction industry have been described. The work has consisted of establishing suitable off-the-shelf software products and a basis for a theoretical understanding of the problem based on systems thinking. In order to build a robust system model of construction, it has been necessary to collaborate with a medium sized Civil Engineering Construction Company who are at present working with the research team to construct a system description of the construction process using the SSADM approach.

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The Impact of IT on Construction Procurement

A. Bailey and M. J. Riley

Abstract

This paper reports on the research carried out within an SME Contractor that specialises in both new and maintenance type work for the petrochemical industry. The business processes for the procurement of materials and sub-contractors by the Contractor were mapped using a range of methods including the existing quality procedures, the links between the contractor and their petrochemical clients was similarly mapped

An understanding of systems and logistics allowed a redesign of processes and a simple IT support system was produced and installed to allow the contractor to improve and automate the procurement process. The results show that worthwhile cost savings can be obtained with only a minimal use of IT provided that it is correctly designed and implemented with business needs in mind.

Key outputs of this paper are that (a) the existing low use of IT in construction offers great potential for its use in performance improvement; (b) there is a need to address and optimise the complete project system rather than the sub-systems of the contractor, supplier or client; (c) the implementation of even simple IT systems, properly designed and implemented can create worthwhile improvements in time and cost.

1. The need for change in the construction industry.

The construction industry is often regarded as a business backwater that is rife with bad practice and slow to adopt the new ways and tools of working that are prevalent in other areas. The use of information technology is one such tool that can assist in the improvement of its performance by assisting in the streamlining of the many repetitive support tasks that exist within a typical construction company.

The size of the typical construction company may be partly responsible for the slow adoption of new working practices, especially from the information technology (IT) fields. The low barrier to entry in the construction field means that many firms are small with 94% of construction companies employing less than 8 staff (Latham, 1994), of which the vast majority will be used in the physical process of construction itself, including the management of that process. This means that few have IT departments or specialist IT support staff and where it exists IT is mostly used for some of the fundamental work processes the company performs such as estimation, design and accounting. Processes in areas such as procurement that have been automated or which have seen the introduction of IT within the retail and automotive sectors are still conducted without assistance in the construction sector (O'Brien; 1994; Riley et al, 1997).

The adversarial attitudes, now changing slowly in the U.K. construction industry, result in extra costs and reduced efficiency in the procurement chain. The lack of co-operation includes the sharing of information between clients/contractors and contractors/sub-contractors where each level of the supply chain guards its own information carefully.

The main purpose of this paper is to offer guidance on the benefits that can be immediately attained from the use of IT, although better relations with suppliers/contractors and clients is essential in maximising the benefits of IT establishing better ways of working is beyond the scope of this paper.

2. Methodology.

The work reported here was undertaken in a SME construction contractor which carries out both project and maintenance work in the petrochemical industry. The focus of the study was on the operations at one site where the majority of work is of the maintenance type. The interactions of the contractor with both client and supplier were examined and subjected to the steps for Business Process Improvement (Harrington 1991).

In some ways the construction industry is at an advantage compared with other sectors as it can use other sectors past lessons to guide the process of performance improvement. Areas of development with acronyms such as EDI, MRPII, DRP, BPR, BSE have been tried in other industries and the limitations and advantages documented. These techniques and technologies are now beginning to be applied to the construction sector to prevent the loss of capacity to foreign competition that has occurred in manufacturing. With a large turnover of small companies on the construction sector the overriding driving force behind change in construction industry is the need to improve, or else risk being taken over or even ceasing to trade.

The techniques used by the researchers were drawn from the Business Systems Engineering toolbox (Watson 1994). These tools have been successfully used internally within individual businesses or departments, and across business boundaries throughout the supply chain. The examination of documentation and interviews were combined with analysis methodologies to provide an initial view of the processes that are undertaken in procurement. This preliminary model was then used to gain a full understanding by following the actual process through with the people involved.

The criteria used to judge the performance of the systems examined here is a modified version of the performance index (PI) advocated by Coopers and Lybrand (*equation 1*). The main impact of IT on these Systems is through reductions in cost, although other improvements are possible in. lead time safety, quality and service level. The inclusion of safety as an element of the index is due to the construction industry requirement for safe working and the rigours of the petrochemical environment (Evans et al, 1997).

$$\text{Performance Index} = \frac{\text{Safety} * \text{Quality} * \text{Service Level}}{\text{Performance Index Cost} * \text{Lead Time}}$$

(equation 1)

3. Construction industry procurement process details.

A generic route to the improvement of the construction maintenance procurement process is presented along with the actual effects of taking these steps on the performance of the system examined. It is important to note that with the published examples of process change being taken from larger organisations, the large number of small companies in the construction sector make it essential to consider the scalability of the solutions that are proposed. A small solution for a small company may cause problems when the flow of information exceeds the IT systems ability to cope and the upgrade path is blocked because proprietary systems were initially used.

3.1. Generic procurement process

The generic system of procurement and control in civil engineering maintenance is derived from the petrochemical sector and therefore possesses attributes that may not be found in a less controlled environment Figure 1). All steps within this system are undertaken manually by both the contractor and client.

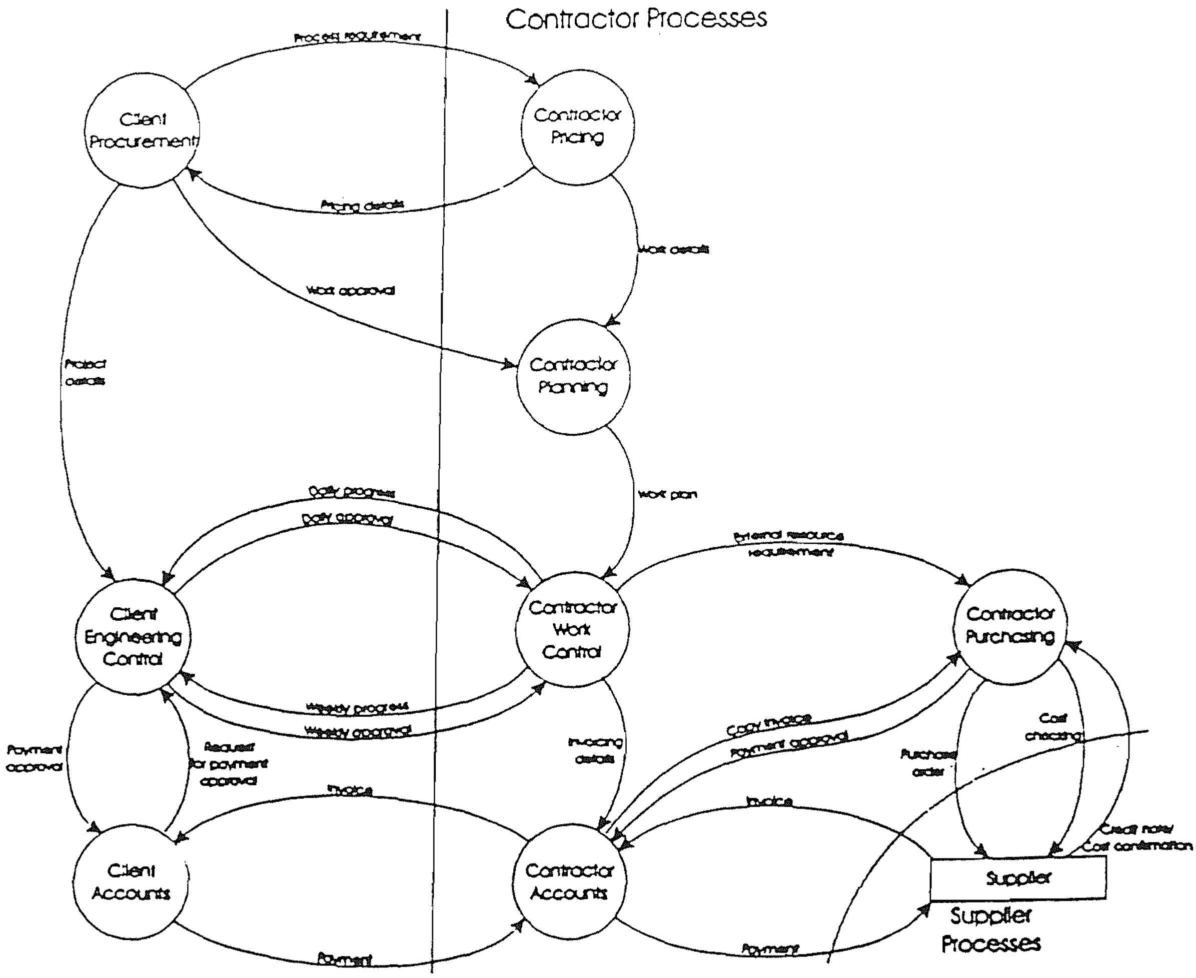

Figure 1: Data flows for maintenance type Construction procurement

3.2. Possible system improvements

A gradual reduction in the human content of the non-value adding steps such as report generation and handling is possible by increasing the connections and data transfer between client's and contractor's systems. The sharing of information in a common database format enables the elimination of all paper handling except for invoicing and payment control. Table 1 shows a possible path to improved procurement performance in a maintenance contract environment utilising information technology alongside the enabling technology (Lyons, 1995). The proposed steps improve performance of the system by introducing IT to a distinct process before starting to link the operations together.

Step	Mechanism of Improvement	IT requirement (enabler)	Performance Increase (of total)
1. implement automation of internal reporting steps	reduce processing time	data storage, transaction processing	20%
2. create electronic links between contractor and client for job request	reduce lead time	information transfer	25%
3. low 'electronic' but not automatic acknowledgement of completion	reduce processing,	transaction processing	30%
4. share work details on a database (Ahrned et al. 1995)	Reduce processing, lead time, increase quality	data storage, information transfer	55%
5. allow invoicing, clearance and electronically	reduce processing,_reduce costs		70%
6. connect existing systems together for complete electronic processing	automatic handling of system	open systems, process support	100%

Table 1: Steps to improving SME construction procurement performance

It is possible to gain some improvement by implementing items from this list individually, as has been performed in this research. However the largest step gain in performance is from linking all the systems to allow completely electronic processing of information between client and contractor. Note that this schema is dependant upon the use of open systems so as to allow interaction between the systems introduced at the various steps. A compromise solution of using a standard data exchange format or program type such as an SQL database system would comply with this requirement.

3.3. Actual system improvement

Step I was implemented and tested within separate procurement streams and the results of following Steps 2-6 were generated through the use of process maps. In this manner the savings created by following the pathway can be estimated. In implementing step I two systems were improved by following the procedure for process improvement advocated by Harrington (1991). Process elimination was not possible, given the external constraints of data quality and site integrity, therefore a path of process integration followed by automation was decided upon as it offered the quickest route to greater performance in the logistics chain.

3.3.1. Payment control

The first system altered was the payment control process which was automated using Microsoft Access 95 to create a database. The system took approximately one week of work, excluding initial process mapping, to complete and was run in parallel to the existing manual procedure for one month to correct any problems which required a further three days of programming effort. A process map of the system is shown in Figure 2.

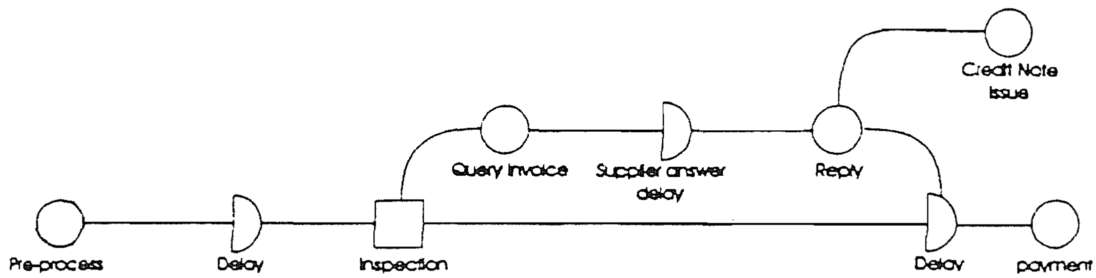

Figure 2: Payment control process map

The essential performance criteria for judging process improvement were, in order of importance: time, quality and level of service. The impact of the new payment control system upon these metrics is shown in Table 2.

Metric	Impact	Reason
Time	*25%* handling time reduction, no overall reduction	Total time constant due to 90 day payment terms
Quality	Small improvement	
Level of Service	Unquantifiable at present but increased	Historical data allows quicker and more accurate job costing

Table 2: Impact of IT system on performance

3.3.2. Work control

The researchers conducted a series of interviews with both client and contractor personnel to determine the requirements for each of the steps in the work control process. The need for operational control at the client location meant that process elimination was not possible so the researchers attempted to obtain process improvement through the integration and streamlining of existing processes. A process map of the current system is presented in Figure 3 with processing internal to the contractor utilising IT to create output for the client. Shaded symbols represent the steps that were automated by the researchers reducing total process time by 30% for these steps contributing to a 18% total process time improvement.

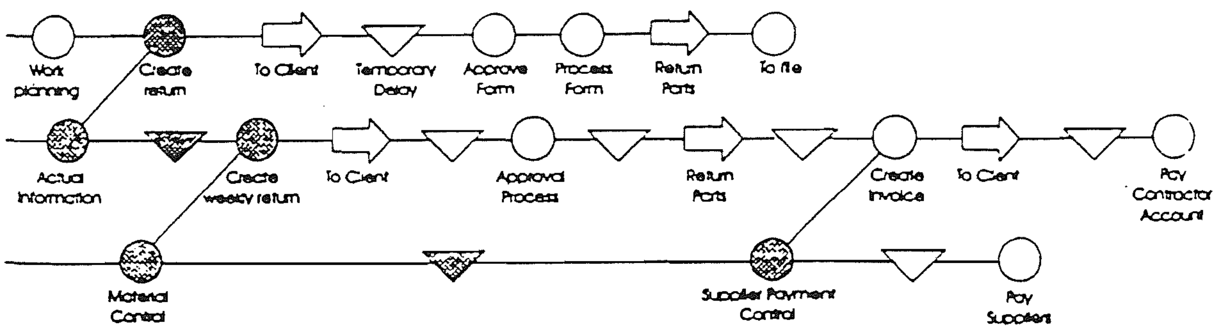

Figure 3: Contract control process

In creating the final solution the researchers have drawn upon the ideas of Electronic Data Access (EDA) to allow client and contractor access to a shared pool of information in order to eliminate or reduce the calculation and transport elements. The redesigned system that incorporates a database which can be accessed by both contractor and client takes concepts from many different sources (Upton 1996) to provide an open ended solution to the problems of data sharing between the two parties. The benefits of this approach include shorter transaction times with the client receiving information as soon as it is input by the contractor and lower transaction costs, due to elimination of paperwork and transportation steps.

4. Conclusions

This paper demonstrates the potential savings in construction procurement in a maintenance environment through the use of information technology to improve performance. Due to the prevalence of SMEs in the UK construction sector and the existing low use of information technology a series of small steps is proposed to enable gradual rather than radical change. Thus incremental performance gains are possible with successful implementations perhaps leading to a desire to utilise more IT for further benefits.

The route to process improvement presented here is drawn from established sources and the performance gains at each step calculated from the authors knowledge of the business processes within the client and contractor. This information leads us to suggest that greater information sharing between client and small contractors will result in cost savings in the procurement of maintenance services.

The scalability is provided by the use of well known and widely used software to create the final software applications which can be moved to more powerful platforms later in the contract's or companies' development.

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A Decision Support System Based upon Economic Order Quantities for Use in a Civil Engineering Contractor

M J Riley, D C Brown and A Bailey

Abstract

A decision support model was created based upon the theory of economic order quantities and maximisation of return for the investor. A new model for maximising return on investment (ROI) is presented which provides more reliable results for low cost, small volume items as typified in the construction maintenance environment. The model was incorporated into the materials purchase system of a civil engineering contractor to guide the selection of order quantities. Estimated savings on the overheads of the purchasing process are presented for sample items.

Introduction

The construction industry has been set targets to increase efficiency, reduce its impact on the environment and improve the quality of life (Egan Report, 1998, Wright et al 1995). There are two basic ways of achieving such efficiency gains; either by step changes in the delivery of the *whole* project or by management using new tools to create incremental improvements. Both approaches are relevant and need to be used. This paper describes a management tool to support the second improvement approach. Although the improvements described may not appear to be significant, in fact they are significant when compared to the profit margins usually found in the construction sector.

This paper presents some of the results to reduce the costs of material purchasing within a small-medium sized enterprise (SME) with a turnover of approximately £10 million specialising in building, civil and maintenance contracting within the petrochemical sector. About 90% of their work is by direct negotiation rather than competition and this has led to a co-operative way of working rather than the traditional confrontational way. This has also allowed a more strategic view of, amongst other things, purchasing. The emphasis of the whole research programme was to reduce supporting costs as much as possible and in particular purchasing costs.

Purchasing Environment

This research looked at inventory and purchasing decisions for materials used in maintenance works costing less than £5000. This general area is important given the increase in the use of Build, Operate and Maintain contracts within all construction sectors and the fact that the nature of the actual work tasks carried out as part of maintenance work is small value but high in number. The aim of the management tool in this paper is to reduce the overhead costs associated with the purchase of materials rather than reduce the costs of material purchase through the use of alternatives.

Economic Order Quantities and Return on Investment

The original work in this area is by Ford W. Harris (1913) who defined a theoretical solution to the determination of economic size of production lots. The Economic Order Quantity (EOQ) is the order amount that minimises all the relevant costs associated with purchasing that particular item including inventory holding costs and ordering costs. A body of literature has developed around this subject which was reviewed by Erlenkotter in 1990. In short, the EOQ model has been extended to scenarios with quantity discounts (Monahan, 1984. Jo Min, 1992a), competing vendors with identical products (Jo Min, 1992b), supplier ordering (Goyal, 1987), trade credit (Kingsman, 1983. Ashton, 1987). The effect of different times at which costs are incurred was discussed by Bregman (1992) who recognised the decapitalisation that occurs when following the EOQ rigidly in an inflationary environment. The important concept of discounted cash flow analysis was applied to date terms supplier credit by Carlson *et al* (1996).

However businesses are not judged on the profit maximising potential of their ordering but upon the return which they provide on capital or equity employed. This fact was recognised and a model for maximising return on equity or return on investment (ROI) constructed with the optimum order quantity being termed the ROQ (Tate, 1964). Trestsch (1995) showed that ROQ EOQ and referred to Just in Time (JIT) systems operating with reduced inventory but stopped before demonstrating the relationship between reducing order costs, reducing order sizes and increasing ROI. It is the drive to reduce overhead and process costs which has enabled JIT manufacturing to provide higher returns rather than the reduction in inventory which reduces the equity involved in the business.

This paper develops an ordering model for use within a civil engineering maintenance environment based on ROQ and illustrates savings in terms of reduced overheads from following its implementation.

Defining ROQ

The equation (1) below shows the return on investment for an equity funded purchasing operation. (after Trietsch. 1995)

$$\text{ROI} = \frac{[\text{annual profit}]}{[\text{equity}]} = \frac{D\left(M - \frac{S}{Q}\right) + \frac{IQ}{2}(C+M) - F - J\left(\frac{CQ}{2}\right)}{L + CQ} \qquad (1.)$$

where

D = annual demand

Q = reorder quantity

M = marginal profit per item (in £)

C = unit cost (in £)

I = Rate of return earned by free funds

J = annual holding cost per £ invested in inventory

F = annual fixed costs (in £)

S = re-order cost (in £)

L = owner's equity excluding inventory

Note the use of the term $IQ(C+M)/2$ which is the income on the funds freed on the sale of items from inventory. Trietsch states that the interest term is $ICQ/2$ which represents the interest on the money invested in inventory as opposed to the interest on the sale receipts for a given annual demand. Following Trietsch's method we calculate ROQ.

$$\frac{d\mathrm{ROI}}{dQ}=\frac{(L+CQ)\left(\frac{DS}{Q^2}+\frac{I(C+M)}{2}-\frac{JC}{2}\right)-C\left(D\left(M-\frac{S}{Q}\right)+\frac{IQ(C+M)}{2}-F-\frac{JCQ}{2}\right)}{(L+CQ)^2} \quad (2.)$$

$$\frac{d\mathrm{ROI}}{dQ}=\frac{\frac{LDS}{Q^2}+\frac{2CDS}{Q}+C\left(F-DM-\frac{JL}{2}\right)+\frac{LI(C+M)}{2}}{(L+CQ)^2} \quad (3.)$$

In order to find the optimum order quantity to maximise ROI it is sufficient to set $d\mathrm{ROI}/dQ$ to zero and take the unique positive solution to the quadratic that makes up the numerator. Hence

$$ROQ=\frac{LDS}{\left((CDS)^2-LDS\left(C\left(F-DM-\frac{JL}{2}\right)+\frac{LI(C+M)}{2}\right)\right)^{1/2}-CDS} \quad (4.)$$

This expression for ROQ provides solutions for the optimum order quantity in a wider range of situations that Trietsch's solution, especially in situations of high real interest rates. The output from the model is only of use when $LDS\left(C\left(F-DM-\frac{JL}{2}\right)+\frac{LI(C+M)}{2}\right)>0$

Indeed as this term tends to zero ROQ tends to infinity.

Rational for Using EOQ and ROQ

The EOQ model provides a good initial starting point for guiding purchasing decisions within a construction maintenance environment as it formally takes account of the costs of ordering and storing material. The model is not able to take into account quantity discounts nor the effects of full load/part load prices at this stage; this facility requires further research. However the case study used is typical of situations that are not limited by full or part load limits. Similarly adjustments for extended credit terms are not used as the contractor is on 60 day terms with all the suppliers concerned. Warehousing space is not a limiting factor as most items are of low bulk and those that are more sizeable are only required in limited quantities.

The modified ROQ model (equation 4.) is used due to the importance of maximising ROI in a business. In general ROQ is equal to or less than EOQ and will represent the optimum purchasing strategy however there are certain cases where the output from the model is clearly not useful, these tend to occur with low item costs and low demand.

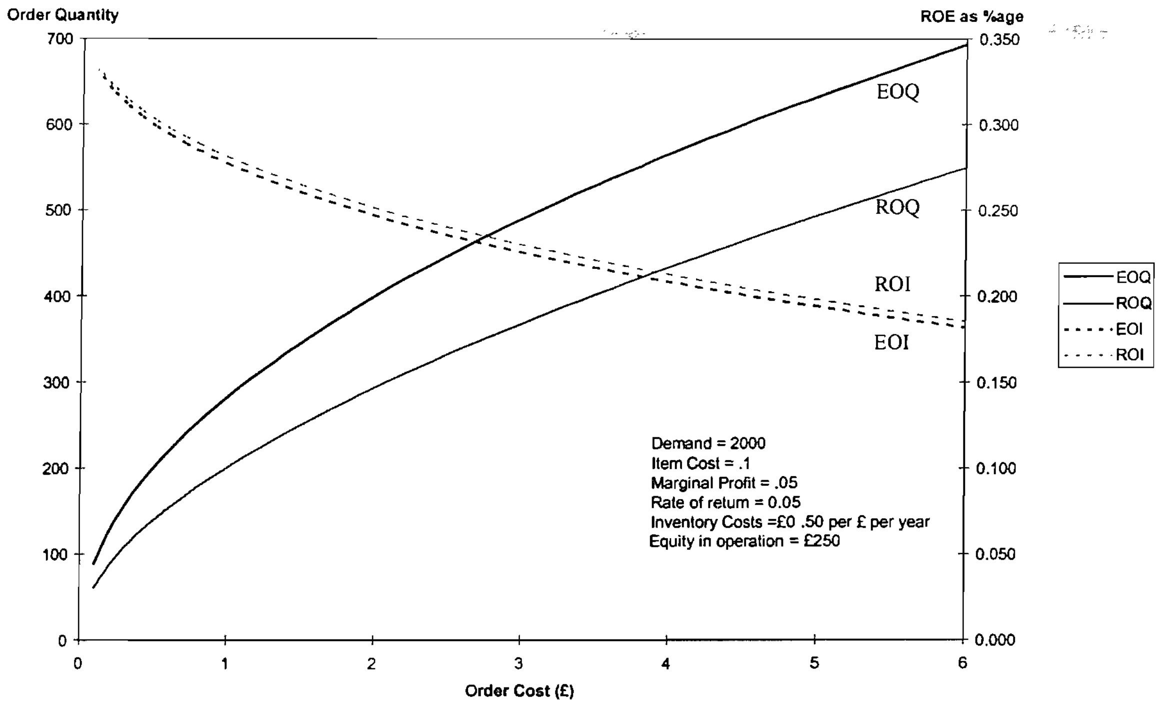

Figure 1: ROQ and EOQ for changing order costs

The advantage of using ROQ over EOQ is shown in figure 1. Purchasing decisions based on ROQ clearly give better returns on investment through lower order quantities than those based on the EOQ model. This also reinforces the benefits of reductions in process cost reduction as ROI increases dramatically in a situation of low order costs and low order quantities. This is the working environment for a JIT manufacturer utilising EDI for automatic reordering whereas the high order cost, high order quantities typically seen in batch manufacturing have a much lower ROI.

ROI is increasingly a least recommended profitability assessment method due to the annual profit concept inside resulting in a situation where one needs to take into account profit and loss account concepts such as depreciation. On the other hand it provides another view of the business and most shareholders would wish to have every view possible. It must also be remembered that most depreciation for contractors relate to plant and that little plant is now owned by contractors with most being hired for specific contracts.

EOQ Decision Support System

Using the EOQ and ROQ models a decision support system was created in Microsoft Excel to assist in the selection of order quantities for frequently used material within the maintenance system. This requires the user to enter data concerning the annual demand and other variables on the form shown in figure 2.

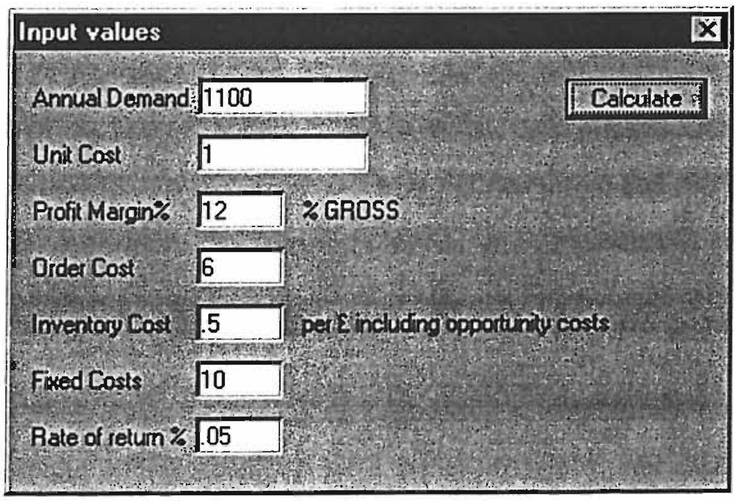

Figure 2: Input Screen For DSS

Typical output is seen in figure 3 where the optimum order quantities are shown along with a graph showing the variation of the optimum according to changes in demand. The user is informed of the requirement to use this tool only for items with relatively consistent demand, which is a key assumption of the model.

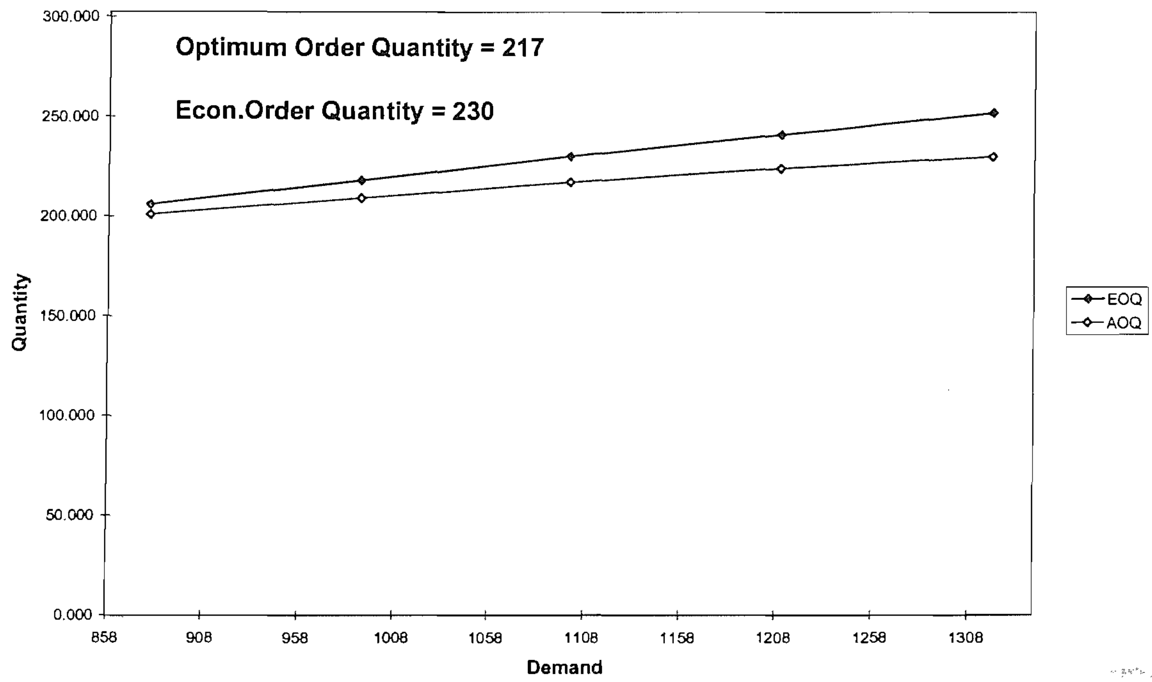

Figure 3: Typical DSS Output

The Model in Use

The use of the DSS on low value items has the potential to reduce overheads by a large multiple of the value of the goods purchased. Existing company purchasing followed a demand based pattern with materials being purchased in the minimum quantities possible when existing stocks were exhausted. Following a revised purchase order strategy will result in a reduction in the number of orders processed. Output from the DSS suggests that frequently used low cost items, such as nails, screws and wood are purchased in bulk once per year with up to 200 fewer orders *per product type*. A basic example is of one variety of screw which was normally purchased by the box when required. Use of the DSS shows that a potential overhead reduction of £20.47 (64%) is possible if the screws are purchased in lots of approximately 1200. Table 1 shows that large reductions in overheads are possible for frequently used items simply by increasing order quantities and reducing the number of orders. The columns are values based on a per annum basis.

Item	Annual Demand	Item Cost	Current Order	Total Cost (ex. Materials)	Optimum Order	Total Cost (ex. Materials)	Saving	%age
47x100 Sawn wood	2900	£0.48	50	£357.00	258	£113.88	£243.12	68%
1.5"x8G CSK screw	1100	£0.015	200	£34.13	1296	£12.38	£21.74	64%
18mm Pine Ply	1238	£17.49	5	£1518.39	46	£463.18	£1055.21	69%
12mm WBP Plywood	302	£16.40	4	£477.60	22	£217.66	£259.44	54%

Table 1: Possible Cost Savings Using DSS

A reduction in the number of orders from the introduction of the DSS is expected. This, combined with a separate invoice reduction exercise (Bailey & Riley, 1997) will reduce overheads and have a significant impact on the profitability of the maintenance operation. Non-perishable items with a high annual demand are suitable for consideration by the decision support system and in the case study presented accounts for 35% of total orders processed. The majority of the remaining orders related to services or sub-contracts. A pessimistic average reduction of 50% of item ordering overheads is possible indicating an approximate total reduction of 17.5% of material purchasing overheads. Once the system has been set up the cost of using it are very low and this will clearly lead to cost savings. These will translate to an immediate increase in the profitability of the maintenance operation in return for the small cost in using the system.

Conclusions

This paper describes a new model for procurement decisions based on maximising the return to the investor and shows that even for low value items significant savings are possible. The costs involved in setting up the system and in using it are very low and so all the savings generated will lead to increased profits.

This model leads to reduced overheads and increased profitability. It is applicable for the majority of project or maintenance work for smaller companies that involve low value stocks and low profit activity.

The decision support system has the potential to be of financial benefit in any purchasing situation that does not specifically involve one-off orders; that is all orders for materials required on a continuous basis are worth assessing. It is not possible to make a priori judgements; all purchases of a continuous nature must be assessed.

This paper demonstrates the value of overhead reduction programmes to increase the return on an investment and show that the ROQ model presented here is more effective at maximising returns than the EOQ model.

A limit on this approach, at this stage, is the inability of taking discounts into account. However, with an understanding of this paper, the decision maker should be able to ensure that the comparison between discount prices and ROQ is properly made; all to often decision are made that ignore the extra costs of, for example, double handling, storage, damage and theft.

Further work could include multiple items combined into a single order, discounts for part/full loads and an increase in degree of automation within the contractor's purchasing database system to incorporate elements of an "expert" system.

The innovation of relating the procurement process to the return for the investor has been shown to be viable and worthwhile, even for smaller scale operations

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RE-ENGINEERING THE CLIENT CONTRACTOR INTERFACE

G. Evans, A. Bailey, M. Reed, M. Naim and M.J. Riley

Abstract

This paper presents research performed from an intensive study at a logistical interface within the construction industry. A multi-national petro-chemical client had a requirement to examine its relationship with its contractor base who were employed mainly on fixed term maintenance contracts. This research was just one initiative in a client wide plan to address future company profitability issues stemming from perceived long term pricing pressures on the cost of a barrel of oil. An holistic, systemic approach was developed for the analysis and applied to a natural grouping of on-site contractors.

Open contractual, financial and site analysis of contractor and client management highlighted a number of areas for improved logistics and information flows and therefore improved operational efficiencies for the site. These included planning and auditability issues the latter of which could be altered within the existing structure. A solution for the planning problems in the system generated a new model for the logistical interface by creating an improved planning function with contractors providing a more knowledgeable and flexible point of contact. Organisational changes at the planning level, revolving around client based planning and site database technology is presented as an improved future model for this client contractor interface.

1 Introduction

This paper examines interfaces between a petrochemical company and a number of contractors working on a UK site in order to improve efficiency. This research occurred against a back drop of a significant thrust in the UK of reducing the cost of construction to remove the international cost disparity as highlighted in the Latham (1994) report. In this report a number of detailed recommendations for improving the construction industry are put forward under areas that can be grouped as Contractual and Related Strategies, Job Effectiveness, and Regulatory. This report goes some way to impacting the Job Effectiveness dimension by analysing the process of maintenance on UK based petrochemical site. Effective interface management has received a new impetus in the purported new practises and principles in philosophies which advocate *process thinking* (Hammer and Champy, Johanson et al, Harrington). Despite the terminology variation, methodologically there is large overlap in these management philosophies and significantly tie into the well developed field of Systems Engineering (Evans et al 1995, 1997). In the latest management literature large improvements in performance are promised through what can summarised as effective identification, streamlining and implementation of change along a process perspective. In essence the inefficiencies within and between process operations are tackled. This is due to the recognition that interfaces create inefficiencies and are highlighted in statistics such as 90% of non value adding time is spent at the interfaces within an organisation (Coulson-Thomas). However this idea of business processes alone is insufficient as the practitioner is left with a question that a systems engineer would ask as "What are the boundaries for change?" i.e. how far along the process must change occur to effect significant improvement?

2. Identifying the System Boundaries

The pre-analysis stage required Trant Engineering Ltd (TEL) to formulate a commercially viable package which provides operational expenditure (OPEX) efficiencies for the site. TELs core business is in civil engineering (design and build) and maintenance with a particular focus on the petrochemical and chemical industries. After working on site in both capital expenditure (CAPEX) i.e. project works, and OPEX (maintenance) roles it understood the system and was well placed to provide constructive solutions for improvement. It was therefore well informed of the issues and commercial realities of contracting on such a site, but its contact with the company was a commercial one with understanding of its immediate interface only. However the client was open to radical good ideas and possessed an understanding that significant gains can only be obtained from looking at the wider system an examination of the wider client contractor interface was proposed.

Having highlighted the requirement for a wider system analysis, boundaries had to be drawn in terms of the scope of the research and the contractors to be analysed. The general boundary was determined by both the level of specialism of the contractor and the remuneration basis of that contractor. Within highly specialised contractors it would be difficult to obtain areas for efficiency gains due to this specialism unless a significant period of time was used to analyse their operations. The remuneration type was used as a selection criteria due to the potential efficiency gains if the contract can be moved away from reimbursable to a unit rate basis. Previous commercial experience shows a 30% reduction in overall cost where this can be achieved.

The actual period of contact with the Oil and Gas company was approximately eight weeks, in which a relatively large list of contractors (33 % of the total number, with a total annual spend of c.£3.3M) was examined. The focus being the interface processes for decision making/communication to the contractors as well as reporting areas for improvement both in the short and medium term. Tested methods for data collection were therefore utilised in construction industry specific areas such as Quality Assurance and HSE including systems tools previously used in other industries (Towill, 1996). In particular the following issues were focused upon, the contract rates, works planning, labour utilisation and the formulation of possible structures to improve the interface between the client and contractor. To make the results generic and not an artefact of this particular client areas for efficiency improvements from this case study as well as those seen operating at other sites are highlighted.

3. System Analysis

The analysis is defined at both the business and operational levels. The first level deals with management response to the OPEX problem and the longer term issues such as the contract structure. The second level deals with the operational planning tasks and day-to-day site activities as well as the communication paths between the client and contractor. Initial analysis of the system started at the business level via the original contract which identified the scope of works for the selected contractors, remuneration rates and health and safety requirements. Tasks and task overlaps were identified wherever possible along with tasks common to contractors that were being performed on-site. Unsurprisingly, simple cost benchmarking of some services highlighted the sound remuneration rates negotiated at the contract stage. The official Operating manual also provided the structure for some of the processes requiring the interaction with the contractor base and was reviewed. Additionally, at the business level some internal reports on some contractors' performance were made available to the research, although these tended to be obtained while questioning the managers in the client organisation.

After identifying client employees in a procedure interfacing with the contractors they were interviewed and this functions information and material inputs and outputs were identified via Input Output analysis. The next function or person in the chain was highlighted in order to build up the complete picture of activities on the site. The processes closest to the interface with clients and contractors were then examined starting with planning. Pseudo process flow charts or bubble charts were then built up for work processes on site which highlights the complexity in the system and the interactions involved. It must be noted that system complexity is inherently linked with the requirement to maintain a safe working environment (avoiding pollution, ensuring operative safety, asset damage etc.).

4. Problems on Site

The analysis performed at the operational level absorbed the greatest proportion of the research time and resulted in the greatest insight into the system and possible areas for future improvement. The starting point is the generated documentation which flows across the interface of the contractor and client. The documentation from the contractor to the client usually consists of a monthly invoice with supporting information. These are standard practices in the industry although no standard form or standard contents are used. Back-up documentation was often in the form of the companies own devising and may not be all encompassing, excluding for example material or plant. However, all of these will be invoiced for within one month of completing the job. This, combined with a lack of client checking of jobs performed on-site, meant that an open loop system of control was in operation.

Open loop control, or empowering contractors to "do the job" that they are the experts in is philosophically sound in line with the creation of partnerships on site. Invoice returns however can be distorted in a number of ways which are included in Table I. This is a generally applicable table and is not specific to this case study however some of these methods for creating additional costs were found. This underlines that contractor selection is of prime importance to the good functioning of the system. This essentially comes down to performing the job correctly, safely, at the right time (implying flexibility), at the right cost and with the right attitude. We must remember that intensive checking by the client representatives creates additional work or overhead to the cost of the overall contract, although the frequency of monitoring can be low and still provide adequate checking of the system.

Method	Eliminated via
A go slow working policy is in operation	Improved site feedback., agree lump sum
The job is charged for twice	Improved procedures for payment
Resources amounts used on site are incorrect	Improved feedback from site
Inadequate on-site supporting documentation	Request for standard data.
Rates of labour not aligned with the contract	Improved checking of invoice
Rates for material not aligned with contract	Improved checking of invoice
Rates for plant not aligned with the contract	Improved checking of invoice

Table I Contractor routes to creating additional costs

Moving away from the detailed operational control issues the other potential areas for inefficiencies across the client / contractor interface are in the process of issuing jobs to the contractors, with a particular focus on planned production maintenance. This revolves around formulating and scheduling the job as well as planning the support around the job. These actions are essentially the clients responsibility.

5. Client Cost Drivers and Potential Solutions

A computerised system exists for the issuing of planned inspection and breakdown tasks upon site structures. Structured analysis took place from the database generating the list of tasks, the route these tasks are communicated to the contractor and the role of planning within this system. The main contractor involved in this process suffered a number of difficulties, namely multiple work orders being issued from the database system to inspect the same building or items of equipment within a building at slightly different times. Sending personnel out to inspect each item individually is inefficient and performance improvement can be gained if jobs are batched. Additionally for breakdown tasks input was required from the client's staff because the original contractor on-site was not capable of making technical decisions (i.e.. what needs to be performed to effect a repair and which contractor to contact). The new contractor has this capability, and if required, is able to delegate the task effectively.

The structure for civils maintenance was designed such that the contractor with knowledge of tasks to be performed will set-up and run a help desk for the field and manage the database holding the planned tasks. The advantages over the old system are:

- The contractor will efficiently batch planned work by rationalising the tasks and by grouping them when they are generated thus reducing overall costs.
- For breakdown tasks, feedback to the originator of the complaint will be performed as the contractor will have an idea of its current work load and the technical difficulty of the job whilst no technical input is required from the client.
- Fewer people are required to run this system.
- Health and safety talks could be performed for a wider audience.
- The number of Non Value Adding (NVA) activities is reduced from 18 to 6.

Multi-skilling of tasks is a viable and efficient method of working especially on a geographically spread location. Labourers are generally cross trained in non-critical areas with the skill requirement is of a lower level than their normal work. An example may be pipe fitters who are able to repaint the piece of pipe installed or to replace the lagging just removed from the old pipe. The effort involved in getting a lagger and painter to do these jobs, each travelling to the site, is an inefficiency if the labour already at the point of work and is capable of applying paint and lagging. Areas where safety is a prime consideration would of course be left to the experts. The application of multi-skilling will usually reduce the number of contractors required on the site at a given time. Additionally correct labour utilisation of well trained competent staff to provide services at the lowest appropriate pay rate would reduce costs. As an example specialist contractors were used at their normal labour rate to ensure safety when working in sensitive areas. Other contractors on site are capable of performing this task although at approximately half the unit rate cost. Safety would not be affected by this change.

Implementing these changes requires the client to be actively involved in the construction industry developments. Utilising either contractor feedback in the form of one off analysis (as in this case) or more formally in the day to day planning can lead to greater site efficiencies. The latter could be feasible if the above structure for a help desk was extended to other site activities. Contractor input in the planning phase would allow for jobs to be more accurately assessed for suitability for lump sum pricing for example. Batching performed from a wider view of the jobs enables more effective utilisation of plant on site where jobs can be phased around plant that is due on-site. This is particularly beneficial where minimum hire periods are required from the plant suppliers. Our analysis highlighted the following client based routes to creating additional costs, and therefore areas for improvement which are highlighted in Table II.

Method	Eliminated via
Batching of work is poorly performed	Improved planning
Contractors are kept on site just in case.	Knowledge of their roles / necessity
Contractors are not asked to leave after projects are complete.	Knowledge of their roles / necessity
Non-optimal usage of labour / unnecessarily high rates of remuneration for some tasks.	Knowledge of labour skills base / remuneration rates
Not utilising multi-skilling.	Identify scope and implement
Remuneration rates / bonus schemes incorrectly compiled.	Improve tender / selection process.
Lack of control over contractors	See Table I.
Over control of the contractors.	Reducing the frequency of loop checking.

Table II Client routes to creating additional costs.

It should be noted that the degree of client control over the contractor would seem to have a large effect on the extra costs incurred over an ideal system with no checking and no mistakes in planning and invoicing. Should a client implement little control over contractors then this may be taken advantage of by the means shown in Table I whereas if over control existed it would tend to limit the amount gained from a partnering philosophy and stifle teamwork thus increasing costs. A good knowledge of contractor practices on site and a robust feedback control system controlling their dealings would intuitively be the best solution to the problems highlighted in Tables I and II.

8. Conclusions

Table III highlights the comprehensive list of tools used as well as the relative insight gained from each of these methods. The usage of a particular research method does not correlate with the insight gained although some steps, talking to the people operating the system in conjunction with a structured mapping technique (the pseudo process flow charts) allowed a long and complex process to be mapped. This is especially useful where a large number of hand offs occurred. Feeding back using these charts to long standing and experienced professionals in the industry created surprise due to the complex nature of the process in which they were involved.

Level	Research Method	**Usage**			**Insight**		
		High	Med	Low	High	Med	Low
Business	The Contract	o				o	
	Internal Reports			o		o	
	The Manual		o				o
	Question Client Managers		o		o		
Operational	Invoiced Amounts		o			o	
	Invoice Documentation		o		o		
	Question Contractors			o		o	
	On Site Analysis			o		o	
	Pseudo Process Flow Charts		o		o		
	Input Output analysis			o		o	

Table III Contact methods for analysing the client contractor interface

The methodology proposed and further developed by the project manager was considered a good method of analysis in this case. Combined with contractor knowledge the interface inefficiencies that existed were highlighted to the client managers and should lead to a reduced operational expenditure. The client contractor interface created most problems when the client attempted to run a system requiring specialist contractor knowledge. Obtaining the required information and subsequent planning of the work created a large number of delays and Non Value Adding activities. Informed planning at this level (i.e. using the contractors on site) can, it is believed, create significant savings for the client. Again feedback of site activities lends itself towards efficient planning (both plant and human resources) and accurate invoices being submitted by the contractors on site. This however costs money and a trade off has to be made between the cost of checking the contractors and the value in doing so.

Improvements within some of these areas has been actioned by the client whilst others are at the consideration stage. The success or otherwise of these recommendations will be largely based on their ability to either improve safety, quality or cost.

9. Acknowledgements

This paper highlights work performed during IMI EPSRC funded research on Supply Chain Methodology For Improving Construction Industry Performance. Their and the clients financial help is gratefully acknowledged. Thanks also to the busy professionals in the system analysed for their time and enthusiastic assistance.

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Hurst Spit Stabilisation: A Partnering Case Study

D. C. Brown and M. J. Riley

Abstract

The stabilisation of a 2 km shingle spit in southern England was initially planned as a traditional civil engineering contract. However, an unforeseen delay at the start meant there was a real danger of not completing the work before winter storms, so a partnering approach was introduced – with successful results. This paper starts off by investigating the potential of partnering to achieve the UK's construction improvement targets. Using Hurst Spit as a case study, it demonstrated that partnering can provide significant benefits for a one-off project without the need for formal agreements. It analysis in particular the culture changes which are required to achieve the full benefits of a partnering way of working.

Introduction

There is a world wide effort to create significant improvements in the construction industry. To this end, ambitious but achievable targets and deadlines have been established to drive this process forward (Tables 1 and 2).

CONSTRUCTION SECTOR PERFORMANCE METRIC	YEAR 2003 TARGET IMPROVEMENT	RANKING (*) IN IMPORTANCE
Total Project Delivery Time.	Reduce by 50%	First
Operation, Maintenance and Energy Lifetime Costs	Reduce by 50%	Second
Productivity and Comfort Levels of Occupants	Increase by 50%	Fifth =
Occupant Health and Safety Costs	Reduce by 50%	Sixth
Waste and Pollution Costs	Reduce by 50%	Fifth =
Durability and Flexibility in Use Over Lifetime	Increase by 50%	Third
Construction Worker Health and Safety Costs	Reduce by 50%	Fourth

(*) Ranking in Industry Importance Obtained from White House Construction Industry Report Workshop Participants Representing the Residential, Commercial, Institutional, Industrial, and Public Works Construction Sectors.

Table 1. US Construction Sector Performance Improvement Targets to be Achieved by Year 2003.
(Source; R N Wright, A H Rosenfield, and A J Fowell)

Performance Metric	Improvement
Cost	30% reduction
Duration	25% reduction
Defects	zero
User benefits	20% improved

Table 2. The EPSRC IMI "Construction as a Manufacturing Process" Key UK Objectives:

The emphasis has been on adopting processes which have proved successful in the manufacturing industry. Technical methods such as just in time (JIT), business process re-engineering (BPR), pre-fabrication and standardisation are beginning to produce benefits in the construction industry.

Although technical issues are important and need to be improved, the real problem is that of culture. Quantum improvements in the construction industry, as required by the improvement targets, will not be attained purely by technology transfer from manufacturing. Significant improvements can only occur by a process change coming from within the construction industry and dedicated to encompassing the whole culture of construction.

The need for a new contract strategy is clearly evident when it is recognised that the profit margins of construction lawyers specialising in litigation are far in excess of the construction companies that they represent. Adversarial working is being replaced by new ways of working in other industries (Towill[1]) and has shown great improvements.

The scenario for a paradigm shift in UK construction culture was proposed by Sir Michael Latham [2] in his report that proposed working in partnering arrangements. This proposed long term partnering relationships with mutually agreed and measurable targets for productivity improvements.

The major drawback of the Latham approach to partnering is the creation of long term relationships between partners, typically lasting 3-5 years and with a continuous stream of work being carried out during the lifetime of the partnering arrangement. Unfortunately this does not address the majority of construction projects in this country where more than 85% are still single one off projects, and the requirement, in the public sector, of a need to satisfy probity by competitive tendering.

In projects where the client and engineer have embraced the philosophy of non-confrontational working, the goal is then to create a partnering way of working after competitive selection of the Contractor whilst still fulfilling three basic requirements:-

- A method of contractor selection that achieves the lowest price.
- A guarantee that the contractor selected will adopt the partnering philosophy.
- A method of allocating risk and profit after the contract has been awarded.

Partnering Structure

The advantages of working together have been strongly promoted by Latham[2]. Many clients are now users of partnering arrangements, but this is primarily for building work rather that civil engineering. It is more feasible to develop long term relationships in this sector of repetitive work loads but considerably more difficult for single one-off projects that predominate in the civil engineering sector. The earlier NEDO report[3] "Partnering: Contracting Without Conflict" also provides a good basis for partnering but again this does not support single one-off projects.

Hellard[4] investigated partnering on a world-wide basis and suggested that partnering is the master key that will unlock the techniques and principles of total quality management (TQM) to improve customer satisfaction. He highlighted some of the problems of partnering, including the danger of no true commitment, those pre-conditioned to adversity, top management paying lip service, the myopic thinking of some to win every battle every day, not bringing all the key players in at an early stage, skimping the early activities or the workshops, culture change not being easy and the use of old standard approaches.

Weston[5] defined partnering as a long term commitment based on trust, dedication to common goals and an understanding of each other's individual expectations and values. Weston[5] studied 139 contracts with the US Army Corps of Engineers, of which 39 were partnered and 100 of which were not. They show clearly partnering producing significant improvements for all parties to the project.

Partnering projects of all sizes was reported by Bates[6], who suggested the principles should include shared goals arrived at through consensus, mutual trust and respect, new attitudes and behaviour, new means of communication and commitment from top to bottom. Weston's[5] view is reinforced by Larson[7], who states that "Whether the contract is awarded on a competitive basis or not, does not appear to affect the success of partnering efforts and is not a serious impediment to success." Schmader[8] carried out a major study of over 200 contracts awarded by the US Naval Facilities Engineering Command (NVAFAC) and again the results reinforce the general advantages of partnering. The paper by Rankin[9] confirms that pre-qualification remains a key mechanism and this should provide an initial source of variables for any partnering selection process.

Although long term partnering is likely to produce the largest benefits there are a considerable number of projects where this approach is not possible. This is particularly true of either "one-off" civil engineering contracts or where the client is a public body. Although recent government legislation has led to a large reduction in the amount of government funded work from about 90% to about 60 % (Survey of Civil Engineering Workload Mix 1991/92, FCEC) the figures are still large. The new enlarged private sector is more able to adopt new procurement methods and contract strategies and hence take advantage of the potential savings from partnering, but probity in the public sector means that they have considerably less freedom to do this. EC law can also prohibit long term partnering. Thus a very large amount of construction work will still be awarded by competition. Latham[2] does little to address this problem.

A key document, The Royal Academy of Engineering *A Statement on the Construction Industry*[10] urges the construction industry to address several factors including the following.

- Focus on customer satisfaction - it cannot be assumed they will know precisely what is wanted at the outset.
- Attention to process as well as to product - research must focus on user friendly guides for clients.
- Meaningful involvement of the client requires mutual co-operation, recognition of objectives, willingness to be open and free agreement to share risks and rewards to produce a successful project.
- Alignment to a common goal to create a win-win environment.

The many advantages of partnering are accepted, but there are still fundamental key problem areas - such as partnering in the public sector – that have received little attention. An analysis of a public sector project on which partnering developed spontaneously has thus been undertaken to assess the benefits of project-specific partnering and to determine a methodology for procuring partnering contractors in a publicly accountable way.

Case Study

Hurst Spit is a shingle spit formed at the end of the Pleistocene period and located at the eastern end of Christchurch bay on the south coast of England (Fig. 1). It is approximately 2km long and at its seaward end reaches a point approximately 1250m from the Isle of Wight. The spit now protects the coastal areas of the Solent to the east, both on the mainland and the Isle of Wight from Atlantic storms. The Spit also protects the salt marshes in its lee, a Site of Special Scientific Interest.

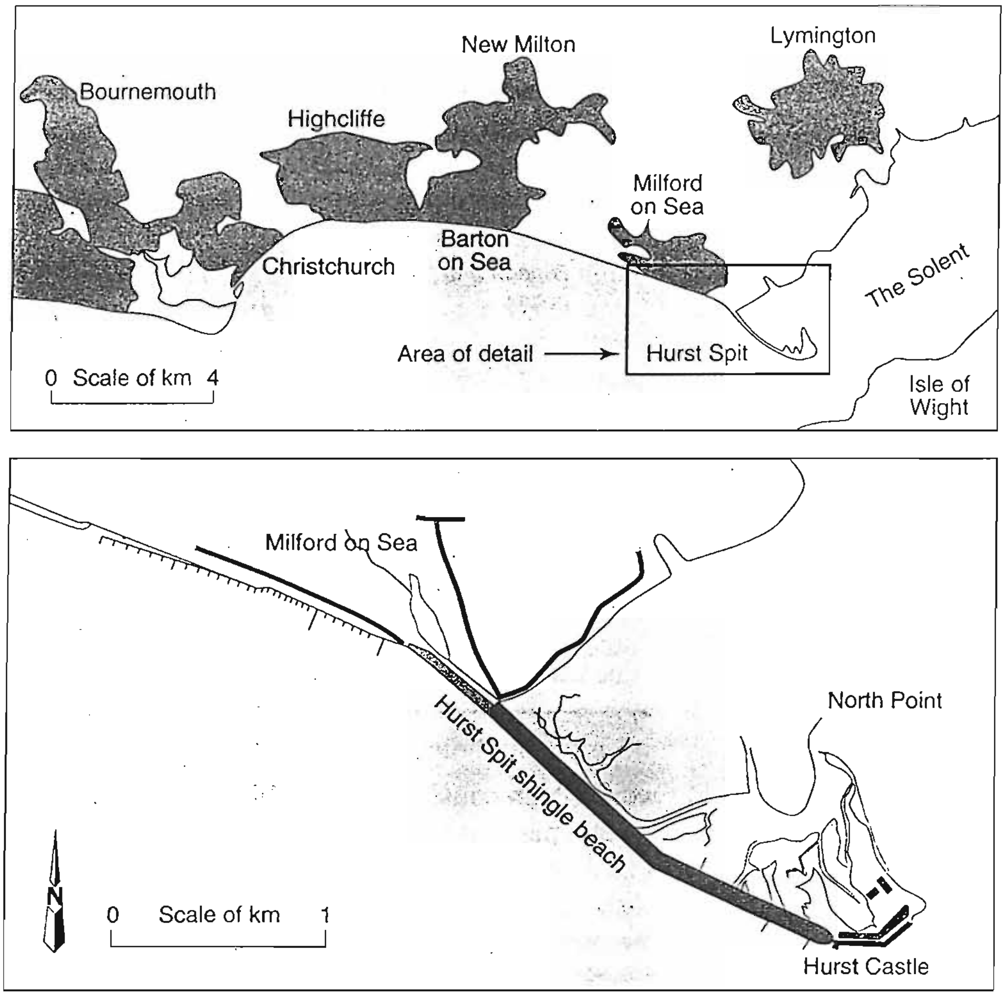

Figure 1 Location of Hurst Spit

Historically the spit was nourished by littoral drift from the west. However, as early as 1609 repairs became necessary due to storm damage. Coastal protection works to its west, which began some 100 years ago, severely reduced the shingle supply for re-nourishment of the spit. In 1974 New Forest District Council took over responsibility for coastal protection from the Borough of Lymington and in 1981 started a programme of annual re-nourishment.

Due to the threat of extensive damage to property and the salt marshes that would occur as a result of the spit being breached, a more permanent stabilisation scheme was developed (Fig. 2).

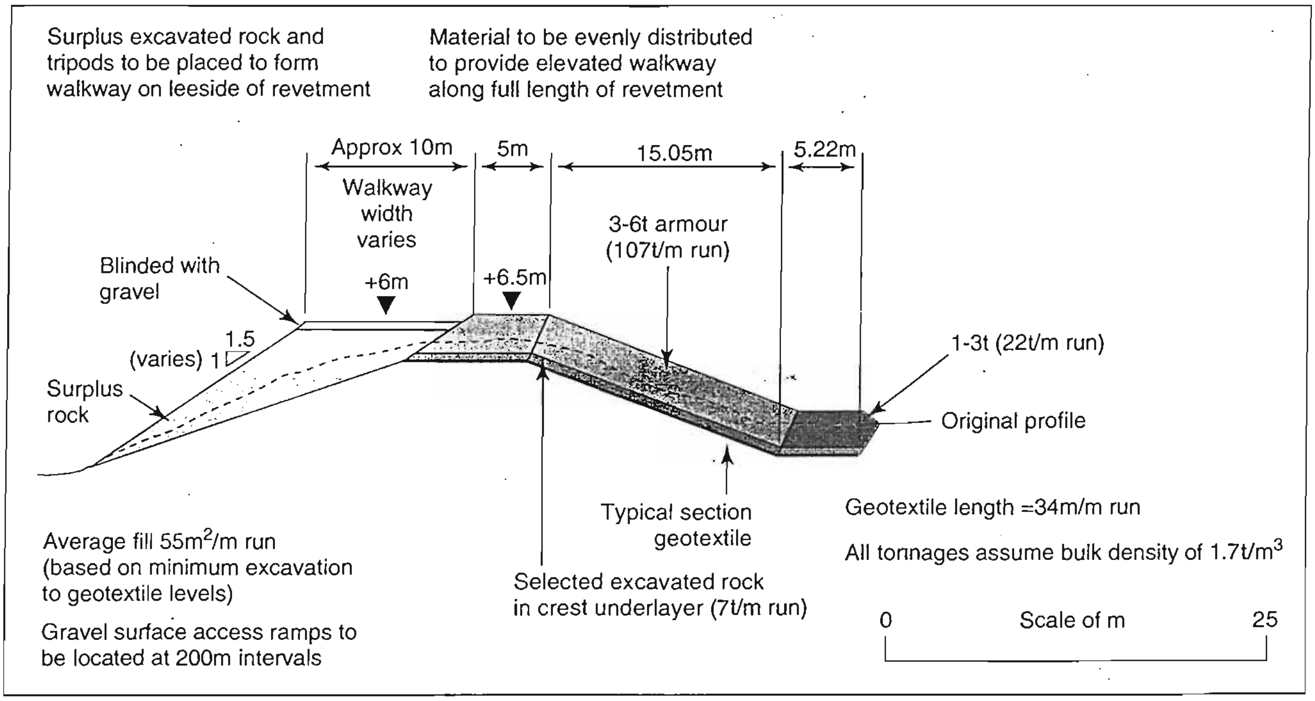

Figure 2 Cross Section of New Stabilisation Scheme

New Forest District Council was the Client for the stabilisation works and the engineer was the assistant director of the council's engineering services department. The resident engineer was also a member of the same department.

The main contractor appointed to undertake the works was Westminster Dredging Company Limited of Fareham in Hampshire. The contract was let under the ICE *Conditions of Contract* 5th edition with amendments. The contract tender price was £5 million with a contract duration of 30 weeks.

The project was expected to take the form of a traditional civil engineering contract, which often results in adversarial confrontations arising between the contractor, engineer and client. The project was both land-based construction and maritime, involving marine dredging for gravel and placing it both on and off-shore. It was thus anticipated by the engineer that the main contractor would be either a marine contractor with a land based sub-contractor or vice versa. In either case the sub-contract value was to be in the order of 50% of the tender sum. In order to give the engineer greater control over the selection of sub-contractors, the ICE *Conditions of Contract* 5th edition was adopted, rather than the current 6th edition.

The project was further complicated as a result of being a new and untried design and it was not possible accurately to predict the standards of work which could be reasonably expected from certain parts of the works. In addition, the project was in an environmentally sensitive area with a high public profile. Delays in completion before the onset of winter storms could have resulted in a serious breach of the spit and hence catastrophic consequences both to commerce and the environment. A breach in the Spit would have led to flooding of the nearby low-lying areas with consequent disruption to agriculture and business as well damage to residential property.

The client was concerned with the outcome of the project and therefore asked contractors interested in tendering. Surprisingly, several large contractors failed to respond correctly to the request and were removed from the tender list.

In order for the employer to obtain a dredging licence from the UK Government for the preferred source of gravel, the cost of two alternative sources of sea dredged gravel had to be compared. Tenderers were therefore asked to submit prices for each of the alternate sources. The contractor which was ultimately successful submitted the lowest prices for each of the alternative gravel sources and, in all tenders received, the client's preferred source was the cheapest.

The contractors tendering for the project had, as usual during the tendering process, asked the client for clarification of certain areas where it was thought that there was ambiguity or where errors or conflicting information occurred in the tender documents. The successful contractor had, however, sought clarification of substantially more points than the other tenderers.

The contractor was duly identified as being the preferred tenderer, with the tender price having a validity period of six months. The contractor was keen to commence the works but due to delays in obtaining dredging licences, the start was delayed.

As a result the contractor became involved with the design and advised the design team on changes which would improve buildability and reduce construction costs and duration all at no cost to the client, but purely due to the desire of the contractor to provide value engineering. The chance event of the delay led to a situation where a contractor had been selected by competitive tendering but was able to suggest changes to the design to enhance buildability.

When construction eventually started cautious optimism existed between the parties for a non-confrontational project which, over time, developed into a high degree of trust which all parties strove to maintain throughout the contract.

Evidence of the success of the partnering which evolved can be found in the fact that during the entire project no contractual letters were written by any of the parties. Furthermore, site meetings were not used for resolution of problems, as these were routinely sorted out on site, but principally for maintaining contact between all of the parties. As a result, meetings rarely lasted more than one hour.

Setting the Stage

The contract was prepared with the expectation that it would be a traditional adversarial contract, but the individuals named in the contract were keen to work in a non-confrontational manner. The main contractor was of similar mind and had already adopted the philosophy of treating others in the way they would wish to be treated themselves, and wished to tender on an equal basis. This philosophy was evident at tender stage when the main contractor raised 20 queries concerning the contract documents, a few being in connection with errors or matters of interpretation, but most were directed at ensuring that no tenderers made incorrect assumptions on key requirements, for use perhaps for claims later. The result of these points being raised was the responses being circulated to all tenderers thereby ensuring a "level playing field", which was the original intention of raising the query.

One area in particular is worth mentioning is that the contract prohibited the use of local roads for delivery of materials, except for small quantities. The main contractor was concerned that some tenderers would price on the basis of significant quantities of rocks being delivered to site by road, likely to be a considerably less expensive option than delivery by sea. The response from the engineer to this query was circulation to all tenderers conforming the original specification.

This example demonstrates two important points

- the tender price offered allowed for providing exactly what the client required
- the contractor, which wished to provide a genuine service to the client, wanted to tender on an equal basis.

The main contractor stated in comments relating to the project

" Our actions at tender stage, in respect of the queries raised, were to seek clarity in order to be able to price what the client actually wanted; to avoid disputes and misunderstandings should we win the contract; to create a 'level playing field'".

One further point demonstrates the motives of the contractor in the project. Due to delays in obtaining dredging licences, the tender validity period expired and the main contractor was asked if the validity period of the tender price could be extended. The contractor agreed to do this even though the tender sum could have been increased whilst still providing the lowest tender.

Before the start of the contract the client, engineer and contractor had all displayed openness and integrity and all were confident of a successful outcome to the project. The relationship developed fully when all parties to the contract, including suppliers and sub-contractors, realised they could trust each other and work together. The fact that the main contractor's culture and policy was not to act as a "traditional" main contractor may have accelerated the development of a partnering approach.

Building the Team

The client and engineer had already established a good basis for the contract to work with the minimum confrontation and were keen to build on the approach demonstrated by the main contractor. The project had the benefit of well written amendments to the conditions of contract, which clearly expressed the degree of risk sharing. It had, for example, been recognised that a possible area for dispute could be sea conditions that prevented working; however, inclement conditions were unambiguously by using wave height, leaving no grounds for misunderstanding.

The attitude of the main contractor to its own sub-contractors was also investigated. The most fundamental difference from traditional adversarial contracts was the policy adopted by the main contractor of paying their sub-contractors when payment was due instead of the commonly adopted "pay when paid" policy.

It was further stated in an interview with the project manager that company policy at all times was to assist their sub-contractors whenever possible, and such measures could include increasing the frequency of payments, the provision of a quick and easily agreeable method of assessing interim payments and helping with engineering services and plant and labour where required.

Two other factors were considered to be important for the success of the contract. Site meetings were held with all interested parties present, including sub-contractors and suppliers. Second, it was agreed that the resident engineer could work with the sub-contractors, thus avoiding any defective work being continued whilst instructions were relayed through the main contractor.

The client also demonstrated the ability readily to adopt different procedures, such as with regard to re-measurement. The difficulties of producing test panels of rock in order to re-measure rock placement was recognised and this method was discarded in favour of measuring the weight of rock delivered to site. This was possible because both contractor and client were prepared to agree the weight of rock delivered and the client was satisfied that the rock was placed in accordance with the contract. Interim valuations were agreed by considering the percentages of work complete.

The resident engineer stated during an interview that in his opinion the main contractor had always undervalued the amount of work done, and in one instance, the resident engineer suggested that the contractor should increase his application for payment. The overall result of this system was that valuations were agreed on the spot and because of the clients accounting procedures the contractor was paid early in every case.

The final observation made by both client and contractor concerns the issuing of instructions relating to unforeseen conditions and variations. There is often reluctance for engineers to issue instructions relating to unforeseen conditions for fear of being thought of as negligent by the client. This frequently leads to disputes with attempts to cover the situation with variation orders. Where the situation is truly unforeseeable no stigma can be attached to an engineer treating it as such, since by definition it could not have been foreseeable. Where variations occur, instructions should be issued promptly so that the contractor is not left with the dilemma of whether or not to proceed with the works at its own risk.

Contract Analysis

Analysis of this project suggests a framework for partnering working using traditional forms of contract, as follows.

- Contractors need to be prepared to tender for a project with no hidden agenda and clients need to produce comprehensive and fair documents for the contractor to work from.
- The client needs to be vigilant in ensuring that the tender prices received reflect the scope of the work expected and are not based on misunderstanding of the requirements of the contract which may result in a claims situation.
- There must be commitment from client, engineer, contractor and sub-contractors to work together as a team, agree interim valuations and ensure prompt payment. The old approach of pay-when-paid has no place in the modern construction industry.
- Care must be exercised in preparation of tender documents to ensure that the works are buildable and any onerous conditions are highlighted at tender stage.
- All parties to the contract must be proactive and prepared to implement change for the benefit of the project.
- A project team must be built up based on mutual trust and elimination of the "us and them" attitude.

The project contained a large element of risk, which was increased by a delayed start. The contractor, at the start of the project, recognised the need for acceleration in order to complete the offshore works before winter.

Two barges were employed, rather than the planned one, to ship rocks at double the rate which had two results. First, the client may have incurred some re-handling charges and, second, the contractor's plant was utilised at a level not originally envisaged.

The acceleration was achieved with no additional costs to the client but with a large reduction in the risk associated with failing to complete the offshore works during the good weather. The final result was a project completed on time, with high quality workmanship and to budget.

Conclusions

The Hurst Spit project shows the step change improvement in efficiency which can be achieved when the vision for partnering working is applied with sincerity and trust. Political brinkmanship and mutual distrust were entirely absent from this management team making the beneficiaries the client, engineer and contractors.

All project team members have recognised the advantages of a partnering approach on the project and would actively attempt to emulate this type of working on future projects.

The motivation for a partnering way of working is a philosophy not an agreement. There is no need for special forms of contract or agreements, especially as these will not necessarily satisfy the requirements of public accountability. However, it is of absolute importance that the philosophy of co-operation be augmented by prompt and fair payment throughout the supply chain.

However, although the organisations involved provide support and a framework, it is not the organisations which set the agenda on site but the character and attitude of the individual members of the teams. Selecting the right people is the key.

Partnering can provide a step improvement in construction even in single projects. In order to provide maximum benefits it is necessary to involve the contractor at the design stage. Partnering is a mechanism specifically developed for the construction industry and as such will provide greater benefits than technology transfer from manufacturing.

Acknowledgements

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OBSTACLES TO CO-OPERATIVE WORKING: LESSONS FROM CONSTRUCTION

D. C. Brown, M. J. Riley and K. A. Killander

1. Introduction

Co-operative working should be the paradigm for achieving competitive advantage in a global economy. Adoption of co-operative values and principles, described by Birchall[1], offers the key to unlock a new organisational culture. Without motivation, mutual support, common goals and values, organisational disfunctionality and disintegration will occur. This effect will be exaggerated in virtual organisations leading to inter-organisational adversity. Maintaining organisational and inter-organisational coherence through co-operation can only occur by trust based interpersonal integration. The management and diffusion of conflict, teambuilding and organisational culture are the foundations for co-operative working. Co-operation provides a business strategy for focusing on customer care together with continuous improvement in quality and reduced overhead costs as a result of common purpose.

The sixth principle of co-operation (Birchall) is defined as co-operation between co-operatives. Co-operation in a virtual co-operative is a very fragile operation. Disintegration of the virtual enterprise can occur quickly as a result of lack of inter-organisational trust and differing expectations and goals.

Construction projects are executed by assembling teams drawn from a number of different organisations. It is, therefore, in this area of inter-organisational co-operation that the lessons learnt in the construction industry can have the greatest impact.

2. The construction industry

Construction projects are executed by the formation of temporal virtual organisations. These virtual organisations are characterised by being composed of organisations with widely varying objectives and expectations. A feature of these organisations is that they are made up of designers, constructors, architects and other professionals in a formalised structure, for the express purpose of delivering a project for a client. However, the participant who has little or no control over the cost, quality or final outcome of the project is the client. The wishes of the client are completely obscured by the adversity created within the virtual organisation through absence of co-operation. Successful projects are characterised by focus on client requirements and co-operation replacing adversity, and inclusion of the client in the virtual organisation.

Construction accounts for approximately 10% of the gross national product of the UK (DoE[2]) and holds a similar position in most of the world's industrialised nations. The size of the industry has for, many years, allowed these inherent inefficiencies to become an accepted part of the construction process. The parties to construction are often adversarial, inefficient and resistant to innovation. There is a world wide effort to create significant improvements in the construction industry. To this end targets and deadlines have been established to drive this process forward. The improvement targets being set are ambitious but considered to be achievable.

Table I show the USA and UK targets. Many countries have established similar targets.

Construction Sector Performance Metric	**USA Government**		**UK Government / EPSRC**
	Target	Rank	
Total Project Delivery Time.	Reduce by 50%	First	Reduce by 25%
Lifetime Costs (Operation, Maintenance Energy)	Reduce by 50%	Second	
Productivity and Comfort Levels of Occupants	Increase by 50%	Fifth =	Improve by 25%
Occupant Health and Safety Costs	Reduce by 50%	Sixth	
Waste and Pollution Costs	Reduce by 50%	Fifth =	
Durability and Flexibility in Use Over Lifetime	Increase by 50%	Third	
Construction Worker Health and Safety Costs	Reduce by 50%	Fourth	
Costs			Reduce by 30%
Construction Quality			Zero Defects

Table I Construction Sector Performance Improvement Targets for the USA and UK

To try to achieve these targets emphasis has focused on transferring improved processes implemented with success in the manufacturing industry to the construction industry. The traditional construction industry is perhaps the last industrial sector to look to the improvements produced in the manufacturing industry; and it should be recognised that many of the methods for improvement developed within the construction industry could be successfully transferred to other industrial sectors. Technical methods such as just in time (JIT), business process re-engineering (BPR), pre-fabrication and standardisation, pioneered in manufacturing, are beginning to produce benefits in the construction industry. Technical issues are important and need to be improved, and without their improvement much of the success achieved so far would not have been possible, however, the biggest problem is that of a non co-operative culture (Lazar[3]). Quantum improvements in the construction industry, as required by the improvement targets, will not be attained purely by technology transfer from manufacturing. Significant improvements can only occur by a culture change coming from within the construction industry and dedicated to changing the culture from adversity into one of co-operation.

Even the simplest of construction projects involves many different participants assembled into a once only team. The organisational structure of the construction industry is shown in Figure 1, and illustrates the range of contributors that are required for a construction project.

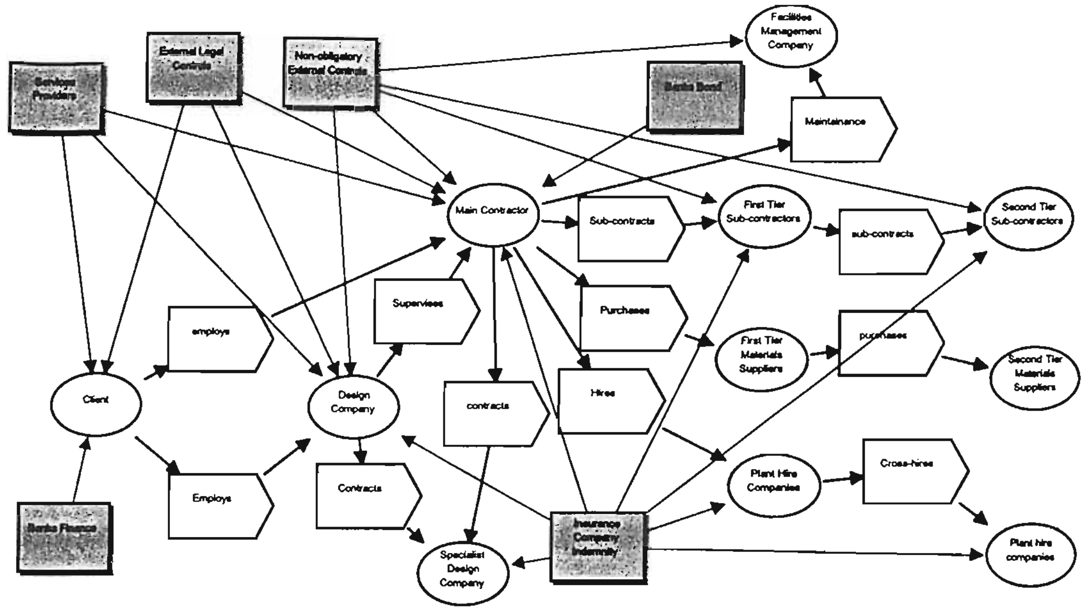

Figure 1 Construction Industry Organisational Structure

As a result of the highly fragmented nature of construction, the industry is blighted by adversity, poor quality and cost and schedule overruns. It has been recognised that construction costs need to reduce, together with construction schedules and generally better value for money needs to be provided. The reasons for these failures can be directly attributed to a lack of co-operation between the parties to a construction project (Brown[4]).

The fierce competition generated by competitive bidding based on lowest price has led to contractors bidding as low as possible to get work, but looking to contractual aspects of the work to obtain additional payment. Pursuing these objectives leads to adversity. The level of adversity in the construction industry is reflected in the anecdote that by the 1980s, the two main products of heavy construction were claims seminars and new attorneys firms specialising in construction litigation (Lazar[3]). In the UK in 1995 the top ten law firms specialising in construction litigation made higher profits than the top ten construction companies but with less than 0.1% of the turnover.

There is a tendency for clients and contractors to assume an adversarial posture with each other as a result of the conflict between clients' costs and contractors' profits. This is essentially a no win situation since one party's gain is another party's loss (Larson[5]). This dynamic is further complicated since it permeates the supply chain between contractor and sub-contractor and contractor and supplier.

Designers and contractors are traditionally adversarial, inefficient and resistant to innovation (Tarricone[6]). Consensus estimates that 30% of the cost a project can be attributed to failures in the design - construct - manage process (Brown[4]). A significant proportion of these failures can be attributed to incongruent goals and the consequent divergence of the various organisations participating in a construction project (Nam[7]). This situation has been named divergence.

Management of the trade-off between the goals of cost, quality and schedule has been one of the central concerns of project management (Puddicombe[8]). Differing prioritisation of cost, quality and schedule as well as non congruent success criteria will cause conflict as to the definitions of a successful project. This can lay the foundations for conflicting courses of action and adversity between the project participants. The need for a new contract strategy is clearly evident. Adversarial working is now being replaced by new ways of working in other industries (Towill[9]) and has shown great improvements. The scenario for a paradigm shift in the culture of the construction industry was proposed by Sir Michael Latham[10] in his report "Constructing the Team", that proposed working in partnering arrangements.

Bates[11] recommends that the principles for non adversarial working should include shared goals arrived at through consensus, mutual trust and respect, new attitudes and behaviour, new means of communication and commitment from top to bottom. These new attitudes cannot be initiated contractually. They will only occur when the culture for co-operation replaces that of adversity in all parties involved in a construction contract. Valuable lessons can be drawn from a construction project where this occurred spontaneously.

3. Case study

The benefits of co-operation in construction are demonstrated by analysis of construction project for the stabilisation of Hurst Spit. The work involved transporting 125000 tons of 6 to 10 ton rocks from Norway and placing them with precision in a designed grid. In addition, the spit was replenished with 250000 tons of shingle, dredged from the shingle banks in the Solent and pumped ashore.

Hurst Spit is a shingle spit formed at the end of the Pleistocene period and located at the eastern end of Christchurch bay on the South coast of England. It is approximately 2km long and at its seaward end reaches a point approximately 1250m from the Isle of Wight. The spit now protects the coastal areas of the Solent to the east, both on the mainland and the Isle of Wight, and salt marshes in its lee, a Site of Special Scientific Interest (SSSI), from Atlantic storms. Historically the spit was nourished by littoral drift from the west, however, as early as 1609 repairs were made to the spit after storm damage. Coastal protection works to the west, which began some 100years ago, cut off the shingle supply for re-nourishment of the spit. In 1974 New Forest District Council took over responsibility for coastal protection from the Borough of Lymington and in 1981 commenced a programme of annual re-nourishment of the spit. Due to the threat of extensive damage to property and the salt marshes that would occur as a result of the spit being breached a more permanent stabilisation scheme was developed.

The project was additionally complicated as a result of being a new and untried design and it was not possible to accurately predict the standards of work which could be reasonably expected for certain parts of the works. In addition the project was in an environmentally sensitive area with a high public profile. Delays in completion before the onset of winter storms could have resulted in a serious breach of the spit and hence catastrophic consequences both to commerce and the environment. A breach in the Spit would have led to flooding of the nearby low-lying areas with consequent disruption to agriculture and business, as well damage to residential property.

The contract was prepared with the expectation that it would be a traditional adversarial contract and used the traditional contract documents. However, the individuals named in the contract to act on behalf of the client, were keen to work in a non-confrontational manner. The Main Contractor was of similar mind and had already adopted the philosophy of treating others in the way they would wish to be treated themselves. It is interesting to study how this wish to work in a non adversarial way was transformed into reality.

The start of the project was delayed for six months due to protracted negotiations with the Department of Transport for dredging licences. This delay provided time for the contractor, client and engineer to develop a co-operative and trust based relationship. When construction eventually started cautious optimism existed between the parties for a non-confrontational project, which over time developed into a high degree of trust which all parties strove to maintain throughout the contract. Evidence of the success of the co-operation which evolved can be found in the fact that during the entire project, no contractual letters[a] were written by any of the parties and that site meetings were not used for resolution of problems, as these were routinely sorted out on site, but principally for maintaining contact between all of the parties, and as a result meetings rarely lasted more than one hour.

It must also be noted that considerable pressure existed with the contractor who was trying to complete the work before the winter weather closed down all work; a situation exasperated by the delay in the award of the dredging license.

The success of the project is summarised in Table II which compares the results of the project with the UK performance improvement targets shown in Table I.

Performance Metric	**Project Performance**
30% cost reduction	Achieved
25% duration reduction	Achieved
zero defects	Achieved
20% user benefits	Exceeded

Table II Project Performance

[a] Contractual letters in construction are used to draw the attention of a participant of failure to perform in accordance with the contract and inevitably leads to claims for additional payments to the contractor, naturally, such moves are resisted by the client.

The study of this project has revealed the mechanisms required for co-operation, and research into the wider construction industry has identified the causes for non co-operation. This project provides evidence of the benefits to the construction industry of a co-operative way of working. The requirements for a cultural change in the attitudes of the construction players has been identified and the importance of mutual trust and common purpose highlighted.

4. Organisational trust

The present of trust based relationships, or relationships which resemble those based on trust, do create an economic advantage in conducting business (Zaheer[12]). The higher the level of trust in the relationship, the lower the cost of doing business, and the higher the level of effectiveness to do business. (Bromiley[13]). Trust in the context of business has been defined by Hosmer[14] as:-

> Trust is the reliance by one person, group or firm upon a voluntarily accepted duty on the part of another person, group or firm to recognise and protect the rights and interests of all others engaged in a joint endeavour or economic exchange.

A critical factor in this definition is the concept of reliance. Reliance implies one party placing its well-being in the hands of another with only limited protection. It also implies that the party relying on another will forbear to act defensively until it is proven with reasonable certainty that the other party has become no longer trustworthy. In a trust based relationship, there can be slippage in both the timing and proportionality of reciprocation, because the mind set of the parties is, or ought to be that all unevenness between the parties at a given point in time is a temporary phenomenon and will eventually be evened out. Consequently, the occasional lack of timely reciprocation or a disproportionate response would not cause the affected party to either retaliate or take on a defensive posture against the offending party.

There are other classes of relationships which appear to be trust based but are much more fragile and only emulate trust based relationships. One of these can be termed a reciprocal based relationship. In this relationship, co-operation between the parties provides maximum group benefit. When one individual or party makes a co-operative move the other party reciprocates. Over time a relationship, mimicking a trust based relationship emerges. However, any action which is seen to be non co-operative or untimely produces a swift and adversarial reaction. The outcome is a rapid change to a highly competitive negative strategy aimed at maximising both self gain and the other party's loss. This is a more extreme strategy than just maximising self gain. In a violated trust based relationship this might be the ultimate outcome but it would take much longer to reach the same level of antagonistic behaviour (Friedland[15]).

Given the fuzziness of the boundary separating trust based and reciprocal based relationships and the fact that both lead to similar outcomes of co-operation, is there any value in ascertaining which type of relationships exists within an organisation?
The implications are definitely significant. In a trust based relationship, the timing and proportionality of each reciprocal action are not super critical. As long as the expectation of the final equity between the parties remains , there can be interim periods of inequality.

In a reciprocal based relationship, however, the timing and proportionality of each reciprocal act is critical. Failure to reciprocate in a timely or proportionate manner, particularly when there is a pattern of non-reciprocation, can quickly send the relationship into a downward spiral from apparent trust to aggressive hostility (Friedland[15]).

In a reciprocal based relationship each side actually determines its response based on the actions of the other party. In any relationship, emulating a trust based relationship, each party is willing to give the other the benefit of the doubt of untimeliness but will react adversely to the first potentially hostile move. At this point, the reacting party moves into an aggressively competitive stance. This adversarial stance can be extremely hostile and decision making is oriented towards making gains by causing the other party to suffer losses. This change in relationship is described by Friedland[15] as the fast track route from co-operation to litigation.

There is, however, a methodology for successfully managing a reciprocal based relationship and making it look and act like one which is trust based. The key is to first identify it as a reciprocal based relationship and to then scan for concessions or acts of good will that the other party is making. These need to be identified, acknowledged and quickly reciprocated. This is not always possible, and sometimes concessions or acts of good will are not always easily identified. To mitigate the effects of failing to recognise concessions or acts of good will, multiple, clear lines of communication must be established and maintained within the organisation so that misunderstandings can be quickly remedied. If reciprocation has to be delayed or is disproportionate, this should be clearly communicated to the other party, together with statement of how equality will be restored.

5. Co-operative dynamics

The motivation for a co-operative way of working is a culture not an agreement. There is no need for special forms of contract or agreements, especially as these will not necessarily guarantee co-operation. However, lessons from construction shows that it is of absolute importance that the culture for co-operation be augmented by prompt and fair payment throughout the supply chain. Late and unfair payment are not the ethics of co-operation.

The principle means for achieving organisational integration can be broadly classified as contractual and social psychological methods. These two approaches embody different assumptions about company dynamics and therefore develop different approaches for integration. This paper focuses on the social psychological approach. Previous research by the Business Engineering Group has shown that contractual methods of integration have limited value. The project at Hurst Spit achieved successful organisational and inter-organisational integration and demonstrated that trust was the key element to integration (Brown[16]). A member of the team for this project stated "as soon as you write down a formal agreement you lose the element of trust which drives the whole set-up. If the will is there you don't need the formal arrangement, if the will is not there you won't create it by writing it down".

The two dynamics for a successful organisation have been identified as communication and motivation (Bowers[17]), of which the most important is communication. Common ownership has been proposed as a mechanism for achieving motivation implicitly by providing congruency of expectations. The reality is that motivation develops from a trust based relationship. Common ownership in itself is not sufficient to develop motivation and can sometimes produce adversity and resentment. Recent discussions on the Southampton Co-op Network mailing list has demonstrated the problems associated with equal pay to all members: there is clearly a notion that pay differentials must exist to provide fair reward for the perceived input to the organisation. Thus, divergence can result from dissatisfaction and perceived under valuation. This situation can only have detrimental effects on motivation.

The most important dynamic for a successful organisation is communication, and it is true, that common ownership should provide and encourage greater communication. Unfortunately, this forum is frequently under exploited and the authors have been witness to disputes arising both within and between co-operative organisations through lack of communication.

6. Organisational conflict

Conflict within and between organisations is frequently due to human factors and the way in which these human issues are managed. The predominant causes of conflict are classified in Table III.

Cause of Conflict	Summary
Task Interdependency	Conflict resulting from dependency upon others (e.g. for information, feedback or completion of a task)
Organisational differentiation	Conflict due to different groups of people perceiving the same thing differently
Values, interests and objectives	Conflicts arising from misalignment of personal goals with the project goal
Communication obstacles	Conflict arising from personal or organisational barriers to communication
Tension	Conflict resulting from unresolved and mounting interpersonal tensions
Personality traits	Conflict escalation due to lack of understanding or inability to manage personalities encountered

Table III: Most Frequent Causes of Organisational Conflict

6.1 Conflict due to task interdependency

Task interdependency is the extent to which two or more social units, people or groups of people, depend upon each other for assistance, information or compliance to perform their respective tasks (Walton[18]). This trait is analogous to the finely tuned relationships that exist between the players of the most successful football teams. The entire structure of an organisation is based on multiple social interdependencies that are established between members of the organisation and amended as people leave or join that organisation. These interdependencies grow in depth and complexity with the life of the organisation. Hundreds and sometimes thousands of tasks have to be undertaken by different sub-groups within the organisation to produce an output.

Dysfunctional conflict related to task interdependency has been a significant cause of project failure within the construction industry (Gardiner[19]).In terms of organisational design, good communications and shared understanding are particularly important, especially when activities are linked by reciprocal interdependency. When organisations or groups within an organisation are communicating at cross purposes, either due to a simple misunderstanding or because of prior assumptions, beliefs or when they are just failing to communicate at all, the seeds are sown for conflict at a later stage.

Organisational team building does not remove or reduce these interdependencies, but it can be used to strengthen the relationships and increase the trust between parties. This will then minimise the damaging consequences of non-conformance by any party and create a better understanding and appreciation of the organisational networks. Team building in this context helps members of the organisation to see beyond their own limited boundaries of operation and provide an incentive for each member to help meet the needs of the other members.

6.2 Conflict due to differentiation

There is an optimal degree of differentiation for every organisational sub-unit, defined principally by the degree of uncertainty in its environment. It can be concluded, therefore, that over differentiation or under differentiation can be a cause for conflict (Lawrence[20]). This is a particular problem in the construction industry where project organisations are created from functionally separate, geographically separate and often culturally separate organisations, meaning that high differentiation exists even for small projects. The result of high differentiation is that members of one camp within an organisation often regard members from another camp with wariness and caution. Although organisational differentiation is an established concept, which has received significant attention in many large organisations, smaller organisations and co-operatives in particular have failed to address the problem. Dysfunctional conflict due to high differentiation still occur with great regularity.

Team building which brings people or organisations together enables some of the differences to be smoothed out. This process allows members from different organisational backgrounds with different mind sets to become familiar with and to learn to understand better where the other participants are coming from. A commonly accepted view can eventually emerge, in the vein of "we all agree to accept that the glass is half full and not half empty". This brings with it a congruent increase in trust and allegiance to the organisation and not just a participant's individual part or contribution. The benefits of team building will be particularly apparent within a virtual organisation.

6.3 Conflict due to differing values, interests and objectives

Organisations are composed of and influenced by a diverse range of people, with competing as well as common interests. The interests of participants are based on values that may or may not have relevance to the organisation. The same problem also extends to inter organisational groups. If aberrant interests are shared by persons collectively within the organisational structure, then a potential for inter group conflict exists. The challenge is to be aware of and manage these interests to obtain a balanced set of best interests for the organisation.

The need for a shared common goal is one of the requirements for successful organisational teams (Adair[21]). Many members of an organisation are only briefed on their particular input and not provided with a more holistic picture of the organisation's goals and expectations. Not surprisingly, this frequently results in needless misunderstandings and conflicts.

6.4 Conflict due to communication obstacles

Barriers to communication can be attributed to organisational or personal obstacles. In most organisations common experience eventually reduces communication barriers. However, many examples in a wide range of organisations exemplify the tenet that the less each individual knows about each others job, the less collaboration occurs and that this lack of knowledge can lead to unreasonable demands through ignorance (Miller[22]). Effective communication is the key concern for any serious attempt at team building.

6.5 Conflict due to personality traits

Certain personality attributes can increase conflict within an organisation (Walton[18]). Most relationships involve mixed motives and therefore require a degree of behavioural flexibility if they are to be managed optimally. Organisation members who are unable to adopt this flexibility when appropriate may be drawn into and cause an escalation of unnecessary conflicts.

Psychometric testing may alert an organisation to these problems, but even without such testing, which is seen by many as intrusive and unwelcome, a team building event will almost certainly bring out these characteristics. This will then enable strategies to cope with the problem to be developed in a proactive and beneficial way.

7. Case for team building

The decline of pyramidal organisations in recent decades has been mirrored by the growth of other organisational forms. In the 1990s, teamworking, networking and co-operation are some of the more important forms that have dominated the debate in organisational design (Harland[23]). The problem being experienced by current organisational practice is a failing to meet the demanding requirements of today's socially complex organisational environments. Organisations are still hampered by a high incidence of dysfunctional conflict.

Team building provides a method for organisational development and has the potential to achieve significant lasting effects in a relatively short time. Organisations undergo change and modifications as time progresses. These can vary from structural modifications to metamorphic change, bringing with them a changing set of organisational needs. The trust and opportunity for communication facilitated by team building provides the members of the organisation with the confidence to adapt to changing demands and needs.

The importance of developing an organisation as a social unit is described by Zander[24], who states that "responsible members make their group stronger if they help participants recognise they constitute a whole, want to remain as members and want to do what the group needs." The use of team building techniques is a convenient mechanism to accelerate the integration process which is necessary to override the effects of differentiation and peoples' shortcomings.

The chemistry needs to work between the members of the organisation. Teambuilding allows members to interact socially and observe other members. Even simple measures like this can reveal unwelcome organisational aberrations that can be avoided or resolved before conflict arises. An organisation whose members have learned to communicate effectively provides a firm foundation from which to develop the organisation and to deliver greater value to the client.

The key to understanding organisational effectiveness lies in the ongoing interaction processes that take place among the members of the organisation as they work on a task. Members of an organisation who work together but do not share with one another uniquely held information critical to the task in hand can cause the quality of the resulting output to suffer. Team building within an organisation provides the opportunity for the members of that organisation to interact with and learn from each other at a time when the cost of making mistakes is small and the stakes are low.

8. Removing barriers to co-operation

The organisational barriers to co-operation can be grouped into four categories, of which one is external to the organisation and the other three internal:-

- Intrusions from the outside world (external)
- Organisational climate (internal)
- Organisational culture (internal)
- Organisational structure (internal)

Intrusions from the outside world can cause significant barriers to co-operation. These arise as a result of a misconceived belief that co-operation equates to bureaucracy. This leads to a reluctance by the outside world to trade with a co-operative organisation due the perception that decision making will be by committee and the organisation will lack dynamism, and hence be stagnant and resistant to innovation. Thus to the outside world, the co-operative organisation is seen as a dinosaur rather than a market leader, bringing increased external pressure to the success of the organisation.

There is no single way to deflect this negative pressure, however, one successful way is to encourage potential critics to "buy into" the organisation and demonstrate the flexibility and innovation that can be achieved by co-operation. Another way is by championing the benefits of co-operative principles. In a trust based co-operative organisation client care will be paramount since internal conflict is eliminated and all efforts are directed to client satisfaction.

Organisational climate refers to a situation and its links to the thoughts, feelings and behaviour of the organisational members. It is temporal, subjective and subject to direct manipulation by people with assumed power and influence. Co-operation cannot exist when a situation can arise, either by chance or design, which adversely impacts on the ability of the organisational members to perform.

These obstacles can be alleviated by identification of situations which detract from the organisations performance. Once these situations have been identified, procedures and processes need to be incepted to mitigate and eliminate their effect, or preferably to prevent their occurrence in the first place.

Organisation culture, in contrast to climate, refers to an evolved context within which a situation may be imbedded. It is rooted in history, collectively held and sufficiently complex to resist many attempts at direct manipulation. A negative aspect of culture is the passive acceptance of continuing to carry out a task in a certain manner for no better reason than that is the way in which it has always been undertaken. This aspect of culture can be the cause of a major barrier to co-operation. If the culture for non co-operation exists then cultural resistance to change prevents it from occurring.

Cultural change to enable co-operation can only be achieved by collectively removing barriers which prevent its occurrence. This is the major problem within the construction industry where the culture for non co-operation, conflict and adversity is so deeply entrenched that it is difficult to change. Short term changes to culture can be produced by radical actions, such as a massive infusion of new personnel into the organisation. However, without collective support for the culture change brought about by radical actions the previous culture will soon resurrect itself.

Organisational structure refers to the formal patterns of activity and decision making within an organisation and its external environment. Structure is created both by design and formed by an organisation's evolution. There are a multitude of perspectives as to the evolution of organisational structure, but management and time play the principle roles. If the organisational structure is such that various groups or individuals within an organisation hold equal levels of authority, then it only requires one group or individual to be resistant to co-operation to prevent co-operation occurring entirely.

This obstacle can be removed by education. The wishes of the majority must be expressed to the minority and consensus for co-operation reached. When this is done well, members of the organisation previously opposed to co-operation will frequently champion the cause.

9. Conclusion

The construction industry is endemic with conflict and adversity. In an effort to rectify the situation various attempts have been made at contractually forcing co-operation. This has had limited success. Organisations working together in a co-operative environment guided by mutual goals provides a viable alternative to the industry malaise of litigation and claims.

This is proven by the study of a construction project where co-operation occurred spontaneously. It was shown that it occurred because a culture change had been brought about which gave individuals and organisations the freedom and confidence to work together with mutual trust and respect. This project demonstrated the massive benefits that can be achieved by co-operation.

The understanding of the problems and the lessons learnt in construction are directly transferable to other organisations, particularly organisations wishing to work in a co-operative manner, since the primary cause of disfunctionality identified in construction is a lack of co-operation and trust. Technical improvement methods used in manufacturing have had limited success in construction. The major stumbling block to increased performance is the required change in the culture, roles and expectations of the participants. A combination of organisational and technological integration is required.

It was found that there are many obstacles to co-operation, all of which can be overcome if trust exists between participants. Trust has been shown to be the motivator and driving force behind co-operation and can only occur when the mind set of the participants is focused in this direction. There are relationships that mimic trust which need to be identified and carefully managed if an organisation is not to degenerate into adversity.

This paper has identified and investigated the causes of individual and organisational conflict and the organisational barriers to co-operation. The benefits of team building have also been espoused and the ability of team building to eliminate conflict described. Six causes for human conflict within an organisation have been investigated and methods of resolution proposed. However, the truly co-operative organisation will eliminate the causes of conflict rather than resolving the dispute.

Co-operation is also inhibited by organisational barriers. These barriers take four forms, three internal and one external. Of these the greatest barrier to co-operation is organisational culture. In the construction industry this has thwarted almost all efforts to achieve co-operation.

The lessons learnt from the construction industry are common to many other organisations. Co-operation will not occur whilst there are obstacles preventing it. The first task is to identify what these obstacles are, and then set about removing them. Organisations that undertake this process will be able to achieve co-operative working and reap the benefits and rewards associated with it.

This paper has presented the obstacles to co-operation. A forthcoming paper will provide a toolkit for achieving co-operative working.

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A MULTI-CRITERIA APPROACH TO CONTRACTOR SELECTION

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Abstract

This paper describes a multiple-criteria decision support system (MCDSS) for the selection of the most appropriate contractor. The system can accommodate the unique characteristics of a project in addition to the qualifications and capabilities of those contractors assessed. The system first evaluates the list of contractors by matching their qualifications with specific project conditions. A short list of eligible contractors is thus selected and the MCDSS compares the current capabilities of the short listed contractors and their plans for the project under consideration, to select the most appropriate contractor. The Delphi method was used to evoke expertise and obtain reliable assessment values for all criteria related to the contractor qualification, while the analytic hierarchy process was used to assess the specific project conditions. The system can be easily modified to adopt specific conditions of the proposed project and also to facilitate the decision maker in explaining the reasons for the elimination of excluded contractor.

Keywords: analytic hierarchy process (AHP), contractor selection, decision support system, multiple criteria

INTRODUCTION

An important characteristic of the construction industry is that the majority of contractors involved are small-scale firms. In many countries, there are thousands of contracting firms, which range from sole traders to large firms employing a workforce of several thousands, (Roger *et al* 1993). The existence of a large number of contractors in a limited number of projects and uncertain construction industry environment results in intense competition between them. Among this large number of contractors, selecting the most appropriate one is an important decision to be made by the client.

In selecting a contractor, various selection criteria such as experience, performance in past projects, financial strength, etc., should be considered simultaneously. It is important to use additional decision criteria other than the lowest tender (Hardy *et al.*, 1981; Samuelson and Levitt, 1982; Bent, 1984; Nguyen, 1985; Hauck and Kline, 1986; Friis, 1987; Jaselskis and Russell, 1990; Ledbetter, 1994; Herbsman, 1995, Working Group 3, 1997). However, these researchers focused on single principal criterion to evaluate the contractor, i.e. the duration, experience, quality of performance, project safety, or discounted cash flow as approaches to introduce tangible selection criteria in addition to lowest tender for identifying the best contractor. Identifying the best contractor does not necessarily mean that this contractor is the most appropriate one to the project under consideration. However, the proposed method provides a systematic methodology to incorporate all relevant criteria simultaneously for the selection of the most appropriate contractor. In this context, the capability of each contractor should be evaluated based on the specific requirements of the project in hand. Further, the selection method should be simple, normally accurate and transparent so that the method can reason why a particular contractor is selected for a particular project. On the other hand, a study carried out to measure the contractors' opinions in the multi-criteria selection approach by Jennings and Holt (1998) indicated that contractors tend to agree with clients' importance levels of multi-criteria selection factors.

In this paper, a formal method to select the appropriate contractor for a project is proposed and verified. The presented method evaluates the past experience of the contractor performance in recent projects and the contractor's current capability to perform the project; intended plans for the execution of the proposed project and overall financial stability. The method will facilitate reasoning so that an explanation can be provided on why a certain contractor is accepted or rejected, which is very necessary in public projects.

CONTRACTOR EVALUATION

Awarding a construction contract to the lowest bidder, without considering other factors, can result in problems such as cost over-runs, delays and poor performance (Crowley and Hancher, 1995). The lowest bidding contractor may tend to adopt a confrontational "claims oriented position" once the project is awarded as a means of making-up any financial short full. Whilst a low tender sum may seem appealing to the client at tender stage, the project may encounter problems if the contractor is, for example, not able to complete the work on time or compromises on the quality of construction to reduce the contractor's cost.

Another problem with current contractor selection methods is that they depend on the skill, experience and knowledge of the decision-maker. The experience and relevant knowledge of the decision-maker (his/her judgement) varies from one to another and there are no minimum standards that guarantee the quality of the selection process. Even with an experienced and knowledgeable decision-maker, their procedures are kept confidentially and there is still no systematic procedure by experts that can help in evaluating the contractors' qualifications, current capabilities and method of work, in comparison with the specific conditions and requirements necessary for the specific project in hand.

It is often true that no dominant alternative contractor that is better than all other contractors in terms of all decision criteria will exist. Thus, the decision-maker is faced with a trade-off issue which requires a structured framework to enable the decision-maker in selecting the most appropriate tender with high confidence and, further, help in reducing the effort and time consumed in the evaluation process. In addition, the evaluation process depends to a great extent on (i) the level of experience, (ii) the effort made by the decision-maker and (iii) the quality of information, which may vary from one situation to another. Therefore, the decision-making process for identifying the most appropriate contractor/tender requires skill and expertise, along with a systematic and pre-defined selection procedure. Such a decision support system (DSS) to assist the decision-maker in identifying the most appropriate contractor for specific project is discussed in this paper.

PROPOSED CONTRACTOR EVALUATION METHOD

Bid price is an important factor in awarding a contract. However, other major factors greatly influence the success of a project, and hence such additional factors should be considered in evaluating and awarding a contract. The chosen contractor should have the specific capability to meet the unique project conditions and requirements, which cannot be generalised and quantified in the bid price only.

In order to identify these factors, an initial literature study was carried out and a questionnaire survey was developed which consisted of 127 decision factors for the evaluation of contractors grouped under five categories, namely (a) experience, (b) past performance, (c) financial stability, (d) current capabilities and (e) work strategy. This design of survey suggested by the authors based on their engineering background and experience and then the significant criteria can be identified on the basis of this survey results.

A total of 450 questionnaire forms were distributed among respondent groups in the construction industry, including consultants and experts in public-sector organizations in Egypt, Kuwait and the UK. Table 1 shows the number of experts contacted and their response rate using either using postal questionnaires or interviews during the application of the Delphi method. An average response rate of about 22% (Middle East 31% and UK 23%) was obtained. Experts during the survey added and deleted some of initial set of criteria, resulting in a total of 90 criteria adopted for the final analysis. All possible care was taken to maintain the accuracy and authenticity of the factors by selecting the best available experts in the construction industry. The results of this survey (Mahdi, 1999) constitute the basis of identifying the most important decision criteria included in the proposed contractor selection model.

		Posted Questionnaires		**Reply to the Questionnaires**		**Interviews**	
	Country	**Building**	**Heavy**	**Building**	**Heavy**	**Building**	**Heavy**
1st Round of the Delphi method	**Egypt**	110	70	45	32	-	-
	Kuwait	60	60	32	30		
	UK	80	70	23	15		
2nd Round of the Delphi method	**Egypt**					3	3
	Kuwait					3	7
	UK					-	-
3rd Round of the Delphi method	**Egypt**	-	-	-	-	1	-
	Kuwait	-	-	-	-	3	2
	UK	-	-	-	-	-	-

Table 1: Questionnaire Survey responses

The Delphi method, Dalkey *et al* (1970) was applied to determine the relative degrees of importance of the contractor criteria, based on the rating of the experts, using both questionnaires and interviews as follows:

1. Postal questionnaires were issued to each expert (450 questionnaires sent) and selected on the basis described in the literature review. The experts assessed each criterion in the questionnaire by assigning a value between one and five on a Likert scale (David and Ronald, 1987). These ranged from (1) very important, (2) important; (3) average, (4) low and (5) very low importance.
2. Statistical analysis was carried out to refine these criteria with the purpose of identifying the relevant criteria and their relative degrees of importance.
3. Structured interviews (16 interviews) with key experts were conducted in the first round of interviews, for the purposes described later in this section. The same forms of questionnaire were also used to organise these interviews.
4. Statistical analysis was carried out to refine the criteria, which resulted from the first round of interviews with the purpose of identifying the relevant criteria and their relative degrees of importance.
5. The refined criteria that resulted from the previous step (4) were given back to the key experts for reassessment and to assure the relevancy of the identified criteria. This step was the third round within the Delphi method. Interviews with 5 key experts in Kuwait and 1 key expert in Egypt were carried out in this step.
6. Statistical analysis was carried out to refine the criteria, which were the output of the previous step.
7. The criteria that resulted from the final statistical round were used directly in the AHP method, using their relative degrees of importance, Mahdi (1999).

The relevance of each decision criterion was statistically analysed using SPSS™ (1993). The results were provided to selected experts for re-evaluation until the change in the relative weights for the relevant decision criteria had no significance according to the concepts of the Delphi method.

Screening of the contractors (shortlist)

Project-specific factors and the requirements of the owner, along with the factors representing the qualifications of the contractors were first analysed simultaneously to identify the possible few contractors suited for the project.

Contractor qualification factors

The decision criteria thus derived were classified as follows.

Experience record

This group of criteria is represented in terms of (1) number of years working on similar projects and in construction generally, (2) total work volume on similar projects and in construction generally, (3) average work volume on similar projects and in construction generally, (4) working with different contract types (as indicator to the risk share willingness), (5) working in similar geographical conditions, and (6) working in similar weather conditions in similar projects

Past performance record

This group of criteria helps to assess how the contractor has met the defined objectives in (a) previous projects and, (b) in similar projects, in terms of (1) cost, (2) quality of work, (3) schedule, (4) safety, (5) client satisfaction, (6) relationship with subcontractors, (7) relationship with suppliers and (8) relationship with insurance companies.

Financial stability of the contractor

A bidder's financial longevity and his/her capacity to meet financial obligations, both short-term and long-term, as well as the financial reporting practices represented by: (1) contractor's credit level or payment record to his/her creditors, such as suppliers and subcontractors (2) quality of financial statements, (3) adequacy of banking arrangements, (4) liquidity ratio, (5) operations ratio, and (6) leverage ratio.

The purpose of ach criterion and its measurements are detailed in Mahdi (1999).

Project-specific conditions:

Various project-specific conditions were evaluated, namely (1) project budget (2) expected quality, (3) project complexity, (4) political factor, (5) project owner's willingness to share project risks, (6) project time schedule, (7) project unique features, (8) sensitivity of design change and (9) project owner's involvement in the management process.

A set of criteria is defined based on the above factors to shortlist the large number of contractors to a manageable number (for example 3 or 4 contractors). Finally, a short-list of contractors out of the total list of contractors (about 25%) is selected in this screening phase.

The relative degrees of importance for these project criteria were determined using the analytic hierarchy process (AHP) by the decision-maker on a project-by-project basis. The AHP is a theory of measurement concerned with deriving dominance priorities from paired comparisons of homogeneous elements with respect to a common criterion or attribute (Saaty, 1994). AHP may be thought of as a multi-attribute utility theory (MAUT) approach (Shtub, *et al,* 1994). It was introduced by Thomas Saaty (1980) to provide a simple multiple-criteria analytic method for evaluating alternative solutions (Goicoechea *et al.*, 1992). AHP helps in identifying priorities on the basis of the decision-maker's knowledge and experience of each problem. AHP takes into consideration judgements based on people's feeling and emotions as well as their thoughts (Saaty, 1994). The strength of AHP lies in its ability to structure a complex, multi-person, multi-criteria problem hierarchically and then to investigate each level separately, combining the results as the analysis progresses. The philosophy behind AHP described by Golden *et al* (1989) as *Analytical* by using numbers, *Hierarchical* by structuring the decision problem into levels, and *Process*-oriented because of its step-by-step approach.

Analytic hierarchy process applicability

Since its introduction in the mid-1970s, AHP has been applied to many types of decision problems. Applications can be found in such diverse fields as portfolio selection, transportation planning, manufacturing systems design, and artificial intelligence (Saaty, 1994). There are more than 150 published papers that use AHP to model diverse problems such as conflict analysis, urban planning and space exploration (Golden *et al,* 1989). The majority of these applications have introduced analytical solutions for the problems that involved both quantitative and qualitative criteria (Skibniewski and Chao, 1992), which is similar to the selection process that is the objective of this paper. One of the recent applications of AHP was carried out by Alhazmi and McCaffer (2000) in which a project procurement system selection model was developed.

Final contractor selection

The short-listed contractors are then evaluated for the final stage of selection in terms of their current capabilities and submitted plans and method statement against the specific project conditions.

Current capabilities

Assessment of a contractor's capabilities to perform the proposed project involves the assessment of (1) contractor capacity, (2) management ability / adaptability / co-ordination and (3) current resources / workloads.

Contractor work strategy

The adaptability of method statement and submitted plans by a contractor are assessed compared with the specific conditions of the proposed project based on factors such as (1) cash flow, (2) manpower schedule, (3) procurement schedule, (4) equipment schedule, (5) quality assurance and control plan, (6) safety plan, (7) organisational structure/qualifications of the staff and (8) type of work sub-contracted.

MODEL DEVELOPMENT

Several methods are available to evaluate the multiple criteria decision-making problem, which involves different objectives of varying importance to the decision-maker. Out of the several methods (ranking, rating, paired comparison, successive comparisons), paired comparison using AHP along with ratings using the Delphi method, is used in determining the importance of each factor. The criteria are evaluated to determine their relative degrees of importance.

The proposed selection method follows two appraisal processes, as discussed earlier namely (a) a screening process, and (b) a contractor selection process.

Screening Process

In the screening process, the predefined contractor criteria, namely (a) seven experience criteria (EC_i, $i = 1, 2... 7$), (b) sixteen past performance criteria (PPC_i, $i = 1, 2... 16$) and (c) six financial stability criteria (FSC_i, $i = 1, 2... 6$) are compared with nine project criteria (PC_j; $j = 1,2... 9$) for all available contractor alternatives (Ca_r; $r = 1, 2... k$; where r is the specific contractor, k is the total number of contractors) using AHP.

Based on this comparison, a short list of the most appropriate contractors is obtained to be in the final stage of the proposed contractor selection method.

The relative weight of EC_j, PPC_i, and FSC_i using the Delphi method (Equations 1a, 1b and 1c) is tabulated. Further, the project criteria "PC_j" are defined and compared to identify the alternative contractor "AC_r" rating.

Development of the evaluation (mathematical) model proceeds through the following steps:

Step 1: The weight vector of the criteria EC_{iw}, PPC_{iw}, and FSC_{iw} is derived on the basis of the Delphi method in the following form:

$$\begin{array}{l}\text{Contractor}\\ \text{Experience}\end{array} [EC_{iw}] = \left[\begin{array}{l}
\text{Experience in similar projects } (EC_{1w}) \\
\text{Total Work Volume in similar projects } (EC_{2w}) \\
\text{Average Work Volume – last 3 years } (EC_{3w}) \\
\text{Work Volume in similar project using Lump-Sum Contract – last 3 years } (EC_{4w}) \\
\text{Work Volume in similar project using Unit-Price Contract - last 3 years } (EC_{5w}) \\
\text{Work Volume in similar geographical conditions - last 3 years } (EC_{6w}) \\
\text{Work Volume in similar weather conditions - last 3 years } (EC_{7w})
\end{array}\right] \quad \text{Eq. 1a}$$

$$\begin{array}{l}\text{Contractor}\\ \text{Past performance}\end{array} [PPC_{iw}] = \left[\begin{array}{l}
\text{Cost Performance Level - last 3 year projects } (PPC_{1w}) \\
\text{Quality Performance Level - last 3 year projects } (PPC_{2w}) \\
\text{Schedule Performance Level - last 3 year projects } (PPC_{3w}) \\
\text{Safety Performance Level - last 3 year projects } (PPC_{4w}) \\
\text{Client Satisfaction Performance Level - last 3 year projects } (PPC_{5w}) \\
\text{Relationships with Sub-Contractors - last 3 year projects } (PPC_{6w}) \\
\text{Relationships with Suppliers - last 3 year projects } (PPC_{7w}) \\
\text{Relationships with Insurance Companies - last 3 year projects } (PPC_{8}) \\
\text{Cost Performance Level in similar projects - last 3 years } (PPC_{9w}) \\
\text{Quality Performance Level in similar projects - last 3 years } (PPC_{10w}) \\
\text{Schedule Performance Level in similar projects - last 3 years } (PPC_{11w}) \\
\text{Safety Performance Level in similar projects - last 3 years } (PPC_{12w}) \\
\text{Client Satisfaction Performance Level in similar projects - last 3 years } (PPC_{13w}) \\
\text{Relationships with Sub-Contractors in similar projects - last 3 years } (PPC_{14w}) \\
\text{Relationships with Suppliers in similar projects - last 3 years } (PPC_{15w}) \\
\text{Relationships with Insurance Companies in similar projects - last 3 years } (PPC_{16w})
\end{array}\right] \quad \text{.Eq. 1b}$$

$$\begin{array}{l}\text{Contractor}\\ \text{Financial Stability}\end{array} [FSC_{iw}] = \left[\begin{array}{l}
\text{Credit Level } (FSC_{1}) \\
\text{Auditors Assessment in last 3 years } (FSC_{2}) \\
\text{Adequacy of Banking Arrangements } (FSC_{3}) \\
\text{Liquidity Ratio } (FSC_{4}) \\
\text{Operations Ratio } (FSC_{5}) \\
\text{Leverage Ratio } (FSC_{6})
\end{array}\right] \quad \text{Eq. 1c}$$

Step 2: The weight vectors of the specific Project Criteria (PC_{jw}) are determined using the AHP method represented as follows:

i. A list of criteria is determined project-by-project by the decision-maker according to their relevancy to the specific project conditions. These criteria may be represented as follows:

Project Specific Criteria [PCiw] =

$$\begin{bmatrix} \text{Proposed project budget } (PC_1) \\ \text{Proposed project quality } (PC_2) \\ \text{Proposed Project Schedule } (PC_3) \\ \text{Project Complexity level } (PC_4) \\ \text{Political Influence of the project } (PC_5) \\ \text{Risk sharing level of client } (PC_6) \\ \text{Uniqueness of project } (PC_7) \\ \text{Design sensitivity of the project } (PC_8) \\ \text{Owner involvement in project management } (PC_9) \end{bmatrix}$$

ii. The decision-maker identifies the relative importance of project specific criteria PC_{jw} using the AHP method as follows:

$$PC_{jw} = \begin{array}{c} \\ PC1 \\ PC2 \\ . \\ . \\ PC9 \end{array} \begin{array}{c} \begin{array}{cccc} PC1 & PC2 & \cdots & PC9 \end{array} \\ \begin{bmatrix} 1 & PC12 & \cdots & PC19 \\ PC21 & 1 & \cdots & PC29 \\ . & & \cdots & . \\ . & . & \cdots & . \\ PC91 & PC92 & \cdots & 1 \end{bmatrix} \end{array} \quad \text{............................Eq. 2}$$

The weight vector of the PC_{jw} is derived from Eq. 2 on the basis of the AHP method as follows:

$$[PC_{Jw}] = \begin{bmatrix} PC1w \\ PC2w \\ . \\ . \\ PC9w \end{bmatrix} \quad \text{...Eq. 3}$$

Step 3: Assess the impact of each criterion PC_{jw} on EC_i, PPC_i and FSC_i to produce other vector matrices $[EC_{iw}]_{PC_{jw}}$, $[PPC_{iw}]_{PC_{jw}}$ and $[FSC_{iw}]_{PC_{jw}}$ as follows:

a. The relative weights of the contractor experience criteria EC_i are reassessed with respect to each specific project criterion PC_j by solving the matrices of Eq. 4.

i. The matrices $[EC_i]_{PC1}$, $[EC_i]_{PC2}$ ... $[EC_i]_{PC9}$ can then be defined as follows:

$$[EC_i]_{PC1} = \begin{array}{c} \\ EC1 \\ EC2 \\ . \\ . \\ EC7 \end{array} \begin{array}{c} \begin{array}{cccc} EC1 & EC2 & \dots & EC7 \end{array} \\ \begin{bmatrix} 1 & EC12 & \dots & EC17 \\ EC21 & 1 & \dots & EC27 \\ . & & \dots & . \\ . & . & \dots & . \\ EC71 & EC72 & \dots & 1 \end{bmatrix} \end{array}$$

.

................................Eq. 4

.

$$[EC_i]_{PC9} = \begin{array}{c} \\ EC1 \\ EC2 \\ . \\ . \\ EC7 \end{array} \begin{array}{c} \begin{array}{cccc} EC1 & EC2 & \dots & EC7 \end{array} \\ \begin{bmatrix} 1 & EC12 & \dots & EC17 \\ EC21 & 1 & \dots & EC27 \\ . & & \dots & . \\ . & . & \dots & . \\ EC71 & EC62 & \dots & 1 \end{bmatrix} \end{array}$$

ii. The weight vector matrices corresponding to the matrices of Eq. 4 as follows:

$$[EC_{iw}]_{PC1} = \begin{array}{c} PC1 \\ \begin{bmatrix} EC11w \\ EC21w \\ . \\ . \\ EC71w \end{bmatrix} \end{array}$$

.

....Eq. 5

.

$$
[EC_{iw}]_{PC9} = \begin{bmatrix} EC19w \\ EC29w \\ . \\ . \\ EC79w \end{bmatrix}
$$

iii. Each vector matrix of Equation 5 represents a column in the matrix of Equation 6 for all contractor experience criteria to identify their new relative weights.

$$
[EC_{iw}]_{PC9} = \begin{array}{c} \begin{matrix} PC1 & PC2 & \ldots & PC9 \end{matrix} \\ \begin{bmatrix} EC11w & EC12w & \ldots & EC19w \\ EC21w & EC22w & \ldots & EC29w \\ . & & \ldots & . \\ . & . & \ldots & . \\ EC71w & EC72w & \ldots & EC79w \end{bmatrix} \end{array} \qquad \text{.............................Eq. 6}
$$

Then the eigenvector Equation 6 is compared with the criteria of Equation 3 (PC_{jw}), to produce the new relative weight of EC_{iw} as shown in Equation 7a and similarly, the new relative weights of the criteria PPC_{iw} and FSCiw can be identified as shown in Equations 7b and 7c.

$$
[EC_{iw}]_{PC_j} = \begin{bmatrix} EC1w \\ EC2w \\ . \\ . \\ EC7w \end{bmatrix} \qquad \text{.. Eq. 7a}
$$

$$
[PPC_{iw}]_{PC_j} = \begin{bmatrix} PPC1w \\ PPC2w \\ . \\ . \\ PPC16w \end{bmatrix} \qquad \text{.. Eq. 7b}
$$

$$[FSC_{iw}]_{PC_j} = \begin{bmatrix} FSC1w \\ FSC2w \\ . \\ . \\ FSC6w \end{bmatrix} \qquad \text{Eq. 7c}$$

Step 4: alternative contractors (AC_r) are evaluated based on Equation 7 to obtain the relative weight for each contractor with respect to EC_{iw}, PPC_{iw} and FSC_{iw} as follows:

i. Paired comparison matrix between AC_r are carried out for each criterion of EC_{iw} to produce weight vector matrix $[AC_r]$:

$$[AC_{rw}]_{EC_i} = \begin{array}{c} \\ AC1 \\ AC2 \\ . \\ . \\ ACk \end{array} \begin{array}{c} \begin{array}{ccc} AC1 & AC2 & \quad ACk \end{array} \\ \begin{bmatrix} 1 & AC12 & \ldots & AC1k \\ AC21 & 1 & \ldots & AC2k \\ . & & \ldots & . \\ . & . & \ldots & . \\ ACk1 & ACk2 & \ldots & 1 \end{bmatrix} \end{array} \quad \text{(where i = 1, 2, ..., 7)}$$

ii. Weight vector matrices of the contractors with respect to each criterion of experience criteria EC_i are obtained based on the AHP method as follows:

$$EC1$$

$$[AC_W]_{EC_1} = \begin{bmatrix} AC11 \\ AC21 \\ . \\ . \\ ACk1 \end{bmatrix}$$

$$. \qquad \text{Eq. 8}$$

$$.$$

$$EC7$$

$$[AC_{rw}]_{EC_7} = \begin{bmatrix} AC17 \\ AC27 \\ . \\ . \\ ACk7 \end{bmatrix}$$

iii. Matrix $[AC_{rw}]$ of size 'k x 7' is obtained based on Equation 8.

$$[AC_{rw}]_{ECi} = \begin{array}{c} \\ \end{array}\begin{matrix} EC1 & EC2 & \dots & EC7 \end{matrix}$$

$$[AC_{rw}]_{ECi} = \begin{bmatrix} AC11w & AC12w & \dots & AC17w \\ AC21w & AC22w & \dots & AC27w \\ . & & \dots & . \\ . & . & \dots & . \\ ACk1w & ACk2w & \dots & ACk7w \end{bmatrix} \text{.......Eq. 9}$$

iv. Equation 9 is multiplied in the vector matrix of Equation 7a to obtain the ranking of the AC_{rw1} with respect to EC_{iw} as follows:

$[AC_{rw}]_{ECiw} = [AC_{rw}] \times [EC_{iw}]$..........Eq. 9a

In similar analytical method, the evaluation of alternative contractor with respect to past performance (PPCi) and financial stability (FSCi) criteria as represented in Equations 9b and 9c.

$[AC_{rw}]_{PPCiw} = [AC_{rw}] \times [PC_{iw}]$..........Eq. 9b

$[AC_{rw}]_{FSCiw} = [AC_{rw}] \times [FSC_{iw}]$..........Eq. 9c

Equations 9a, 9b and 9c are summed up to give the final relative weights for all the alternatives contractors $[AC_{rw1}]$ in the first stage of proposed method as follows:

$[AC_{rw1}] = [AC_{rw}]_{ECiw} + [AC_{rw}]_{PPCiw} + [AC_{rw}]_{FSCiw}$..........Eq. 10

Equation 10 will list the relative weights of each alternative contractor.

Selection process

According to their relative weights obtained from Equation 10, about 10% of the contractors are analysed in the second stage:

Two groups of the contractor criteria, namely four current capabilities criteria (CCC_i, i = 1, 2, ..., 4), and eight contractor work strategy criteria (WSC_i, i =1, 2, ..., 8) are compared with nine project criteria (PC_j; j = 1,2, …, 9) for all available contractor alternatives using AHP.

$$\text{Current Capabilities } [CCC_{iw}] = \begin{bmatrix} \text{Management Capability } [CCC_{1w}] \\ \text{Equipment Availability } [CCC_{2w}] \\ \text{Manpower Availability } [CCC_{3w}] \\ \text{Procurement Capability } [CCC_{4w}] \end{bmatrix}$$

$$\text{Contractor Work Strategy } [WSC_{iw}] = \begin{bmatrix} \text{Cash flow } [WSC_{1w}] \\ \text{Manpower Schedule } [WSC_{2w}] \\ \text{Procurement Schedule } [WSC_{3w}] \\ \text{Equipment Schedule } [WSC_{4w}] \\ \text{Quality Control and Assurance Plan } [WSC_{5w}] \\ \text{Safety Plan } [WSC_{6w}] \\ \text{Organizational Structure and Professional Qualifications of the Staff } [WSC_{7w}] \\ \text{Type of Work Subcontracted and its percentage } [WSC_{8w}] \end{bmatrix}$$

Step 5: The weight vectors of the criteria current capabilities criteria (CCCi) and work strategy criteria (WSCi) are reassessed with respect to each project criterion of PC_j in a similar procedure that is described above in ***Step 3*** Equation 4. Then new weight vectors of $[CCC_i]_{PCj}$ and $[WSC_i]_{PCj}$ are obtained in a similar procedure to that followed in Equations 5, 6 & 7.

$$[CCC_{iw}]_{PCj} = \begin{bmatrix} CCC1w \\ CCC2w \\ . \\ . \\ CCC4w \end{bmatrix} \quad \text{.........Eq. 11a}$$

$$[WSC_{iw}]_{PCj} = \begin{bmatrix} WSC1w \\ WSC2w \\ . \\ . \\ WSC8w \end{bmatrix} \qquad \text{..........Eq. 11b}$$

Step 6: A similar analytical procedure to *Step 4* is followed to evaluate the alternative contractors AC_r with respect to each criterion of Equation 11 and then the matrices $[AC_{rw}]_{CCC_i}$ and $[AC_{rw}]_{WSC_i}$ are established as follows:

$$[AC_w]_{CCC1} = \overset{\text{CCC1}}{\begin{bmatrix} AC11 \\ AC21 \\ . \\ . \\ ACk1 \end{bmatrix}}$$

.

. ...Eq. 12

.

$$[AC_{rw}]_{CCC_6} = \overset{\text{CCC4}}{\begin{bmatrix} AC14 \\ AC24 \\ . \\ . \\ ACk4 \end{bmatrix}}$$

Matrix $[AC_{rw}]$ of size 'k x 4' is obtained based on Equation 12.

$$[AC_{rw}]_{ECi} = \begin{array}{c} \begin{matrix} CCC1 & CCC2 & \dots & CCC4 \end{matrix} \\ \begin{bmatrix} AC11w & AC12w & \dots & AC14w \\ AC21w & AC22w & \dots & AC24w \\ . & & \dots & . \\ . & . & \dots & . \\ ACk1w & ACk2w & \dots & ACk4w \end{bmatrix} \end{array} \qquad \text{Eq. 13}$$

Then, the matrix $[AC_{rw}]$ is multiplied in the vector matrix of Equation 11a to obtain the ranking of the alternative contractors $[AC_{rw2}]$ with respect to CCC_{iw} as follows:

$$[AC_{rw2}]_{CCCiw} = [AC_{rw}]_{CCC_{iw}} \times [CCC_{iw}] \qquad \text{Eq. 14a}$$

In a similar analytical method, the evaluation of alternative contractors with respect to work strategy criteria (WSC_{iw}) as represented in Equation 14b.

$$[AC_{r2w}]_{WSCiw} = [AC_{rw}]_{WSCiw} \times [SC_{iw}] \qquad \text{Eq. 14b}$$

***Step** 7:* Equations 14a and 14b are summed up to give the relative weights of the alternative contractors out of the second selection process.

$$[AC_{rw2}] = [AC_{rw}]_{CCCiw} + [AC_{rw}]_{WSCiw} \qquad \text{Eq. 15}$$

Step 8: The summation of the relative weights of the top contractor out of Equation 10, from Process 1, and the relative weights resulting in Equation 15, Process 2 gives the final relative weights of alternative contractors as follows:

$$[AC_{rwf}] = [AC_{rw1}] + [AC_{rw2}] \qquad \text{Eq. 16}$$

Then, the most appropriate contractor is the one who gets the highest relative weight out of *Step 8.*

Implementation of the model

A computer-based Decision Support System (DSS) was developed for the implementation of the proposed method. The developed DSS helps the decision–maker to manage a large number of criteria, reduce the complexity of data handling and create a feedback system that can be utilised for the evaluation of future projects. The schematic of the proposed DSS is shown in Figure 1.

The contractor information (represented as a database in Paradox ™) along with the expertise modelled using the Delphi method and the results of AHP (Excel ™) proceed using an expert system shell (Level-5 Object ™ is selected as KBES). The KBES establishes the rules required to select the best contractor alternative.

A graphical user interface is developed to connect the various computing components, which facilitate the data input/output in a user-friendly manner.

Summary and Conclusion

A contract awarding process based on price alone should not be the sole basis of contractor selection; rather, a detailed analysis of all possible factors should be considered. This paper introduces a DSS which considers the specific conditions of a proposed project and the adaptability of current capabilities and qualifications of a contractor to perform the proposed project taking into account the project specific conditions. Such a DSS can reduce the limitation due to individual judgment and increase the fairness of decision-making. The use of a computer support system organises the proposed evaluation process and helps to make it less complex, less time consuming and therefore easy to use.

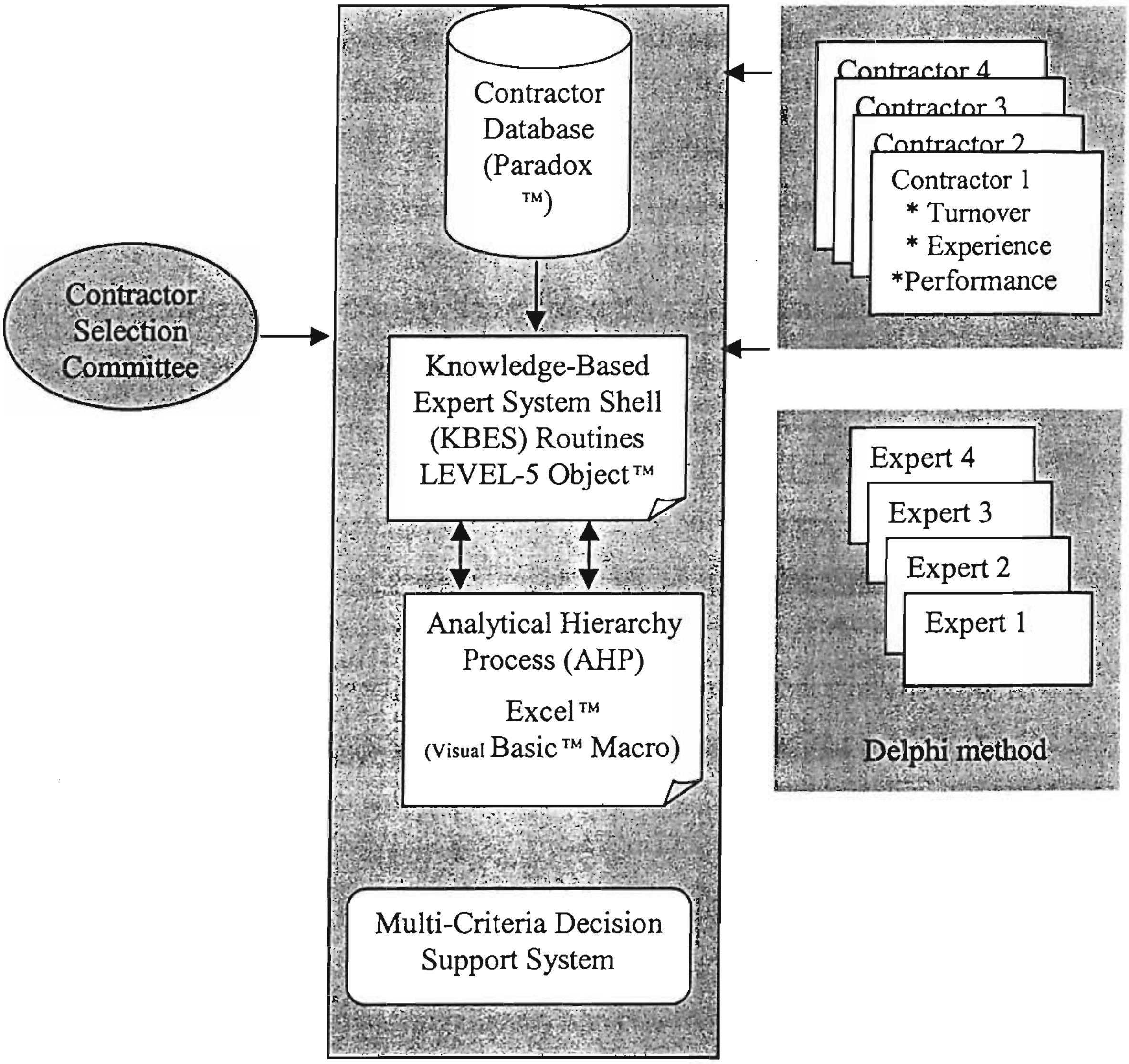

Figure 1 The proposed contractor selection system

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Comparison of Cultures in the Construction and Manufacturing Industries

M J Riley and D Clare-Brown

Abstract

This paper investigates and compares the culture found in a construction company with that found in two manufacturing companies since large differences in culture might reduce the potential for the construction sector to adopt management tools developed in the manufacturing sector. In order for the comparisons to be valid the culture within the physical production process was observed. The results were obtained by use of questionnaires and intensive interviews with individual members of staff using a UK government sponsored questionnaire. A vertical section of each company was sampled such that equivalent organisational levels could be directly compared. The main findings are that the culture existing in construction has significant differences to that found within the manufacturing industries. It will not be possible to transfer management tools from one industrial sector to the other without substantial redesign. The culture within construction was found to be *project culture* in comparison to manufacturing which was found to be *company culture*.

KEYWORDS: construction industry, manufacturing industry, management, culture, performance, innovation, communications.

Introduction

There is a worldwide drive to improve efficiency and reduce construction costs. Table 1 shows performance improvement targets that have been set within the UK and the USA. Many other countries have likewise set their own targets. The targets for the USA come from a construction industry workshop report (Wright et al 1995) and the UK targets come from a Government drive to reduce infrastructure costs. These UK targets developed from the Latham Report (1994) and the Egan Report (1998); these were UK Government sponsored "big picture" investigations into the efficiency of the

UK construction industry. The UK Government Departments have established organisations to support industry in achieving these targets – details of one such organisation is available at web site www.m4i.org.uk . The targets set are demanding but achievable as reported by Brown & Riley (1998). However the targets set will not be achieved by simply forcing contractors to reduce prices even lower than they are at present, with their existing tight profit margins. The only way to achieve targets of this magnitude is to achieve a step change in project delivery. By step change we mean that the whole process used to deliver a project to the client undergoes a complete and significant change and, importantly, that the client plays a significant role to drive the changes through the whole supply chain. Such a step change will not be possible without a major change in culture within the companies involved in the project and as the Royal Academy of Engineering (1996) states, "It is clear that the challenge of changing the culture in the construction industry ....is daunting".

Performance Metric	**USA Government**		**UK Government /EPSRC**
	Target	Rank	
Total Project Delivery Time	Reduce by 50%	First	Reduce by25%
Lifetime Cost (Operation Maintenance Energy)	Reduce by 50%	Second	
Productivity and Comfort Levels of Occupants	Increase by 50%	Fifth =	Improve by 20%
Occupant Health and Safety Costs	Reduce by 50	Sixth	
Waste and Pollution Costs	Reduce by 50%	Fifth =	
Durability and Flexibility in Use Over Lifetime	Increase by 50%	Third	
Construction Worker Health and Safety Costs	Reduce by 50%	Fourth	
Costs			Reduce by 30%
Construction Quality			Zero Defects

Table 1. Construction Sector Performance Improvement Targets for the USA and UK
USA source: Wright Rosenfield Fowell, UK source: Engineering and Physical Science Research Council's Innovative Manufacturing Initiative Program
Blank spaces indicate no target for that metric

It is important for all companies to create nurture and manage a culture that is appropriate to their ambitions and business environment and construction companies have two aspects to consider. The first aspect is the culture exhibited within the company as an independent organisation and referred to as *company* culture. The second aspect is the culture exhibited by the company acting in its role as part of the construction project and referred to as *project* culture.

An important task for any construction project manager is to ensure that the optimum *project* culture is developed. However before this can be achieved a clear understanding of one's own company culture must be achieved.

A difference in culture between the construction and manufacturing industries might be expected since there are significant differences in their business environment. These differences include the geographically distributed nature of construction, the dynamic nature of site management, the highly mobile and itinerant work force and the large number of companies and organisations that have to work together in the project. Perhaps the most significant difference is the time scale involved; a construction project has a fixed duration lasting, for a typical UK civil engineering project, about two years whereas manufacturing provides a long term stable environment.

The traditional UK construction industry is also typified by conflict and an adversarial attitude between all the parties to the project whereas this is less common in manufacturing. These problems and proposed solutions are discussed in the author's book "Working Together – Tools for an Integrated Construction Supply Chain" (1999).

LESSONS FROM THE MANUFACTURING INDUSTRY

In order to achieve the improvement targets set in Table 1 the construction industry is urged to use the engineering management tools developed by the manufacturing industry. For example, the Royal Academy of Engineering states:

> *The Construction Industry would benefit significantly from the study and adoption of best practices from manufacturing and other industries. Elements are identified which could lead to early advantage: they include better supply chain management and considerable improvements in culture and organisation.*

However, manufacturing practices can only be transferred to construction if there is no significant difference in culture between the two sectors. A large difference in culture is likely to make this transfer difficult. An understanding of any differences will allow the redesign of manufacturing practices before their transfer to construction. Any major differences might, indeed, prevent the transfer of such practices.

The objective of this paper is to identify the culture that exists in both manufacturing and construction in order to assess the viability of transferring "best practice" engineering management tools from manufacturing to construction.

CULTURE - A BACKGROUND

Culture is used to describe the collection of "soft" management and behavioural variables that form the psyche of the business organisation. In order to manage and influence culture it is necessary to first define and then develop a conceptual model of what culture is; however, it is typical of many soft issues that there does not exist a single accepted definition or model of culture. This is illustrated by the fact that Kroeber and Kluckholn (1952) identified 164 definitions of culture and that, almost four decades later, Ott (1989) still found that no clear definition had been developed, finding seventy three words or phrases used to define culture from fifty eight publications. With this difficulty of definition it is essential to know something of the history of culture in order to understand and manage it.

Bowers (1969) highlighted five variables that composed culture and highlighted communication as being the most significant. Harrison (1972) proposed a model consisting of four basic variables. Lundberg (1990) suggested six basic ingredients as representing culture. Maloney (1989, 1991) defined culture as "the set of assumptions shared by members of the organisation about the desired and appropriate behaviours, including how these assumptions are reinforced and how they are communicated to members, old and new" and suggested that the business environment has perhaps the largest influence on culture. This would mean, for example, that a company working in a high technology area should place greater importance on research, new product and process development and innovative problem solving.

Drennan (1992) defined culture as meaning "how things are done around here" but again this simple phrase hides the fact that culture is built up from many factors and is influenced by a range of variables that change over time. Culture develops through the normal and traditional methods by which things are done. The acceptable standards are established and become the norm. It is rooted in history, collectively held and sufficiently complex to resist attempts at direct manipulation. Drennan suggests that it is the company's internal environment that has the most influence on employee attitude and not the external environment such as rising unemployment or global competition.

It is important to understand that there is no ideal organisational culture able to guarantee success for the company because every company is unique (Gorman, 1989). The appropriate culture for an organisation depends on many factors, including the age of the organisation, market, geographical location, history and even the preferences of the chief executive and top management. There is a temptation for any particular company to simply implement management approaches from other successful companies in order to change attitudes to culture but this is naive and dangerous and quite likely to create negative results (Brown and Riley, 1999).

An overall view of culture is provided by research from the National Economic Development Office (1990), (NEDO) which defined culture as the amalgam of aspirations, attitudes and values shared by the employees. Although there is no single best culture that will guarantee a successful company, NEDO found that, regardless of company size, the cultures of all successful companies shared a similar philosophy with similar characteristics. In the NEDO research "success" was measured in terms of the company being able to achieve the objectives of the company owners; this usually focused on profit but often included growth, reducing company risk, commitment to employees and improving product range. The cultures of all these companies were found to have the following characteristics (NEDO):

- Strong and identifiable.
- Embodies a clear mission statement, which encourages commitment and co-operation across functions.
- Encourages the acceptance of change and new ideas - especially from outside and hence avoids the problem of "not invented here".
- Engenders continuous striving for improvement and positively discourages complacency.
- Dictates that customer considerations pervade all activities.
- Ensures that targets are set through consultation with those responsible for their achievement.
- Links rewards to company performance and personal achievement.
- Generates enthusiasm and dedication.

The NEDO model of culture has been used to enable the comparison of the different cultures between companies. The NEDO model of culture has also been used as the basis for a detailed questionnaire to help companies assess their own culture and this questionnaire, described later, has been used for this research.

Research Method

1. The culture of a construction company was analysed and compared with the culture of two manufacturing companies. These companies were selected to be of equivalent scale in terms of, for example, revenue, number of employees, volume of international trade.
2. Two manufacturing companies were selected to represent the manufacturing industry. Their results are used as benchmarks for similar observations of the culture within a construction company. One manufacturing company was an automobile manufacturer and the second was the producer of a brand name beverage. The construction company selected was a civil engineering contractor. Since the "manufacturing" phase of a construction project is carried out on site, it was felt that observing a construction site would be more appropriate than observing head office. The equivalent "manufacturing" phase in the manufacturing companies was one of their production lines.
3. The culture within each of these three companies was investigated using an industry standard questionnaire.
4. Interviews were also conducted following the return of the questionnaires in order to carry out a quality control check on the their accuracy.
5. Each company was defined by observing employees within the same equivalent *vertical section* of the company's organisational structure. This included the appropriate director, middle management and the operators and unskilled workers.
6. The perceptions of culture observed in each of the three companies' vertical sections were compared.
7. The results across the three companies were determined, analysed and discussed.

DESCRIPTION OF THE THREE COMPANIES

The Construction Company

The construction company is the civil engineering contracting arm of a UK international construction group, established over sixty years ago and having a group revenue in excess of £700million. The company is responsible for more than half of the group's revenue. Other companies within the group are responsible for residential building and mineral mining operations.

The company has a management philosophy which aims to maintain and reinforce the company's culture and to guide and support the behaviour of all employees. Their mission statement emphasises the primary concern for customer satisfaction and the importance of employee development and training to ensure high levels of quality and safety in all aspects of their work.

The research was based on a major road contract in Southern England. The contract value was over £25 million and involved the construction of approximately 5 kilometres of new road plus side roads and structures and with a contract period of 140 weeks. The traditional strategy of design-bid-build was used. There were 30 full time staff controlling over 60 sub-contractors. The most senior manager working full time on the contract was the site agent who reported to a contracts manager/regional director whose role was to co-ordinate several sites and report to the managing director of the company. The site agent had a successful record of managing similar highway projects. Sub-contractors were managed in two different ways. Many of the sub-contractors were under the direct day to day control of the main contractor (effectively their employees) and these were included in the survey. Other sub-contractors managed themselves, working independently from the main contractor with minimal interaction to achieve a set task; these were not included in the survey since they were effectively part of the supply chain.

The Production Manufacturing Company

The production manufacturing company selected was an automobile manufacturing plant that is part of a global group. The group has been responsible for original and fundamental work in improving production manufacturing methods.

The plant manufactures a single vehicle type. The group has another manufacturing plant in Europe producing the same vehicle type. Thus, the plant observed had direct competition from both within the group and from other manufacturers world-wide. Components were sourced from both inside and outside of the UK. The UK division employs some 50,000 people and a turnover in excess of £600million.

Management has been passed to plant level but subject to the wider group decisions. The group has a long established practice of developing its management by moving staff to different plants throughout Europe and the world.

The research focused on the production line within the plant.

The Process Manufacturing Company

The parent group of the process manufacturing company was established over 200 years ago and produces, in over 40 countries worldwide, a range of specialised beverages for human pleasure/delectation which are sold in over 130 countries. It has built up a strong portfolio of brand names. The company observed is a speciality UK division responsible for a particular brand of beverage. The UK division had a turnover in excess of £300million and employs some 1500 people mainly on two sites.

The group has a stated commitment to become a world leader through a company environment based upon:

- an innovative approach to business and intelligent risk taking
- a distinctive competitive edge on quality and customer service in all areas of the business
- empowering employees to contribute fully to, and benefit from, the continuing success of the company
- a determination to set the standards for the industry

The company operates three eight hour shifts with each shift supported by shift fitters and shift electricians provided from a different division within the company.

The research was based on the production line of one particular beverage.

Questionnaire Design

To make direct comparisons same questionnaire was used by all three companies.

An existing industry standard questionnaire was used to ensure that results could be compared over time and across different industries. This questionnaire was the "Innovation Management Tool Kit Questionnaire" prepared by the UK government sponsored National Economic Development Office (NEDO). The NEDO questionnaire asks employees, at all levels, their views on culture and these are assessed against the NEDO responses to that question. The NEDO response is based on the their research into the culture associated with successful companies. The scores for all the questions are used to build up a picture of culture within the company. This approach is somewhat prescriptive but has the advantage of being reproducible. The full NEDO questionnaire is extensive and limited space precludes its inclusion here but copies of the questionnaire can be obtained from NEDO and a copy appears in Riley (1998) which is available at the web address attached to the references.

The NEDO questionnaire investigates ten key areas that were identified as defining the culture of a business and are:

1. Company values: measures the attitudes, aspirations and values of the company as shared by employees; measures the understanding for what the core business is and the uniqueness of the company's business from the employees point of view.
2. Employees: measures the selection, motivation, training and performance/rewards aspects.
3. Internal communications: measures the effectiveness and style of company internal communications
4. Structure: measures levels of responsibility, areas of activity and their inter-dependencies within the organisational structure of the company.
5. Customers: measures customer relations and how, and at what level, this is monitored.
6. Finance: measures the responsibility and control that employees have over both internal and external financial aspects and the relationship with investors.
7. Suppliers: measures the input of new ideas and management processes from suppliers and the supply chain.

8. Competitors: measures the understanding that each level in the organisation has regarding competitors since it is essential that they are known and managed.
9. Technology: measures employees' understanding of technology support and management.
10. New products and processes: measures the generation of new ideas and products and how employees contribute.

The score for each of these areas is expressed as a percentage of the actual score against the NEDO score and this is used as the measure of that aspect of culture. A higher percentage score indicates that the company score is closer to that obtained from the NEDO work and indicates that the company culture has more of the characteristics usually found in successful companies.

DESIGN OF VERTICAL SECTION THROUGH THE ORGANISATIONAL STRUCTURE

The design of the "vertical section" through the company organisational structure is critical if a true comparison in the variation of culture between the companies is to be achieved. It is important to compare the culture between equivalent occupational levels. The occupational levels are defined from Level I (director level) to Level VII (unskilled labourer level) with the various supervisory and management levels located within this scale by using the following five categories, based on a work profiling approach:

1. The number of reporting steps to the head of the UK organisation; defined as a number 0, 1, 2, 3 etc.
2. The financial impact of their performance are defined and scored as 1 (extreme), 2 (very substantial), 3 (substantial), 4 (large), 5 (moderate), 6 (small), 7 (none).
3. Their responsibility for resources are defined and scored as 1 (overall), 2 (very substantial), 3 (substantial), 4 (large), 5 (moderate), 5 (small), 6 (none).
4. Their responsibility for personnel are defined and scored as 1 (overall), 2 (very substantial), 3 (substantial), 4 (large), 5 (moderate), 6 (small), 7 (none).
5. The time span for job errors to take effect are defined and scored as 1 (annually), 2 (monthly), 3 (weekly), 4 (daily), 5 (immediate).

A senior member within each company was asked to assess each of their employees under each of the above categories in order to place them within the vertical section of their organisation thus allowing comparison between companies. The results are shown in Table 2.

The number of questionnaire respondents related to the occupational levels is as follows.

Construction Company: all site staff and at least three staff from each of the relevant sub-contractors responded. At level one, one response; at level two, one response, at level three, three responses; at level four, nine responses; at level five 25 responses; at level six and seven, over 120 responses from sub-contractors.

Production Manufacturing Company: all staff from one shift responded. At level one, one response; at level two, one response, at level three, three responses; at level four, no staff at this level; at level five seven responses; at level six and seven, over 100 responses.

Process Manufacturing Company: all staff from all the shifts responded. At each shift there is at level one, one response; at level two, one response, at level three, one responses; at level four, one response; at level five three responses; at level six and seven, over 30 responses. No difference was observed between shifts.

RESULTS OF THE SURVEY

Table 3 presents the overall results of the NEDO questionnaire for each occupational level within each of the companies and for each of the ten NEDO culture areas. The combined results of the process and production manufacturing companies are used, for this paper, as bench marks for the generic manufacturing industries and referred to in this paper as *manufacturing*. It is interesting to note how close their scores are, even though they represent quite different industries; it is accepted that, with a sample of just two companies, they cannot be seen as representing the whole of manufacturing.

Table 4 shows the analysis of the variance of the scores of Table 3 with companies analysed in pairs and the F and P values calculated. Areas of significant differences between companies are highlighted in the table with a star adjacent its P value. The F test calculates the variance ratio, F, that allows a judgement to be made as to whether the sample variances of two sets of data belong to the same sample; in other words it helps to assess whether the different companies responses to the NEDO questionnaire are the same or different and hence whether they have the same culture or not. The P value or p level of the test indicates the significant level at which the F test hypothesis would have to be rejected.

Figures 1, 2, and 3 show the mean score for each culture area related to the occupational Levels I to VII for each company.

DISCUSSION OF RESULTS

Cultural Profile for the Construction Company

The construction company scores are shown in Table 3 and Figure 1. There appears to be a greater variability in the quality of perceptions of culture than those for the manufacturing companies. The scores for each occupational level shown in Figure 1 shows no common trend; this demonstrates poor shared perceptions between occupational levels. The view that trade workers should not be expected to understand or worry about these business aspects is clearly no longer relevant. This view is based on the lack of communication on business aspects between different levels that should be known across all employees. It is particularly important that all levels understand the importance of customers. The increased use of sub-contractors makes the situation more difficult for construction since the higher levels are likely to be employees of the main or prime contractor whereas the lower levels are likely to be employees of sub-contractors rather than the main contractors. This makes the project manager's role of managing the culture of the whole project very difficult, but it is important to be aware of the differences in culture, aspirations and objectives of the sub-contractors.

Cultural Profile for the Production Manufacturing Company

The production manufacturing company scores are shown in Table 3 and Figure 2. The culture scores of each occupational level tend to move together demonstrating shared perceptions between occupational levels. The higher levels of management have a greater awareness of competitors, suppliers and, to a lesser degree, finance.

Cultural Profile for the Process Manufacturing Company

The process manufacturing company scores are shown in Table 3 and Figure 3. The culture scores of each occupational level tend to move together demonstrating shared perceptions between occupational levels. The higher levels of management have a greater awareness of competitors, suppliers, and, to a lesser degree, finance. Generally, most employees understood that they were part of a worldwide business with strong interdependencies but were proud of and loyal to their own company.

Comparison Between Industries

The comparison of the culture scores is shown in Table 4 and supported by Figures 1, 2 and 3. The following points arise from their inspection.

1. A comparison of the production manufacturing company and the process manufacturing company results show no statistically significant difference in their results and justifies the amalgamation of the two sets of results into one combined set representing the whole manufacturing sector and referred to as manufacturing. This supports the idea that culture within the manufacturing sector is similar and that the management tools within this sector can rely on this.

2. A comparison between the construction company and the process manufacturing company found four of the ten NEDO areas to be significantly different:

- Culture: The culture was more clearly defined in the process company and contained more innovative values
- Communications: The construction company had significantly better communications than the manufacturing companies
- Technology: The process company was more technically innovative than the construction company
- New Products and Processes: The process company showed greater awareness of the possibilities and potentials.

3. A comparison between the construction company and the production manufacturing company found five of the ten NEDO areas to be significantly different. These were the four found in the above section together with the structural area.

Comparison between Occupational Levels

The scores of each occupational level, from Figures 1,2, and 3 can be compared based on the NEDO areas.

- Culture: The culture of both manufacturing companies was significantly more clearly defined than construction. All their staff were conscious of their company's strategies and felt strong team spirit in spite of the difficult economic situation. Many of the personnel on the construction site knew nothing of the company's management philosophy; this was a disappointment to the project manager.

- Employees: The construction company scored lower than both manufacturing companies although the variances showed no significant statistical difference. However, individual responses did show significant differences in some key areas, particularly in the way that employees regarded the reward system. As an example, the question "I receive a bonus based on the company's performance" received a positive response from 3% of production engineering, 15% of construction and 91% of the process manufacturer; this bonus was not part of the normal remuneration package for each worker.

- Internal Communications: Many of the hourly paid staff at the production manufacturing company felt that they did not have sufficient opportunity to state their opinion and this led to a feeling that many of their concerns were not being addressed and created an unsatisfactory situation. The situation in construction is significantly better.

- Structure: Both manufacturing companies had a flatter organisational structure than that existing in construction and the structure on a major construction site is not obvious, particularly to sub-contractors new to the site.

- Customers: All three companies scored similar profiles. The construction company had an erratic set of results probably due to the large number of sub-contractors. Some sub-contractors often have no clear idea of who the real client is and even less knowledge of the client's attitudes and aims for the project.

- Finance: There were no significant differences between companies with all scores being low.

- Suppliers: There were no significant differences between companies with all scores being low. The slightly higher scores for construction probably reflects the situation on site which relies on greater interaction with suppliers and sub-contractors; greater support from their suppliers in terms of new product information and quality control is expected.

- Competitors: The culture of all three companies is highly competitive and it is interesting to note the heightened understanding and attitude to competition at the lower levels in construction. This is probably reflects the focus on "least cost" selection processes found on most construction sites.

- Technology: The results for manufacturing are similar with lower results for construction.

- New products and processes: The results for manufacturing are similar with lower results for construction.

SUMMARY AND CONCLUSIONS

Each of the companies chosen were considered as "blue chip" representatives of their respective industries. Each has its established management system to support continuous improvement; none had recently carried out any significant change program. As such it is felt that they may be considered as good representatives of their respective industries and therefore the results are believed to be typical and acceptable.

There were significant differences between the construction and manufacturing companies in 4, perhaps 5, cultural characteristics (40%-50%) in the cultural profile. This infers that the transfer of management ideas and methods directly from manufacturing to construction is not likely to be successful unless considerable effort is taken to modify these management tools or the culture in the construction industry. Modification of existing manufacturing management tools will require a change in vocabulary and context.

The organisational structure on a construction site usually includes a large percentage of subcontract staff. For this reason the main contractor will have to rely on a larger and deeper company hierarchy to reinforce company culture, corporate memory and management.

A typical construction company appears to have two cultural identities; the corporate or "head office" based culture and a distinctive, separate, project culture associated with each unique construction project. Each sub-contractor on site will have its own unique culture which will be different to the prime contractors culture. These cultures have to be brought together to create a single unifying project culture to improve working relationships. Management tools have to be developed to achieve this; for example, one way of achieving this is by implementing an "induction" process to help the integration of new operatives and sub-contractors into the project's culture when they arrive on site; a second example would be the use of partnering tools.

In comparison, the manufacturing industry appears to have only a corporate or company based culture.

The majority of respondents were very interested in the research programme and were appreciative of the interest being shown in their views about their company. This highlights the importance of communication between all levels. Communication helps employees feel they contribute and are empowered. This leads to increased efficiency and reduced costs.

Although there were differences, the culture profiles of the two manufacturing companies did, essentially, agree with each other. This suggests that these culture profiles are reasonably typical of the manufacturing industry as a whole and can be used as a bench mark for other companies and industries.

The results from the construction company profile indicate that the shared values are quite different compared with the manufacturing companies.

In construction the soft issues and the beneficial effect of managing the soft issues are less understood.

Many of the hourly paid staff at the production manufacturing company felt that they did not have sufficient opportunity to state their opinions and this led to a feeling that many of their concerns were not being addressed; this was not felt by management to reflect reality. Management stated that staff are the most important asset and has set up systems such as a "suggestions box" (with reward system) and company newspapers etc to ensure good communication. It appears that company newspapers are viewed as one way from management and that suggestion boxes are not a seen as an effective communication to management. It is likely that the hourly paid employees are referring to daily, work related communication rather than management's more strategically based "big picture" communication when they talk about communication.

The results show the construction industry being less innovative than the manufacturing industry. This may not be a true reflection of reality since the nature of a construction site is one of continually producing new solutions to unique site production situations. This sort of innovative thinking may be taken for granted by site staff and not thought of as being anything special and hence not scored as such. The role of innovation needs further research.

From the scores it appears that the culture or the cultural profile of an organisation evolves in part (if not mostly) as a consequence of productivity improvements accomplished rather than changed to accept productivity improvements. It is therefore possible that many strategies could be developed that would facilitate more rapid productivity improvements by consciously attempting to simultaneously "shape" the cultural profile.

This research has highlighted some of the areas of dissatisfaction and also areas of potential benefit by managing culture. A greater understanding and appreciation of cultural issues should be encouraged in the construction industry to achieve increased benefit and value for the client.

There is a problem on construction sites of developing an integrated project culture due particularly to the use of large numbers of sub-contractors. Fortunately the increased communication that takes place, as of necessity, with sub-contractors helps to co-ordinate cultural interactions. This increased communication follows from the use of contractual documents and the formal planning and management required to control sub-contractors in this relationship.

The need to manage the rather random nature of sub-contractor culture has been subconsciously known by project management staff in that the same sub-contractors are used on several projects if at all possible. The improved relationships that are being created naturally leads to the increased use of supply chain management tools and an increased use of partnering ways of working.

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Occupational Class	I	II	III	IV	V	VI	VII
Title in: **Production Comp** **Process Comp** **Construction Comp**	Plant Manager Production Director Contracts Manager	Production Manager Head Brewer Site Agent	Superintendent Production Manager Sub Agent & Works Manager	Not used Ass Prod Manager Senior Engineer & Section Foremen	Supervisor Supervisor Site Engineer/ Foremen	Group Leader Tradesman Tradesman	Operative Operative Labourer/ Operatives
Number of steps to report to head of UK organisation	1 1 1	2 2 2	3 3 3	 4 4	4 5 5	5 6 6	6 6 6
Financial impact of performance	Extreme = 1 Extreme = 1 Extreme = 1	V. Substantial = 2 Substantial = 3 V. substantial = 2	Substantial = 3 Substantial = 3 Substantial = 3	 Large = 4 Large = 4	Large = 4 Moderate = 5 Moderate = 5	Small = 6 Large = 4 Large = 4	Small = 6 Small = 6 Small = 6
Responsibility for resources	V. Substantial = 2 V. Substantial = 2 V. Substantial = 2	Substantial = 3 Large = 4 Substantial = 3	Large = 4 Large = 4 Large = 4	 Moderate = 5 Moderate = 5	Moderate = 5 Moderate = 5 Moderate = 5	Small = 6 Small = 6 Small = 6	Small = 6 Small = 6 Small = 6
Responsibility for personnel	Overall = 1 Overall = 1 Overall = 1	V. Substantial = 2 Substantial = 3 V. substantial = 2	Substantial = 3 Substantial = 3 Substantial = 3	 Large = 4 Substantial = 3	Large = 4 Large = 4 Moderate = 5	Small = 6 Small = 6 Small = 6	Small = 6 Small = 6 Small = 6
Time span for job errors to take effect	Annually = 1 Annually = 1 Annually = 1	Monthly = 2 Annually = 1 Monthly = 2	Monthly = 2 Monthly = 2 Monthly = 2	 Monthly = 2 Weekly = 3	Daily = 4 Weekly = 3 Weekly = 3	Immediate = 5 Daily = 4 Daily = 4	Immediate = 5 Daily = 4 Daily = 4
TOTAL SCORE	**6** **6** **6**	**11** **13** **11**	**15** **15** **15**	 **19** **19**	**21** **22** **23**	**28** **26** **26**	**29** **28** **28**

Table 2 Showing Definition of Occupational Level: the Scores and Criteria

INDUSTRY SECTOR	CULTURE	EMPLOYEES	INTERNAL COMMUNIC-ATIONS	STRUCTURE	CUSTOMERS	FINANCE	SUPPLIERS	COMPETITORS	TECHNOLOGY	NEW PRODUCTS AND PROCESSES
CONSTRUCTION										
Mean	53.33	52.33	61.89	57.41	64.64	51.57	59.86	64.57	46.64	40.86
Standard Deviation	12.01	14.97	13.62	16.42	18.24	15.32	10.05	11.59	18.15	10.65
PRODUCTION MAN										
Mean	60.79	57.76	47.85	68.15	64.76	45.36	52.67	73.85	65.76	67.21
Standard Deviation	14.04	15.23	19.02	18.33	22.10	29.99	19.83	18.22	18.78	17.22
PROCESS MAN										
Mean	62.32	62.41	48.82	60.77	61.14	41.09	54.50	72.86	62.27	61.50
Standard Deviation	17.05	17.57	19.78	20.36	18.98	29.89	18.39	17.40	17.37	22.00
MANUFACTURING INDUSTRY										
Mean	61.40	59.62	48.24	65.20	63.31	43.65	53.40	73.45	64.36	64.93
Standard Deviation	15.18	13.21	19.15	19.33	20.80	29.75	19.12	17.74	18.14	19.28

Table 3 NEDO Questionnaire Results: Mean and Standard Deviation for each Company and generic Manufacturing Industry

INDUSTRY SECTORS	CULTURE	EMPLOYEES	INTERNAL COMMUNIC-ATIONS	STRUCTURE	CUSTOMERS	FINANCE	SUPPLIERS	COMPETITORS	TECHNOLOGY	NEW PRODUCTS AND PROCESSES
PRODUCTION v CONSTRUCTION **F value** **P value**	4.76 0.033 *	1.60 0.211	10.36 0.002 *	5.60 0.021 *	0 0.986	0.54 0.458	1.65 0.206	3.08 0.086	10.36 0.002 *	28.04 0 *
PROCESS MAN v CONSTRUCTION **F value** **P value**	4.67 0.036 *	3.89 0.055	7.47 0.009 *	0.41 0.525	0.30 0.587	1.47 0.234	0.99 0.326	2.47 0.125	6.69 0.014 *	10.65 0.003 *
MANUFACTURING SECTOR v CONSTRUCTION **F value** **P value**	5.82 0.018 *	3.40 0.069	10.97 0.001 *	3.24 0.074 *	0.05 0.827	0.92 0.34	1.48 0.228	3.15 0.081	10.64 0.002 *	20.10 0 *
PRODUCTION v PROCESS MAN **F value** **P value**	0.13 0.713	1.09 0.301	0.03 0.856	1.96 0.168	0.40 0.532	0.27 0.606	0.12 0.731	0.04 0.842	0.48 0.49	1.16 0.286

Table 4 Results of the Analysis of Variance of Industries Compared

Figure 1 Construction Company Project Site Team Mean Scores

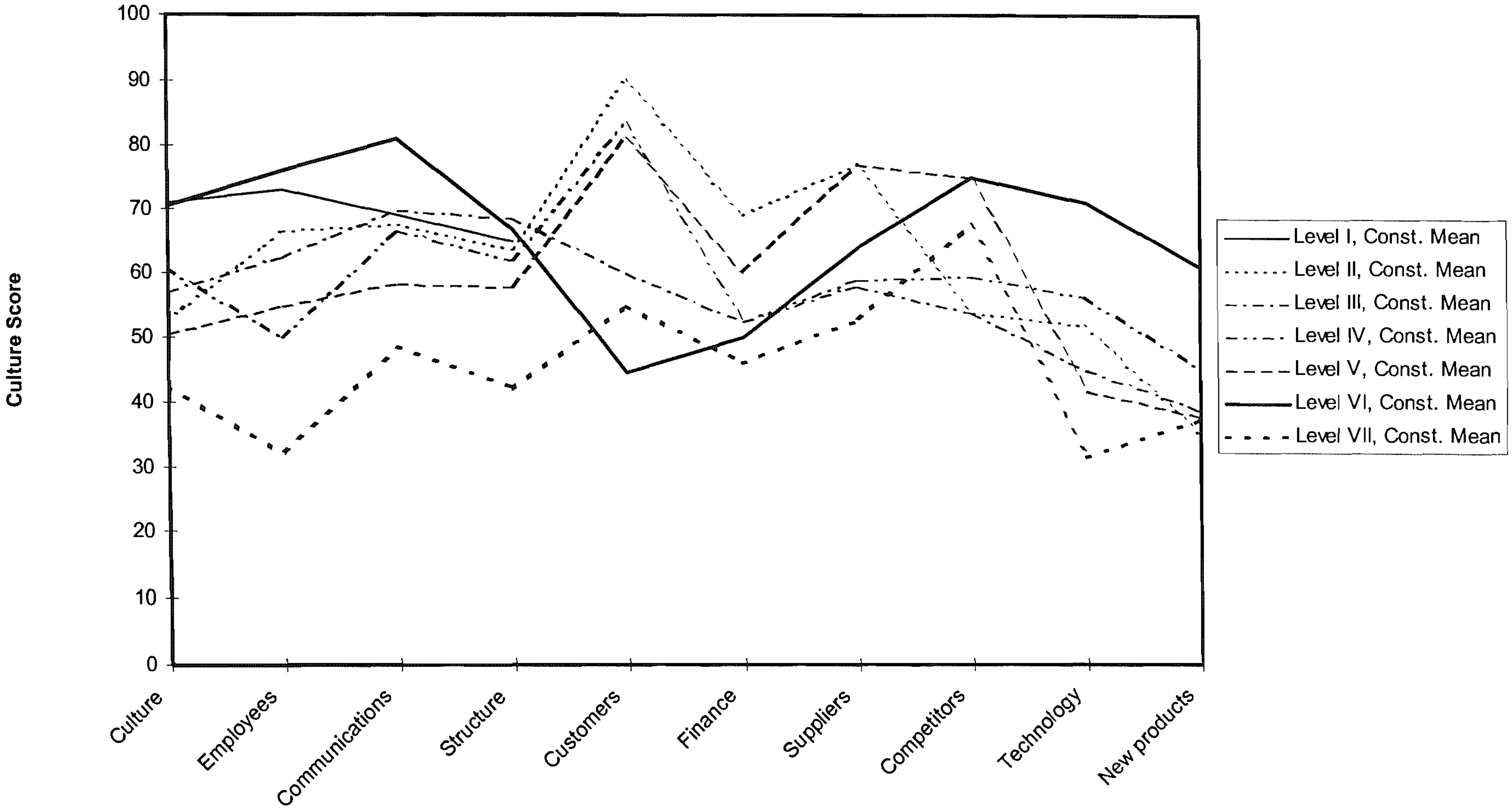


Figure 2 Production Manufacturing Company Mean Culture Scores

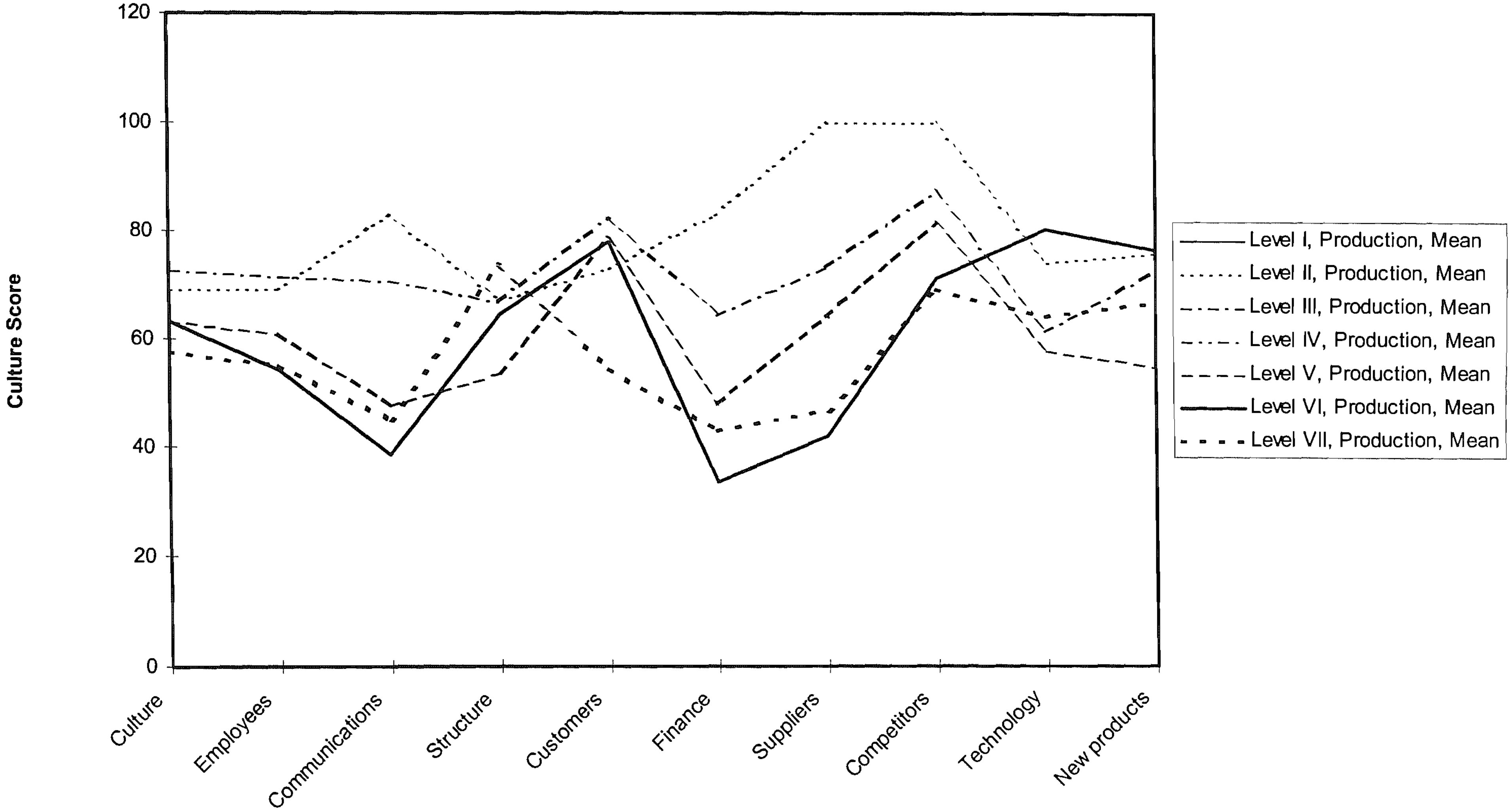
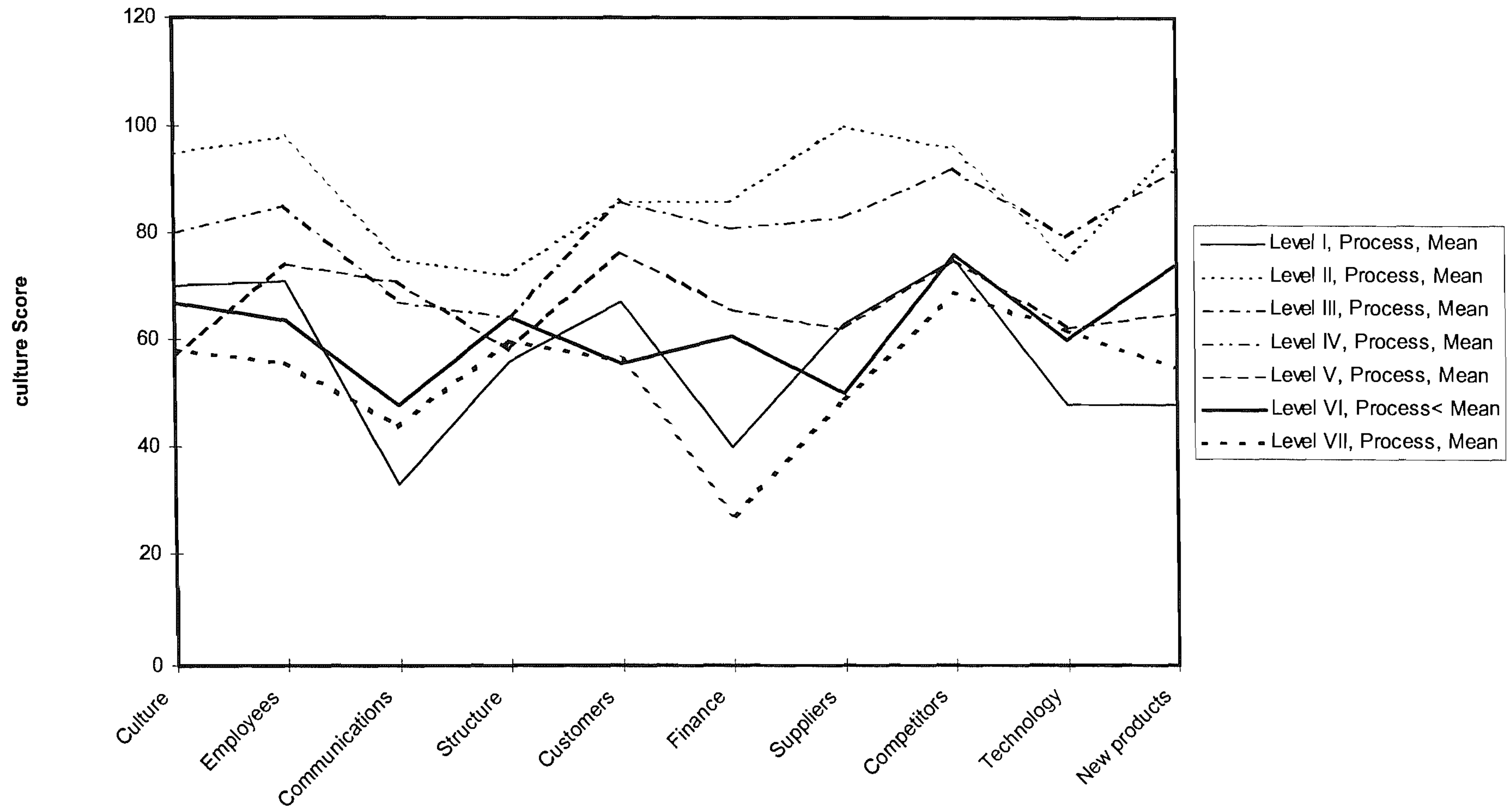


Figure 3 Process Manufacturing Company Mean Culture Scores



CASE STUDY OF THE APPLICATION OF BPR IN AN SME CONTRACTOR

M J Riley and D C Brown

Abstract

The UK Government strongly encouraged the construction industry to improve its efficiency during the 1990s. P Trant Limited, a medium sized civil engineering contractor located in the south of England took on board this challenge and carried out a Business Process Re-engineering programme. This paper describes the process modelling tools used, the re-engineered processes and the efficiency gains produced. It is shown that mature medium sized contracting companies can benefit from undertaking such a change programme and that the benefits are not restricted only to large companies or groups.

KEY WORDS
Construction, Business Process Re-engineering, Modelling Tools, Culture, Small Medium Sized Company (SME)

BACKGROUND

The construction industry is being urged to become more competitive; the United Kingdom's Government has sponsored two investigations into the industry's efficiency during the 1990s (Latham, 1994 and Egan, 1998). Similar improvement drives are seen throughout the world including the USA (Wright, 1995). The importance of improving the efficiency of the construction industry cannot be underestimated since it forms the major industrial sector in most industrialised countries of the world (see, for example, Barrie and Paulson 1992; Paulson, 1980).

The construction industry is characterised by the large number of small companies acting as sub-contractors and carrying out the physical work on site. In the UK out of a total of 209,793 construction companies only 0.6% employed more than 600 people and only 0.8% employed between 300-600 people, (HMSO, 1194). This means that the efficiency of contractors in the Small, Medium sized Enterprises, SME*, sector is critically important to the overall efficiency of the construction industry.

In the UK there are three key participants in construction:

(1) The client who will pay for and own the finished constructed facility.

(2) The designer, usually an architect or engineer, responsible for carrying out the design of the facility. Once work starts on site their role changes to approving construction quality and agreement of payment certificates to the contractor.

(3) The contractor, appointed after the design has been completed, with the responsibility of managing and carrying out all the physical work to construct the facility on site.

These participants are usually supported by a large number of specialised consultants and sub-contractors.

This re-engineering project is focused on an SME contractor since contractor costs represent about 85% of the construction projects costs (excluding land costs) and the potential cost savings, at a national level, are large.

Many SME contractors are still family owned and in their first or second generation of ownership. They have grown into complex organisations in terms of ownership, organisational structure, the wide range of construction projects carried out (size, value, duration, technology level), the wide range of client organisations and level of labour resources and skills employed. The growth of SMEs is usually organic with internally generated funding rather than by the external investment led major steps that large companies are able to take advantage of. This natural growth often means that they have structural organisational inefficiencies.

An outcome of this is the need for most of these companies to stand back and carry out a re-assessment of how they operate and work. This paper describes a structured method for doing this based on the Business Process Re-engineering, BPR, approach.

* The UK government's Department of Trade and Industry define SME as being a company with less

At the start of the research programme the company had the following goals:

(1) To re-engineer the business processes, initially tendering and feedback, in order to reduce costs in a three year period whilst maintaining quality.
(2) To introduce and optimise existing information feedback mechanisms to increase quality and reduce risk.
(3) To improve customer satisfaction, employee job satisfaction, communication and ownership.

DESCRIPTION OF THE CASE STUDY COMPANY

P Trant Limited, PTL, is the SME contractor that forms the cased study in this paper. They are located in southern England and operate as a "main contractor" rather than a sub-contractor; that is they work directly for clients taking on responsibility for the construction of the whole project.

PTL is a family owned company in which members of the family play leading roles in running the business, determining how it operates and deciding on future directions. The employees of PTL range from long serving members staff who have been a part of the business for many years, to more recent recruits whose allegiance to the company is much less mature.

There is great respect and trust between the staff, workforce and the board of directors and the family. The company prides itself on taking care of, and looking after its workforce; they try their utmost to keep staff employed rather than using the more traditional "hire and fire" philosophy. Communications between all levels of the company are, as a consequence, easy and rapid and no great bureaucracy exists.

PTL, as with all contractors, has in effect two parts to its business. One part is the continuous on-going process at head office and the other is carrying out the construction projects on site, which have a fixed and relatively short life span. The company employed about 250 people at the time of the study.

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than 250 employees.

The Business Process Re-engineering programme carried out within PTL is rather unusual in that it was carried out as part of a research programme funded by European Commission, rather than as a management consultant activity. This research programme was funded under the ESPRIT 4th Framework Programme for Research and Technological Development in Information Technologies, Domain 7: Technologies for Business Processes. The research programme included UK, Spanish and German partners in addition to PTL and had a value of 2.7million ECU (1ecu=$1US, approx). The overall programme duration was 24 months. Contract Reference is EU Esprit project 20.777.

However the need for a "big picture" re-organisation of some sort had already been recognised by the managing director (MD) of PTL and the ESPRIT funding allowed the MD's concerns to be acted upon. It is interesting to note that the MD's initial concerns, based on experience, were that the tendering and procurement processes would benefit from re-engineering; as will be seen later the BPR mapping and analysis confirmed the MD's initial concerns.

AN OVERVIEW OF THE BPR METHOD USED WITH THE SME CONTRACTOR

It has generally been accepted that the success of re-engineering relies on support from the highest levels within the company, together with a clear understanding of and empathy with, the fundamental philosophy of business process and systems thinking. It can never be achieved by the application of textbook action steps – the cookery book recipe approach. As Hammer and Champy (1993) said "there is no seven or ten step procedure that will mechanically produce a radical new process oriented design for a business, but there are recognised principles upon which success depends". The re-engineering approach reported here reflects this philosophy.

The approach is shown in Figure 1 which is taken from a deliverable of the research programme (CORE, Deliverable 7B, 1997). This illustrates that much investigation into the background of the business must be carried out before any process modelling can take place. It shows the clear need for "people" based information and input. engineering can then take place.

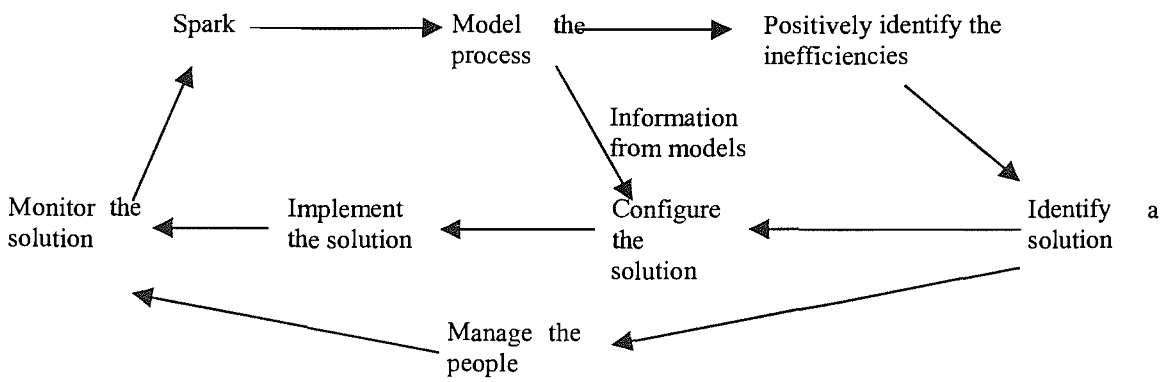

Figure 1: Summary of Approach

MODELLING METHODS USED

Models of business processes and of business interactions play an essential role in the carrying out of any process re-engineering activity. It is not possible to re-engineer any aspect of the company without an understanding of the existing scenario. Models are a valuable means of gaining understanding of how a business operates and form the fundamental communication mechanism for all those within the company to input the actual operational steps. After carrying out a BPR exercise models are equally valuable in describing to staff how a business could or should operate if that business is to be effective. The purpose of modelling the processes is twofold, first, to highlight missing or weak processes and second, to demonstrate the possibilities for greater process integration. Detailed computer based and fully documented models including functions, organisation, data structures, control flow, data flow, human resources and IT support were mapped. Two forms of models have been used, Process Oriented System Design, POSD, and Activity Network.

Process Oriented System Design Model

Process Oriented System Design, (POSD[+]) models are representations of processes and the relationships between sub-processes that make up that process. The method uses a rectangle (represented by the thick lines and bold text) to represent the process and the sub-processes of that process shown as rectangles (with thin lines and non bold text)

[+] POSD is a registered trademark of International Computers Ltd. Source of information on POSD can be found at http://www.prattens.demon.co.uk/home.htm within the process rectangle. These sub-process rectangles touch other sub-process rectangles only if a relationship exists between these sub-processes. This relationship can be of any type that creates a linkage between them; the detail does not need to be known or specified. Other modelling tools are available to describe the detail of this relationship including activity networks.

The size of the rectangles and their relative locations have no meaning or significance. The same sub-process can appear in more than one POSD process model.

POSD can then be used to represent each of the sub-processes by breaking them down into more detailed sub-sub-process, as appropriate, in order to describe the real world. It is possible to show an unlimited number of processes (high level) composed of sub-processes (lower level).

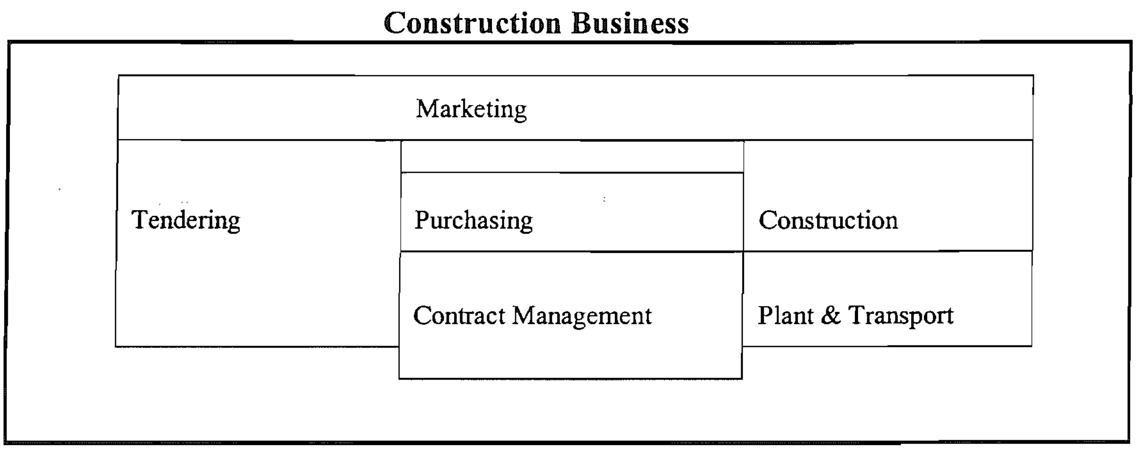

Figure 2: High Level Business Processes of a Construction Business

Figure 2 shows the POSD representation of the high level business processes of a typical construction company. This shows, for example, that the sub-process of tendering has a relationship to the sub-processes of marketing, purchasing and contract management but not to the sub-processes of construction or plant and transport. This shows that the sub-processes of marketing relate to those of tendering and construction but not to those of purchasing and contract management and plant and transport. This POSD model represents PTL but the authors feel that it is typical of the majority UK SME contractors. The activities of the sub-processes are:

- Marketing: forges the relationships between existing and potential customers and persuade them that the company should be allowed to tender for their new construction projects.
- Tendering: this sub-process receives the request to tender from the client and provides the completed tender based on price but including support documentation.
- Contract Management: takes any successfully tendered contract and carries out the physical work to complete the product and then hand it over to the client.
- Purchasing: including materials and sub-contractors
- Plant and Transport: makes these resources available when and where the company requires it.
- Contract Management: assembles and manages the resources to construct the project.

POSD models provided a very powerful way of identifying relationships within the case study business; these diagrams were easily understood by all within the business and were an important communication link to employees. They were easily used by all company staff and this helped to ensure that all knowledge, views and ideas were collected in order to map out a true picture of the processes within the business. This ensured a correct description of the business for all levels within the company.

The key value of POSD is the ability to indicate interactions or relationships between groups of process without having to understand the detail of this relationship that is required for activity networks. The relationships may not be known or properly understood but the fact that it exists is sufficient to improve understanding of the processes.

Activity Networks

Activity networks were used to represent sequences of activities, with each activity producing outputs that are used as the inputs to following activities in order to get things done. The basic model is shown in Figure 3 and shows the use of symbols to impart meaning to the model. This form of modelling uses the symbol of an ellipse to represent the activity itself. Each activity has input and output objects. A variety of symbols are used to represent inputs and outputs, each symbol being chosen to be suggestive of the type of object involved. A circle represents a role object to indicate the responsibility of someone for carrying out the activity. An arrow from the role object indicates what activities it has some responsibilities for. An activity may have more than one role object. It is the role that is modelled and not names or individuals who might carry out that role; within small companies an individual might carry out several different roles.

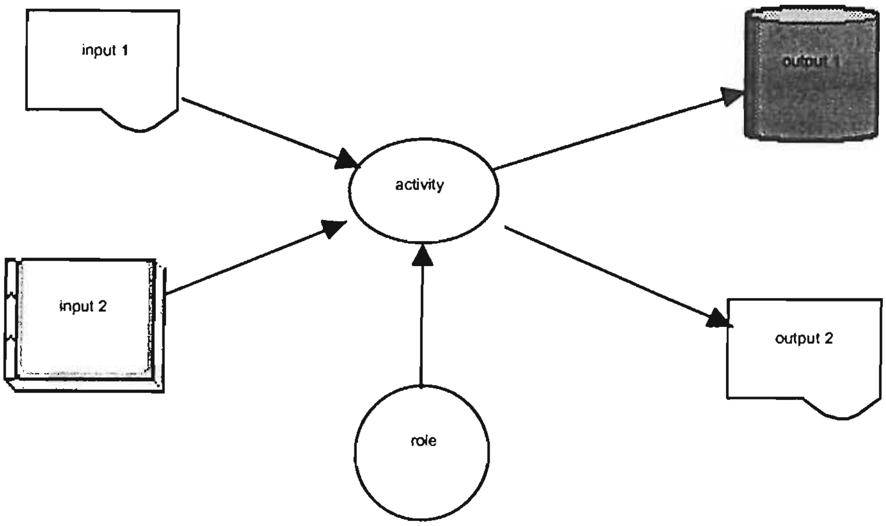

Figure 3 Basic Model used for Activity Networks

The activities are linked to create the network that is the process.

A process is usually built up from a layered or hierarchy of activities. This is represented by using a thickened ellipse (or alternatively by shading the ellipse) to represent an activity that consists of a more detailed network of sub-activities; this detailed network is displayed on another part of the model diagram. This will be described in the contents as "Parts of A" where A is the name of the expanded activity.

All the activity network models used in this case study were produced using the ICL ProcessWise Workbench tool running on a Windows PC. The activity diagrams shown in this paper represent static "pictures" of the way that the company operates and form a valuable communication tools. The software tool used also allows analysis and simulation based on these static models. This analysis can include calculation of elapsed time to perform the process, of capacity and of resources needed. This analysis is used during the redesign process.

MODEL OF THE ORIGINAL BUSINESS SYSTEM

The existing business situation was mapped using both POSD and activity networks and some of these diagrams are included in this paper.

Construction sector companies have to operate in two distinct ways:

1. With a set of temporal processes associated with individual projects.
2. With a continuous set of business processes as exemplified by the work carried out at their head offices.

Mapping the Construction Project

Figure 4 shows the POSD mapping of the high level processes involved in a typical construction project. There are many variations on the contract strategy that links the chronology of these processes for each specific project. This shows the main contractor interacting on one side with the client (provision of information, submission of tenders, agreeing contract, handover of work, payments), with the design companies (to agree construction design, agree payments) and specialist design companies (specialist items). On the other side the main contractor interfaces with the facilities management company, materials suppliers, sub-contractors and plant hire companies.

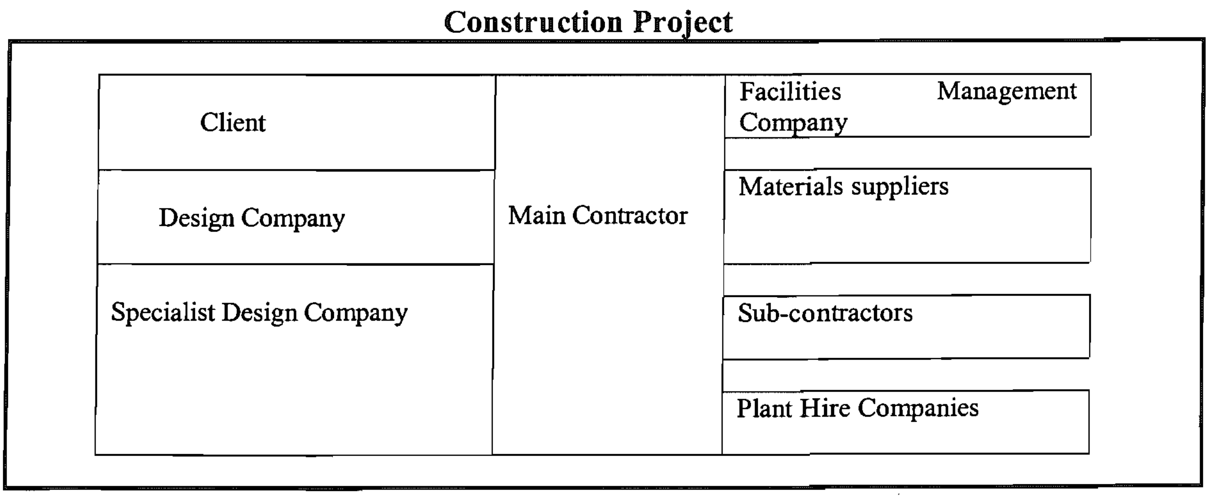

Figure 4 Processes of a Construction Project

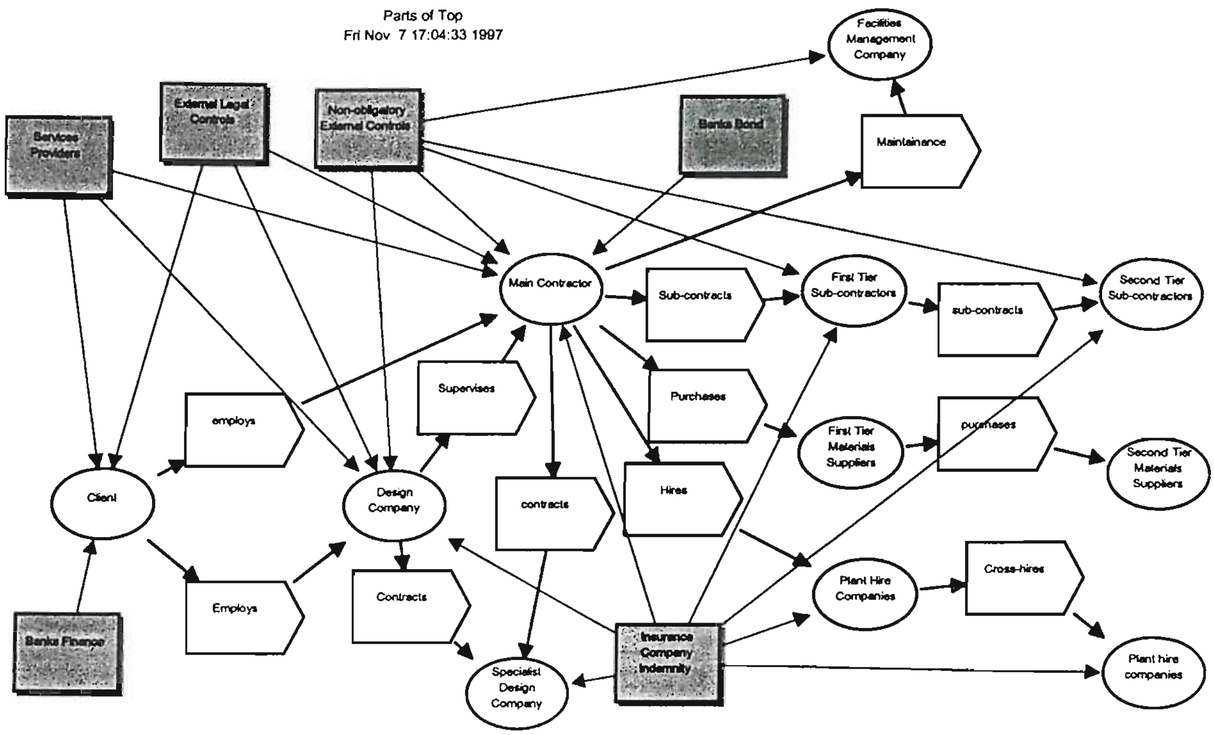

Figure 5 Activity Network Model of a Single Construction Project

A more detailed mapping of the roles and relationships between the participants involved within a single construction project are shown in figure 5. This figure shows the traditional contract strategy that is known as designer led with contractor selected by competitive tendering. Note the relationship between the client, designer and contractor; a contract exists between the client and the designer and a different contract exists between the client and the contractor. No contract exists between the designer and contractor but there is a legal relationship is detailed within the two previously noted contracts. Key roles for the designer are approval of the contractor's work and then approval of payments from client to contractor. Once the project is completed the contracts are discharged and the relationships between project parties are concluded.

The rectangles show the external controls that exist in the environment of the project system and these have a strong impact on the project; note the large number of such controls. The service providers include the water, gas, electricity and telephone suppliers. The external legal controls include the local authority planning and building control departments, the Fire Service, the Health and Safety Executive and

Environmental Agency. Non obligatory controls include trade associations, professional bodies and quality assurance auditors.

Note the large amount of control on the project by parties who provide financial support to the construction parties such as banks and insurance companies.

Only two levels of sub-contractors are shown but in reality this chain could extend by several more levels and there would normally be many such sub-contractors.

"Head Office" Business Processes

Figure 6 is the activity network equivalent to the POSD diagram shown in figure 2. These processes are company based and mainly take place at head office: they are continuous processes rather than finite as are the project processes.

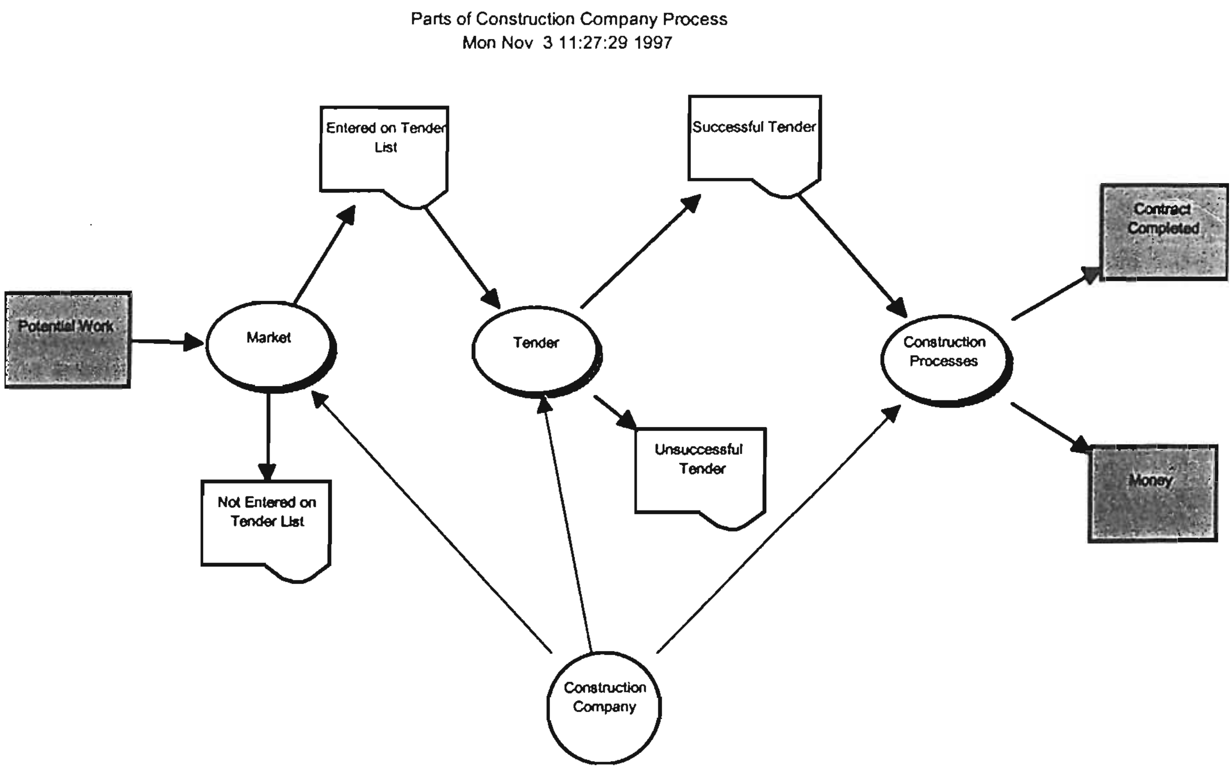

Figure 6 Activity Network of the High Level Processes of a Typical Construction Company

The three high-level processes of market, tender and construction are the core business processes that all construction companies carry out, although the precise way in which this is achieved will vary between different companies. The output of the marketing process is the client's decision to invite the contractor to submit a tender. The output of the tendering process is the client's decision. Once the tender has been awarded to the contractor the construction process is under the control of the contractor.

Large contractors might also include two additional high-level processes that are less relevant to SME contractors and these are finance (to provide the finance for the market) and maintain (to carry out the facilities management function for the client).

IDENTIFYING AREAS FOR CONCERN

The MD of PTL felt a basic need to improve overall company efficiency and felt that one or two areas would benefit in particular. He felt that the tendering and procurement processes had, in particular grown in a somewhat haphazard way and if improved would enable the same people to do twice as much work with no reduction in quality. These areas are critically important to most contractors.

Over 80% of their work had to be tendered for. The traditional way in which contractors obtain more work is to submit a tender to the client for carrying out the work; the lowest tender normally getting the work. The tender is an estimation of the cost for carrying out the work and is carried out by the estimating department. The contractor, in the traditional system, only wins between 5-10% of all tenders submitted. So the most obvious way of winning more work is for contractors to increase the number of tenders submitted. This then increases overhead costs that then lead to increased tender sums which then reduces the probability of winning the tender. This becomes a circulatory problem. Figure 6 highlights the pivotal role that tendering has on the company's business.

Although there is a lack of reliable information it is estimated that materials account for, on average, 40% of construction costs, although this is thought to range from 15% for mainly labour intensive maintenance work to 60% for capital intensive projects (Harvey and Ashworth, 1993). The procurement process is used to purchase not only these materials but also sub-contractor services and plant hire, hence any improvements in procurement that can be achieved as a result of process modelling should yield significant benefits.

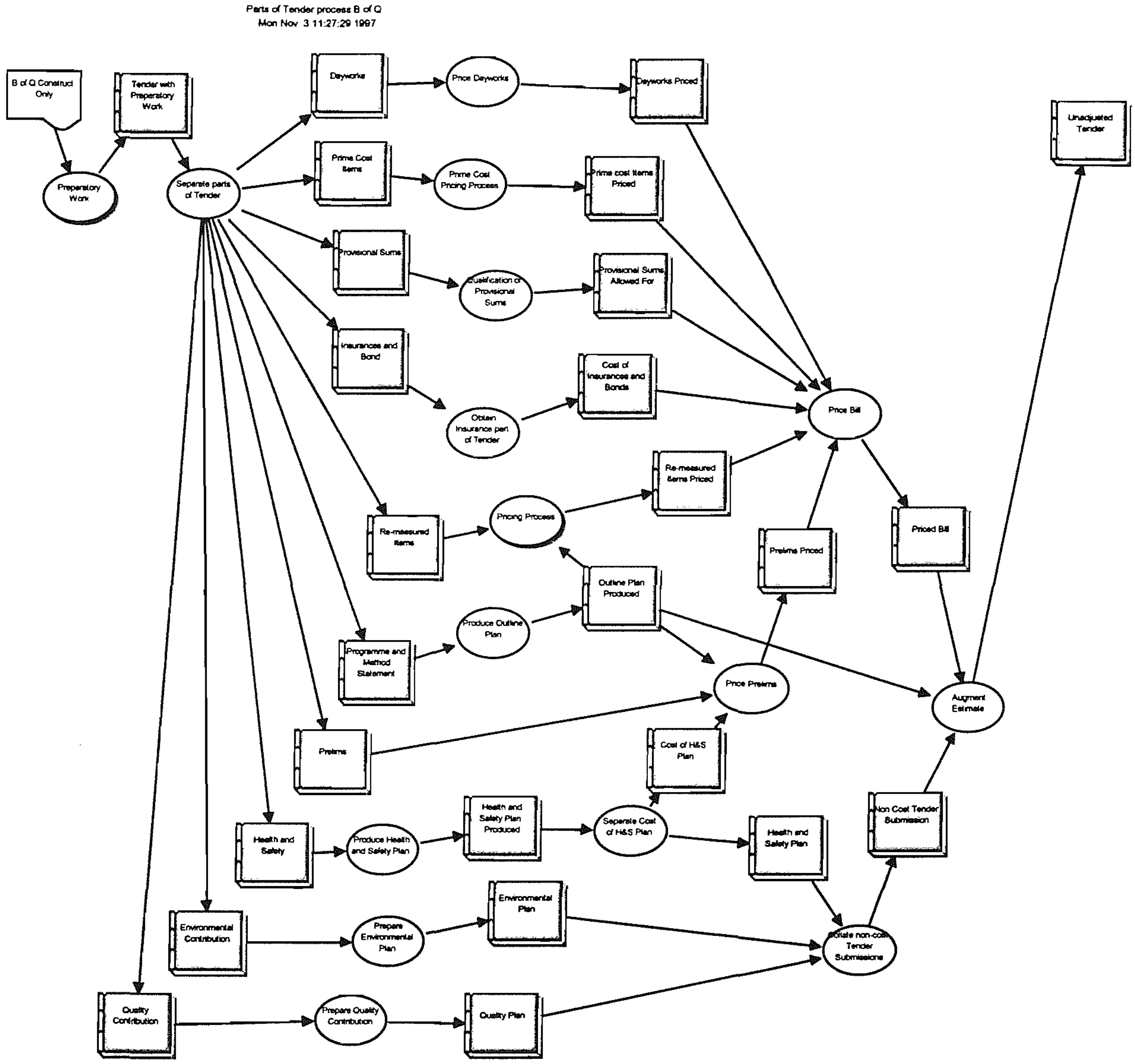

Figure 7 Showing the detail of the "prepare tender" sub process being part of the tendering process.

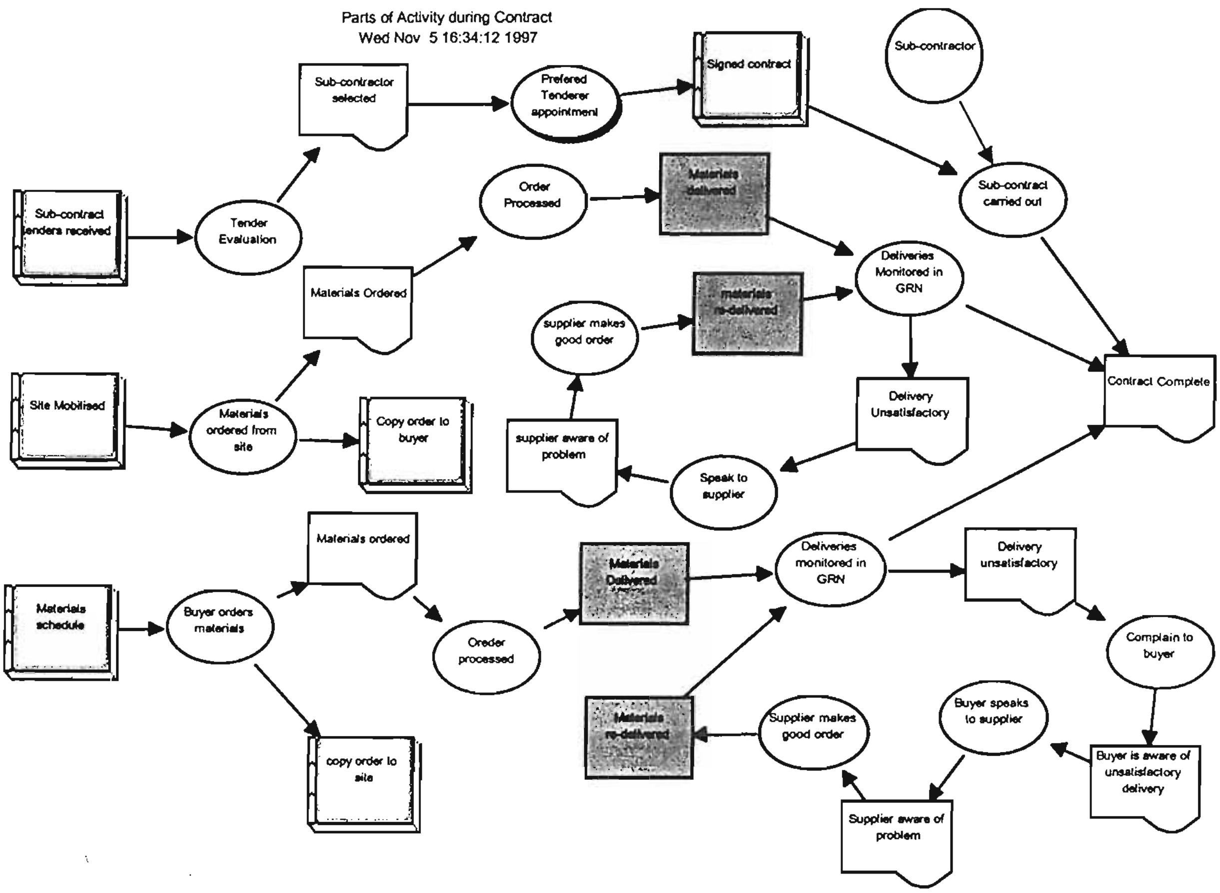

Figure 8 Showing the detail of the "procurement during construction on site" sub process being part of the procurement process.

The processes were further broken down into greater detail, although the mappings have not been included within this paper. Two examples are shown in figures 7 and 8. Figure 7 shows the detail of the "prepare tender" sub process that forms part of the tendering process. Figure 8 Shows the detail of the "procurement during construction on site" sub process that forms part of the procurement process. These figures also give some indication of the complexity of the "organically grown" existing processes.

The following objectives were identified:

(1) To increase the size of contracts undertaken by the company and thus increase the profit and turnover.

(2) To increase the throughput of tenders from the same amount of effort.

(3) To increase the amount of time spent by estimators in looking at ways of "winning" work rather than just preparing estimates.

(4) To reduce the effort required in the tendering process to obtain accurate prices for materials which are bought on a regular basis.

(5) To increase the amount of time estimators have available to spend on obtaining prices for major, high value, materials by reducing the amount of time they spend chasing quotes for lower value items.

(6) To have readily accessible, up to date and accurate cost information on all contracts

(7) To increase the level of inter-departmental integration of information in the company.

(8) To reduce the effort required to produce documentation such as Quality Plans and Health and Safety Plans.

(9) To increase the efficiency of invoice clearance procedures, particularly for larger contracts.

THE RE-ENGINEERED MODELS

The re-engineered processes form a comprehensive set of process models but two sample models are shown in this paper. Figure 9 shows the re-engineered sub-process "prepare for estimator" within the re-engineered tendering process; this should be compared to figure 7 showing the equivalent original "prepare tender" sub process.

Figure 10 shows the sub-process "activity during contract" within the re-engineered procurement process; this should be compared to Figure 8 showing the equivalent original "procurement during construction on site" sub process.

Both examples show the significant role that IT has to take in enabling such changes to take place. The re-engineering process also involved simulation of time and resources to help optimise the re-engineered designs.

Commercial confidentiality precludes the inclusion of the fully detailed re-engineered models.

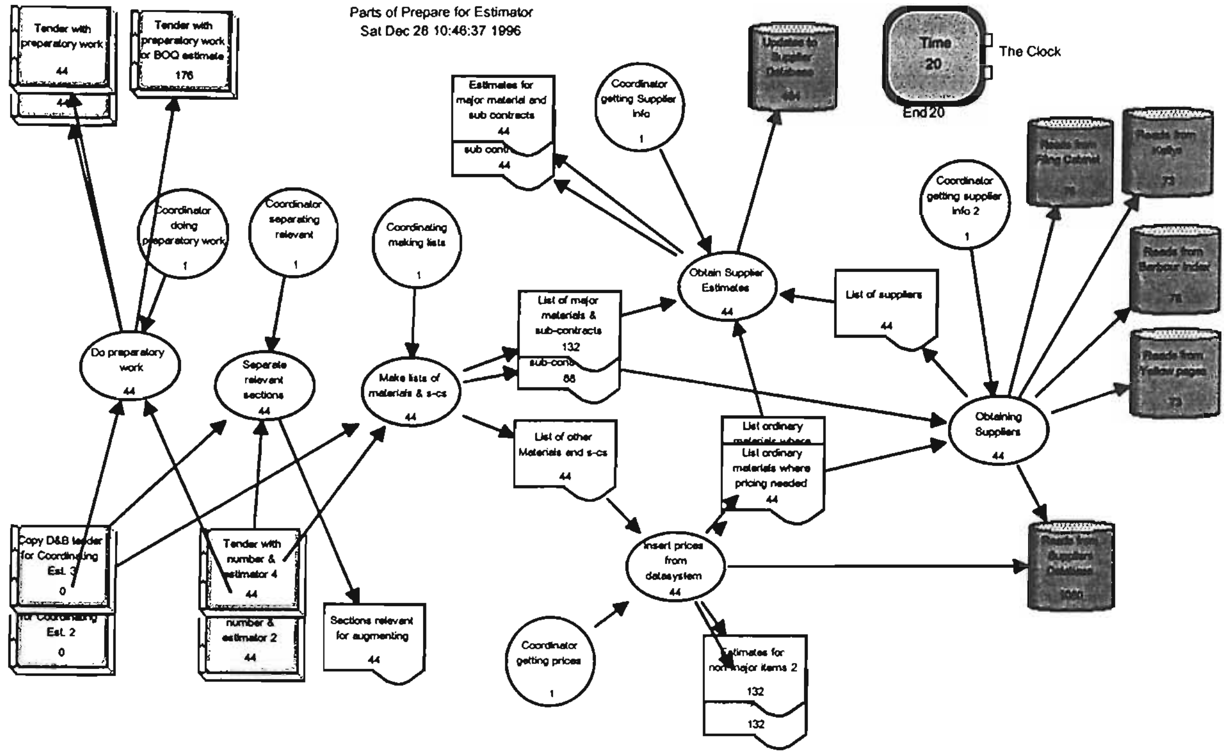

Figure 9 Showing the sub-process "prepare for estimator" within the re-engineered tendering process

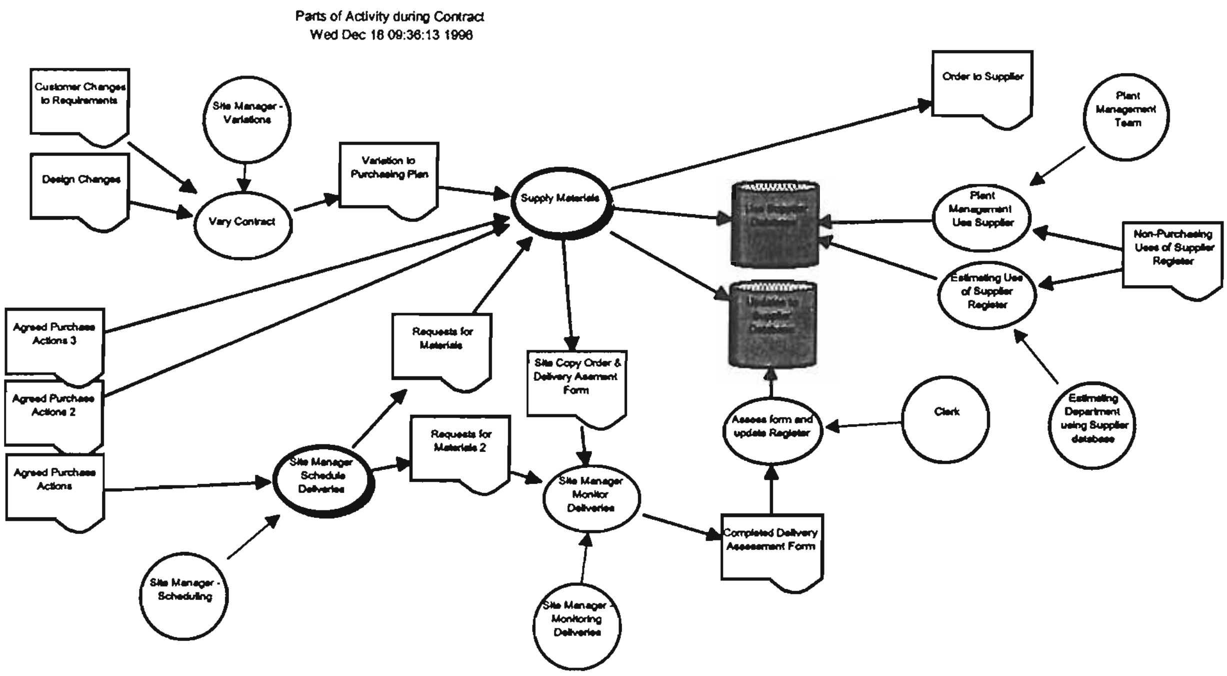

Figure 10 Showing the sub-process "activity during contract" within the re-engineered procurement process

The basic rules followed included;

- Ensure the maximum capture and re-use of information,
- Improve the methods of document creation and control,
- Integrate the technical and economic parts of the tender,
- Increase the use of templates for faster creation of tenders and re-use of experience,
- Improve data flow by reducing physical documents by use of an integrated, company wide, database,
- Improve integration of technical planning and quality management for improved procurement,
- Improve flow of information to suppliers,
- Maximise site based procurement.

Re-engineering programmes need two enablers to achieve worthwhile results; these are a change in culture and technical innovation to enable the increase in communication to take place. The technical innovation in this case study is the use of IT. Existing company processes made little use of IT and the re-engineered processes rely on IT and company wide databases to enable the changes to take place. The re-engineered processes required IT to allow their implementation. As an SME, it is logical to use commercially available software, ideally developed specifically for the construction sector; there is no benefit in bespoke software development bearing in mind the long term maintenance and support that is required. The relative lack of IT use before re-engineering created a need for staff training support. An information manager was appointed to implement the whole IT system and ensure satisfactory training for those that needed it.

BENEFITS AND ADVANTAGES FOR THE COMPANY

The results have been far reaching throughout the company but more importantly a significant change in culture has occurred. The project has been the catalyst of changes that were felt by the MD to be required for some time.

Cultural Change

At Board level it has been accepted that IT does have a support role and that the future of the construction is based on the use of IT. This change in culture is demonstrated by the change in attitude from some of the more cynical senior managers; this changed from "show me a computer that can dig a hole" to "they are only the cost of a couple of JCBs" (referring to the cost of the hardware and software for the company wide data base and JCBs are very common UK excavators). Without this fundamental change then no other changes would have taken place.

Company wide the changes have been equally significant, especially in the acceptance of IT. People are becoming more pro-active in trying to use IT. This is typified by staff saying, "if I had access to IT then I would become much more efficient" rather than the traditional attitude of "I have always done it like this, it does work and why should I change it". All levels of staff now support innovative ideas.

The staff have focused on new common goals with enthusiasm to "get it right" and "make it work".

The whole process has provided confidence that the company is moving forward to become more efficient an effective; this has led to increased job satisfaction.

Process Change

The main area of process change took place in the tendering and procurement processes, although some changes took place in the stores process. Other business processes will undergo change programmes over time.

This change was accomplished by the implementation of an integrated IT system based around a central company database of information. This was a complete, commercial IT package developed specifically for the construction industry by a UK software company.

In tendering and procurement the improvements centred on the sharing of information. Historically, little information sharing took place between these two processes but now the common database enables estimators fast access to up to date prices achieved by procurement on real contracts; prices obtained from suppliers for contracts being tendered for are not as competitive as the prices actually negotiated on contracts that have been already won. Previously the estimators used their own supplier list to obtain prices for materials regardless of the real data being created by procurement on real projects. The IT system is designed to mirror the re-engineered company processes.

GENERIC LESSONS

This paper shows that BPR is appropriate and worthwhile for SMEs and is not a method restricted only to large organisations, as tends to be assumed by those that have not been involved in such a programme. The BPR method described in this paper is appropriate for the owners or chief executives of the SME companies to carry out themselves.

The use of POSD and activity models, as used in this case study, provide ideal modelling tools, especially for SMEs; they are easy to use and permit all to become involved in the re-engineering process. The software used here is also capable of simulation and analysis thus allowing easy comparison of alternative process designs.

SMEs would be able to carry out most of the mapping and analysis on their own although they would be advised to seek external support when re-engineering processes. This will bring in the lateral thoughts that are important to re-engineering.

Re-engineered systems will increasingly need IT support systems to permit the increasing exchange of data and information required to ensure full integration.

SMEs will need to increase their use of IT and should use commercially available systems and not try to develop their own bespoke systems.

IT systems should be used to link sites to head office to speed up payments etc.

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Business Systems Engineering to Achieve the Egan Construction Targets

M J Riley and Professor D.R. Towill

The first author is main contact and academic mentor for Demonstration Project No 112 "Forton Lake Opening Bridge" and details for all M[4]I demonstration projects are at web site www.m4i.org.

Abstract

This paper proposes that the implementation of Business Systems Engineering to a construction project will achieve the continuous business improvement targets suggested by the Construction Task Force chaired by Sir John Egan. Business Systems Engineering can be described as the application of engineering techniques to business processes in order to increase profitability. A brief explanation of the systems approach is included. It shows that the implementation of a series of improvement steps developed by Harrington will achieve the implementation of Business Systems Engineering. Examples of the potential for such improvements have been taken from the large number of demonstration projects that form part of the Movement for Innovation (M^4I) set up with the Department of the Environment, Transport and the Regions to achieve the Egan targets.

Key Words Management, Partnering, Business Systems Engineering

1. Background - The Need for Improvement

The need for improvements in the efficiency of the construction process and profitability of the construction industry as a business have been clearly described (Latham[1]). In July 1998 the Construction Task Force, chaired by Sir John Egan, published their report "Rethinking Construction"[2] to build on the foundation laid down by Latham. As the Egan report states "the UK construction industry at its best is excellent, but that only a few companies are performing at this level". Problems highlighted include low profitability leading to construction companies being viewed as a poor investment by the City; the industry not investing sufficiently in, for example R & D and training to develop proper career paths for supervisory and management staff; clients are generally dissatisfied and do not appear to understand the difference between best value and least price; finally the industry is fragmented which leads to difficulties in co-ordinated "big picture" cross sector improvements.

The Movement for Innovation, M^4I, was launched in November 1998 with sponsorship from the Department of the Environment, Transport and the Regions to help industry achieve the Egan targets. The M^4I has collected a list of demonstration projects that illustrate the implementation of the Egan targets and these are described at web site www.m4i.org.

It is the purpose of this paper to provide a strategy to help companies to identify potential improvements. After describing this strategy examples will be drawn from some of the demonstration projects to illustrate the power of this strategy.

2. Business Systems Engineering – a Systems Based Strategy

It is proposed that a strategy known as Business Systems Engineering will allow projects and the companies employed on them to achieve the Egan targets in a simple structured way. Business Systems Engineering is a formal way of using clear and simple engineering approaches to look at and design the systems that businesses uses, as defined by Gregory Watson[4]. Before this approach can be understood it is necessary to have a clear understanding of the systems approach to problem solving.

2.1 The Systems Approach

The traditional construction project consists of many different companies each working in essentially, an independent way to optimise their own operations with little regard to other companies in the project apart from their immediate employer. This creates disjointed relationships with little or no interaction and with each organisation having their own agenda; there appears to be little incentive to work together. Unfortunately this is not likely to create the optimal result for the whole project as viewed from the client's perspective with respect to money or construction efficiency; in reality it is not in the best interests of the project participants. However the systems approach leads to a more integrated way of working.

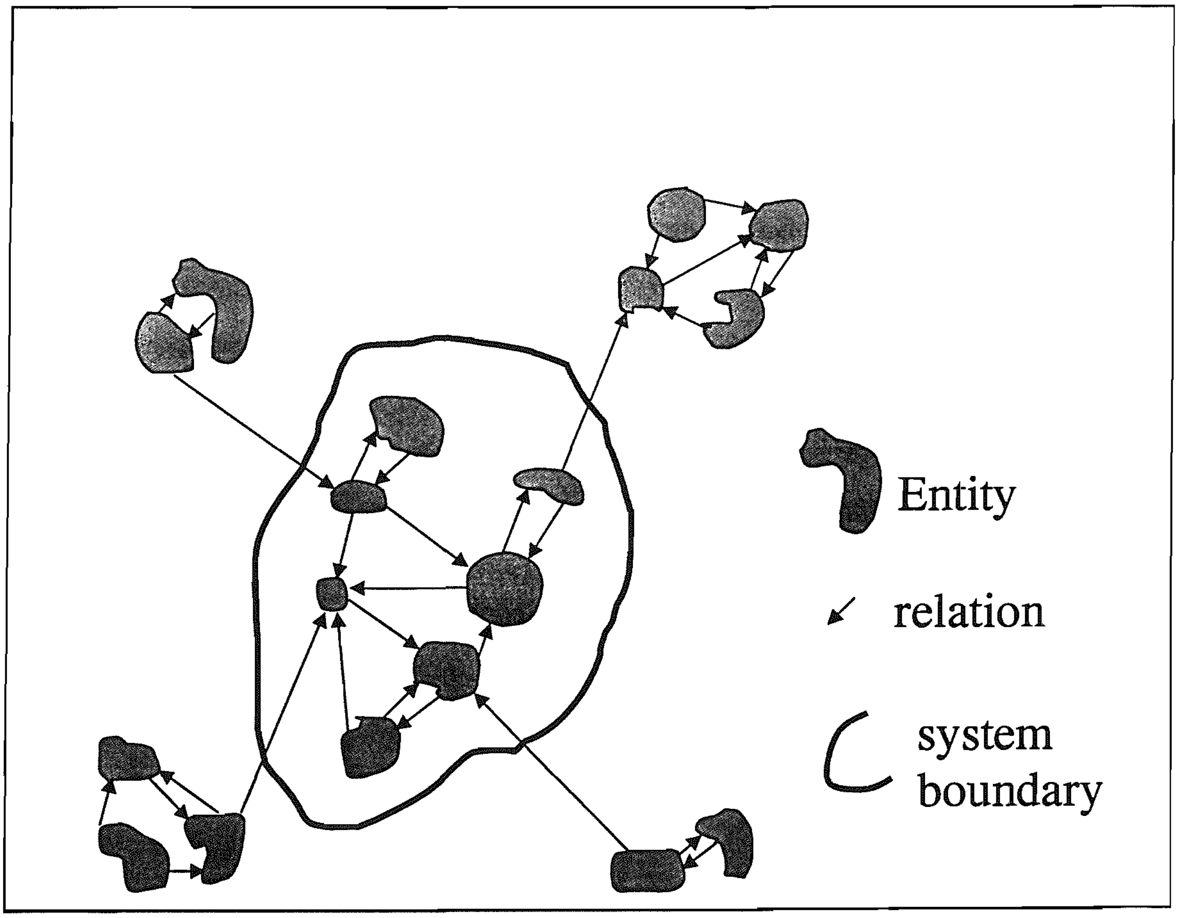

Figure 1. Generic Structure of an Open System

A system consists of sub-systems that have links and that inter-relate with each other; it is an arrangement of interrelated parts viewed as a whole and not broken down into isolated individual functional parts. Systems work within and interrelate to their surroundings or environment and these are known as open systems. Figure 1 shows the generic structure of an open system. All systems have a purpose or reason for existing that satisfies both the system and its environment; for example the main goal for a business would be to make a profit but the environment must be satisfied or it will not buy the goods that the organisation makes.

Thus the systems approach is a way of viewing the world. It is a way of looking at the whole situation in order to view "messy" situations and perceive the order in the chaos. It is important to always view the "big picture" and not just a sub-part of it otherwise unexpected outputs can results from inputs that seem totally illogical as described by Brown and Riley[5]. A system is an integrated combination of components and activities designed to follow a common purpose and only exists in order to help achieve a better understanding of the problem and hence help create a "tool" to resolve that problem.

This is the opposite of analytical thinking that breaks things down into smaller and more specialised parts. It is interesting to note that engineers usually approach a problem by breaking it into sufficient parts such that they can be analysed; the parts are then reassembled to hopefully create a true simulation of the complete problem.

A construction project is a large system built from sub-systems consisting of individual companies. These sub-systems can be further broken down into sub-sub-systems such as the functional departments within individual organisations. The primary aim should be to ensure the optimum Project System is created and managed.

John Parnaby[6] has shown "that an organisation which operates using a systems approach delivers better engineering throughout all its activities".

3.2 Business Systems Engineering

A structured way for engineers to use the systems approach is by the application of Business Systems Engineering.

Business Systems Engineering is a well established management approach that was developed, and proven, to create step change improvements in manufacturing companies. It uses the systems approach to "engineer" business processes and focus the design and operation of the business towards total customer orientation and the creation of customer satisfaction. The methodology is detailed by Gregory Watson[4] and is based on the hard techniques of control engineering and industrial engineering; it is proposed that it would be of significant benefit to apply its principles to the construction project.

Parnaby shows in table 1 the improvements achieved in a UK manufacturing company after applying Business Systems Engineering. Note the improvement in product "ownership" as a direct result of moving away from "functional silos". These figures give an indication of the potential of savings that can arise from the systems approach; it could be argued that such large savings could only be achieved by a fixed location manufacturing company but this paper will show that construction can achieve similar step change improvements.

Benchmark	**improvement**
manufacturing costs	down 30%
material movement	down 90%
lead time	down 75%
Inventories	down 75%
work in progress	down 75%
adherence to schedule	up 30%
product "ownership"	much improved

Table 1 Showing results quoted by John Parnaby following the successful application of Business Systems Engineering in an automotive supply company

It is important to remember that Business Systems Engineering ***is*** engineering - it is the application of ideas and techniques that engineers understand and feel comfortable with. It requires the application of analysis, innovation, synthesis and implementation; it is based on the application of rigour, mathematics and logic; it is essentially the application of fundamental engineering principles. The emphasis is on the way the business achieves its own goals whilst simultaneously maximising value to the customer. This can only be achieved by design and cannot be expected to happen by chance.

Step Number	Action
1	eliminate bureaucracy
2	eliminate duplication
3	value added assessment of all activities
4	simplification of all activities
5	process cycle time reduction
6	error proofing of all activities
7	Upgrading
8	documentation in simple language
9	standardisation of all procedures
10	develop supplier partnerships
11	big picture improvements
12	automation and or mechanisation as justified

Table 2 Basic Steps in Business Process improvement as proposed by James Harrington

A straightforward way of using Business Systems Engineering is provided by Harrington[7] who shows that Business Systems Engineering will be achieved when a company undertakes a series of sequential improvement steps, each addressing a particular aspect of the company's business. These steps are shown in Table 2. Harrington suggests that a company should start with step one and look to improving overall efficiency by reducing needless bureaucracy within the company. Having reduced inefficiencies in this area the company should then move to step two, the elimination of duplication. The initial steps lie within the control of the company whereas the later steps involve co-operation between all the companies involved on the project. Each advancing step will involve increasing effort and commitment to achieve.

3. Application of BSE in Construction

It is proposed that the implementation of Harrington's Business Systems Engineering improvement steps to the whole construction project will lead to significant step change improvements in efficiency, customer satisfaction and produce results that will exceed those set by the Construction Task Force. However, at this stage, no case study has been carried out to demonstrate the implementation of all twelve steps and instead it will be shown that each of the Harrington steps have, individually and probably unknowingly, been the focus of an innovation in at least one of the M^4I Demonstration Projects; these will be described below. In this way it can be demonstrated that each one of the twelve steps, on its own, can lead to improvements. It follows therefore that the application of ***all*** Harrington's BSE improvement steps across all organisations within the construction project will make a significant contribution to achieving the improvements required by the Construction Task Force.

Examples that illustrate individual Harrington Improvement Steps

Step 1 Eliminate Bureaucracy: There are two aspects to this area: bureaucracy within the project organisation system and between the project system and its environment. Examples of bureaucracy within the project system include excessive paperwork and meetings to resolve problems that should have been resolved before they actually occur; projects that have tackled this area include Hurst Spit Stabilisation project[3] and Pennington Sewage Treatment Works, Lymington, Hampshire (NCE[8]). Bureaucracy between the project system and its environment has always been a problem that usually involves Government related organisations although the outcome can sometimes be positive. Hurst Spit is a positive example in which the bureaucratic delays enabled all the organisations to refine methods of working and improve relationships and culture. A negative example is demonstration project no. 112 "Forton Lake Opening Bridge" where delays in issuing statutory legal requirements moved critical foundation tasks into the winter period rather than the summer as originally planned. Although there is little that individual companies can do about this form of bureaucracy, the profession as a whole should always be looking co-operation in this area.

Step 2 Eliminate Duplication: There is considerable duplication in the recording of data and information, especially on site. Material deliveries always involve duplicate copies which often get lost and create delays; there is potential for using bar codes to transfer information in a fault free way very quickly. There are many examples of the same information being recorded separately by two totally different people. For example the right contract strategy (say partnering) ought to reduce the need for two quantity surveyors. Re-engineering just the trail of paper work – how many "carbon copies" have to be produced for no real need – will lead to savings; examples are shown in the Supply Chain Handbook[9]. Using appropriate forms of contract will help; for example the New Engineering Contract reduces duplication in its dealing of activity scheduling and subsequent payments. Demonstration project no 88 "Afan Waste Water Treatment Works" describes how the establishment of framework agreements with all of its key suppliers has resulted in significant resource savings at the enquiry/appointments stages.

Step 3 Value Added Assessment of all Activities: An analysis of recent contracts to identify value adding activities enables areas of management concern to be noted. An example will be to analyse time into the categories of value adding, essential non value adding and non value adding to clearly understanding how time has been used. A real example is described in the Supply Chain Handbook. Another example is demonstration project no 88 "Afan Waste Water Treatment Works" which held a partnering workshop that agreed to deliver value management and value engineering and look at the risk/reward formulae and share savings following on from this.

Step 4 Simplification of all Activities: The philosophy is to simplify over complex tasks in order to ensure better understanding and clearer responsibilities. A successful example of this "kiss" philosophy is demonstration project no. 10 "288 Bishopsgate Office Building" in which standard design solutions and components are used wherever possible and bespoke solutions kept to a minimum. The design for all components and sub assemblies were reviewed with the specialist suppliers to simplify manufacture and production and maximise productivity and quality.

Step 5 Process Cycle Time Reduction: There is a general rule in business that shortening the time taken to get products to the customer increases profits and improves customer satisfaction. Working in partnership can lead to a reduced project duration but this must always be in co-operation with the client; examples do exist in which clients have not been happy with contracts that finish early due to cash flow. An example is of the construction of a motorway service area, which was finished much earlier than the programme originally drawn up. This meant that the motorway itself was not finished and hence there would be no customers. Obviously the client for the services area did not want to make final payments, including retention sums, before they had to. This led to a very heated dispute, although eventually the client did pay up! Many clients, however, do want the shortest project duration as illustrated by demonstration project no. 56 "ASDA New Store" which includes reduction of cycle time from start of steel fabrication to store completion, as a key target by the whole project partnering team. It has also been shown that management techniques developed to reduce cycle time for any one particular project will gradually be transferred to other projects.

Step 6 Error Proofing all Activities: This step directly addresses one of the Construction Task Force's improvement targets. Demonstration project no. 87 "Radius Watford" provides a good example of how committed leadership from the client and main contractor can lead to the elimination of waster of snagging and rectifying defects (often a point of conflict). Defects are often caused by poor management of the interfaces between organisations. A commitment to people, associated with proper training, and the use of site quality forums, buildability workshops mock-ups and consistent and regular inspection regimes will lead to the optimal zero defects scenario. Demonstration project no. 118 "Sustainable Construction Demonstration Project" provides an additional example of adopting a quality driven agenda, again by ensuring the management interfaces are improved.

Step 7 Upgrading: this is essential for construction and there is a definite need to change "mindsets" to make sure this happens. Upgrading needs to be applied, as a process, across the board and will include people training (at all levels), plant and machinery, materials use, construction methods and management techniques and understanding. The need for upgrading people skills is a focus for demonstration project no. 73 "Thames/Morrison Network Partnering – South London" which involves repair and maintenance of 9,000 km of water mains and services to 2.5 million customers. This project aims to create a "win-win" strategy by including comprehensive training through the Thames Water staff development programme or MCL "Investor in People" training. An additional example is demonstration project no. 118 "Sustainable Construction Demonstration Project" in which a commitment to people has been made and uses on the job training.

Step 8 Documentation in simple language: There is considerable potential for simplification of the documentation used at all levels of the project. The use of simple language for documentation used to define inter-organisational relationships is particularly important and an excellent example of this is the New Engineering Contract which has been written as a project management as well as a contract document. Many of the demonstration projects have used this contract including demonstration project no. 112 "Forton Lake Opening Bridge".

Step 9 Standardisation of procedures: A problem is mindset - all construction projects are unique and different to all other projects and standardisation is often thought of as only leading to boring structures. This need not be true and demonstration project no. 56 "ASDA New Store" has a focus on moving towards a production process with standardised components. Demonstration project no. 10 "288 Bishopsgate Office Building" also uses standardised design solutions and components with a minimum of bespoke solutions.

Step 10 Develop supplier partnerships: This area has been recognised as being of critical importance for achieving real improvements and most of the demonstration projects are addressing this area. Of particular interest is demonstration project no. 10

"288 Bishopsgate Office Building", demonstration project no. 112 "Forton Lake Opening Bridge", and demonstration project no. 20 "Hampshire County Highway Maintenance and Construction". Lessons of supply chain management can be found in our Supply Chain Handbook.

Step 11 Big picture improvements: This is the sum of all the previous steps; this is where the real savings can happen and agrees with system theory in that optimisation will only be achieved if the system is optimised and that optimisation of sub-systems in isolation will not lead to optimisation of the whole system. The obvious improvement example taking place is the use of partnering ways of working involving integration of the design and construction teams. Examples of this are found in demonstration projects numbers 112, 56, 73 and many others. Some projects however only address this big picture in terms of one sub area – say quality or product development. Step 11 should look at integrating all the improvements in all the sub areas across the whole project system.

Step 12 Automation: This relates to automation across the whole project system and requires cross industry co-operation. For example the application of robotics for steel frame construction requires radically different design and detailing of the structure in order to enable total robotic erection on site. There is clearly great potential in this area but no M^4I project cites automation as an innovation.

5. Conclusion

This paper has proposed that the application of Business Systems Engineering to the whole construction project would be of great benefit to all within the project. It has been further proposed that the application of Harrington's twelve improvement steps to the whole project will enable Business Systems Engineering to be applied in a straightforward and mechanistic way.

The initial improvement steps can be carried out by individual companies although maximum benefit will only be achieved if it is carried out by an integrated project team. The latter improvement steps can only be carried out by an integrated project team and only after the earlier steps have been achieved.

The M^4I demonstration projects have been used as examples of best practice for individual improvement steps but no case studies are available to illustrate the benefits of carrying out all twelve improvement steps.

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TRUST IN TECHNOLOGY AND THE FUTURE OF THE CONSTRUCTION INDUSTRY

M. J. Riley, M.J. Ashleigh and D.C. Brown

ABSTRACT

The construction sector is being urged to look to other industrial domains for innovative ways of working in order to improve efficiency and profit. This paper looks at engineering psychology research carried out within the gas distribution industry to help understand the problems that will arise in the future as the construction industry begins using large IT decision making support systems. Areas of concern are highlighted.

Keywords: Trust, construction industry, information technology, human supervisory control domains, construction improvement.

ASSUMPTIONS FOR THE FUTURE OF THE CONSTRUCTION INDUSTRY

As with all industrial sectors the construction industry is going through a fundamental rethink as it re-engineers the work that it carries out within its business. It is proposed that the following three factors will coincide to create a radically different future for construction IT.

IT support will become more sophisticated and take strategic high level decisions

At present IT is routinely used in construction to solve specific technical problems predominantly within or restricted to a single technology area. The software often replicates work that the engineer would normally do mechanically in a "long hand" way with the actual algorithm effectively replicating this long hand method. Thus there is likely to be no doubt about the value of the results or to not trust the answer.

IT in many other industrial domains, however, has become much more sophisticated and integrated. It has developed such that key decisions are made at a much earlier or higher level of strategy, which are then acted upon by engineers. Examples include control systems for gas distribution, the manufacture of liquids and powders such as breweries and soap powders, railway networks and petrochemical plants. This IT support presents information that has already undergone considerable calculation and the outputs are such that the user cannot effectively dispute; it is relied upon and used to make a decision. This level of IT sophistication is not normally available or used generally within the construction industry. It is inevitable, however, that such higher level IT support systems will be developed and used within the construction industry in the future. Some early examples are starting to appear including large sophisticated project planning systems, robotics (Japan steel design and construction), product modelling based design processes (Heathrow baggage handling) and tender evaluation (Moustaffa and Riley, 1999). These IT systems are starting to produce results that cannot be checked in detail; a trend that is likely to continue.

Geographically Distributed Decision Making will increase.

Construction already uses a geographically distributed decision making process with parties located in different cities and often different countries. (EU funded BRICK) A key problem found in BRICK was the lack of sufficient band width to cope with real time working involving large drawings, virtual reality and large product models; as compression techniques improve across the whole multimedia spectrum; this problem is quickly being resolved.

International design and build contractors now have contract systems that use design engineers on the Indian sub-continent to carry out the more straightforward detailed design calculations. In many ways this is the equivalent to "globalisation" in manufacturing.

The trend in using multinational and cross-disciplinary teams will increase.

The Rapid increase in the power of hardware and software

The rapid increase in the power of computer hardware and increasing price to value ratio of both hardware and software means that this new hardware and software will inevitably be used by industry as it strives to improve its efficiency. This increased computing power inevitably leads to larger programmes and greater sophistication.

The outcome of these three trends is that the construction industry in the future will rely on engineering decisions made by large, sophisticated IT systems that the engineer will, effectively, not be able to check for correctness. Furthermore, virtual teams remotely located will rely on these IT systems for decision making and communication.

The Problem

Engineers will increasingly have to trust IT outputs that are not capable of being checked manually. In order for this to work in the construction industry in the future will, however, require the engineer to trust both the virtual team and the associated IT environment. To date, little research or understanding exists that suggest what the likely problems will be and the possible solutions.

It is the purpose of this paper to suggest some answers to this problem.

An Approach

In order to address this problem, other industrial sectors were investigated to see if they had already started working with large sophisticated IT systems in the way that the future construction industry will have to work; in this way any lessons already learnt could be transferred into construction.

It was found that Human Supervisory Control domains (HSC) were a suitable comparator for construction. These domains are large, complex manufacturing systems which are centrally controlled using sophisticated networked computer systems, with engineers and supervisory staff located in one control room using System Control And Data Acquisition (SCADA) systems and computer screens for control and communication. Whilst not exclusive, HSC and construction are suitably comparative in the following areas.

This environment is very often volatile, complex and involves high risk. Construction projects have a relatively long duration during which time client's requirements and expectations change. They involve many engineering disciplines which are expected to function effectively for numerous years. Considerable risk is encountered through unforeseeable conditions, arising predominantly from weather and ground conditions. It is now common place to advertise performance by using metrics which are dependent on satisfactory completion of the foundations.

The workers are interdependent actors continuously controlling a dynamic physical process whilst also interacting with each other. Construction utilises companies of architects, consulting engineers and contractors assembled from different organisations into virtual teams to undertake construction projects. These companies are physically remote from each other and from the project.

The need for trust in the technology as well as each other is vital. With the key construction personnel being remote from each other there is a need for the adoption of technology which will avoid the requirement for attendance at the construction site. Delays frequently occur as a result of the need for the architect or engineer to visit the site to resolve a problem. The technology to enable these problems to be resolved remotely exists but so far has not been widely adopted.

The continuous change in organisational structure, redeployment and reduction in labour, as well as having to continuously adapt to changing technologies, can have psychologically detrimental effects on control room operators. This is an increasing problem in the construction industry brought about by a shortage of skilled personnel and the need to increase profit margins by producing a larger output with fewer staff. Organisations are restructuring to improve efficiency, placing larger demands on their staff and even bring staff out of retirement to bridge the skills shortage. All of these have had a detrimental effect on the staff morale.

Interdependent team members are now becoming more remote from each other as well as already being physically remote from the plant they operate. A significant volume of detailed design work is now being undertaken in the Indian sub-continent as a result of skill shortages in the UK and lower labour costs abroad. The staff undertaking these designs are not able to visit the project and IT systems need to be used to substitute for site visits.

Therefore, it is clear that this domain closely mirrors construction, and the way it will have to work.

This paper analyses research that has been carried out into trust and team relationships in an HSC domain and it is proposed that this domain employs one of the most developed systems that we can, at present, use.

Systems used within HSC domains, although in use, are still developing and therefore still suffer from problems and unknowns. The psychological theory from which the research and experimentation builds is set out below

Research from the Human Supervisory Control Domain

The HSC domain increasingly relies on technological systems but this can cause potential cognitive overload for the user leading to problems. The concept of the control room operators tasks have gone through changes, from being reactive to proactive, (Zwaga & Hoonhout, 1994). Control operators need to feel confident that they can rely on their technology, they need to understand how it works and know that it will perform consistently and in line with their expectations.

Preston, 1999 argued that as information processing and telecommunication networks expand and one has greater access to infinite resources and information, physical proximity as a defining factor between people becomes redundant. Teamworking research however, both confirms (Jarvenpaa & Leidner, 1998; Walther & Burgoon, 1992) and refutes (Handy 1995; O'Hara-Devereaux & Johansen, 1994) this argument. This is an important but still unresolved problem within the HSC domain and in order to determine the substance of this, it is necessary to examine how these technologies *support* humans in performing their tasks and whether location is a pertinent factor. Factors such as functional fidelity, perceived usefulness in supporting tasks, (Davis, 1993) and whether people can trust a systems competency, (Muir, 1994), should be a serious consideration.

Within the HSC domains, as people are expected to abandon more and more responsibility to the computer (Sheridan, 1988); ultimately they need to be able to trust it. This has implications on system design, information representation and how systems are controlled from a *human* perspective, (Norman, 1993). Novel technologies have the potential of either enhancing or debilitating the nature of working practices, behaviours and cognition of the human operator. This in turn could affect the degree of trust operators have in a system and may differ depending of the type of technology used or indeed whether the team work face-to-face or apart. Previous research reported that the perception of trust only changed with the competence of the system and not from experience, (Muir 1994). Later studies however (Muir & Moray 1996), found that people do learn to compensate and make adjustments for system errors; hence trust could develop over time but only through experience. It is therefore important to understand some of the concepts of trust.

Concepts of Trust

Although there has been limited research into trust in automation, Muir's (1994) integrated model based on Barber's (1983) *taxonomy of expectancy* and Rempel's (1985) *process of predictability, dependability and faith* brought together these vital factors in the development of trust when using systems. Taking a more holistic view, trust is defined as the willingness to take actions whose outcome depends on people or systems outside ones control, thus increasing vulnerability to someone or something (in this case technology) beyond ones sphere of influence, (Zand, 1972). This willingness is based on a belief in sharing a common goal, Cummings & Bromiley (1996). Zand's Interdependent Spiral of Trust specifies causal effects of initial trust expectations on subsequent information sharing. It is this behaviour that reinforces the initial trust and consequently reinforces the information sharing. The result is a mutually reinforcing dynamic upward spiral of trust. Conversely, if the behaviour does not meet expectations or there is an initial expectation of mistrust, based on an unwillingness to act or lack of commonality, then the spiral deteriorates downwards, thereby reducing appropriate behaviour, creating further lack of trust. Furthermore, Cummings & Bromiley, (1996), in their research of organisational trust used three separate dimensions of trust:

Emotive, trust can be experienced as an emotive belief – having confidence in something or someone.

Cognitive, trust can also be thought of as knowledge or understanding thereby reinforcing expectancy of behaviour.

Behavioural, whether trust is developed or not is based on actual observed behaviour or performance of the person or system.

The two key problems identified from existing research are the relative merits of working in either isolation or as integrated teams and how trust can be developed in these working environments. The three dimensions of trust described above was used in the experimental research to help resolve the two problems identified.

Experimental Work to Resolve the Problems Identified

This paper draws upon research carried out by the Engineering Psychology Research Group at the University of Southampton (Stanton et al, 1999).

The problems that exists in the HSC domain were investigated by use of an experiment whose aims were to examine the concept of trust in technology whilst working in a simulated control room scenario. This was a dynamic task based on real-world gas distribution parameters as described below.

A simulated Gas Distribution System was developed using two dichotomous user interfaces, based on Rasmussens Levels of Abstraction Hierarchy model, (Rasmussen, 1986). The system simulated a gas supply network over a 24-hour period. The Gas

Distribution System consisted of a National Transmission System and four Area Distribution Systems. The National Transmission System supplied the four Area Distribution Systems with controllable amounts of energy. Each Area Distribution Systems supplied the end user with amounts of energy to meet demands. The topologies of the Area Distribution Systems were identical but with different underlying specifications. A framework of the network is shown in figure 1.

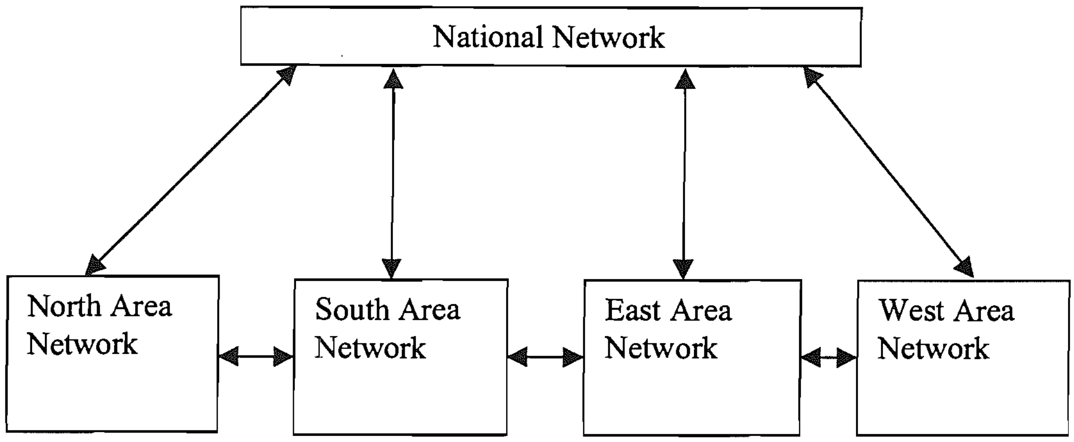

Figure 1 Schematic of the Gas Distribution System

In the experiment the process of distribution had to be continuously monitored to identify unexpected fluctuations in demand and then to decisions take to ensure that gas supply was satisfactory.

The experiment was a two independent-factor design. Four volunteers for the experiment worked on individual networked PC's to represent the geographical area gas distribution system - North, South, East or West. There were four experimental designs; either working together in the same location (proximal) or working in separate locations (distal) combined with using either a virtual or an abstract interface. Telephones were used in the distal condition to enable communication amongst the team members. Two dichotomous interfaces were used as one independent factor and team location as another. The task entailed balancing a real-time gas-network system between the four networked teams, attempting to serve the demands of their individual local demands whilst paying attention to meeting an optimum team performance measure of achieving optimum balance. The experiment used 96 volunteers.

The virtual interface (VI), (figure2) was based on the physical plant manipulations of a gas network. This 2D physical representation provided information on the overall predicted demand and supply over 24 hours, current flow rate, detailed independent profiles of flows and pressures for each consumer in the Area Distribution Systems and regulator and storage information. The network was controlled either by changing the overall supply to the network through the regulator or by increasing or reducing local pressure by emptying or filling the gas holder, (local storage). Effectively these actions replicated the physical manipulations of closing valves etc that would be used by engineers on the real site. The size of the holder changed to represent its state; when empty the holder was reduced in size and expanded as it was being filled.

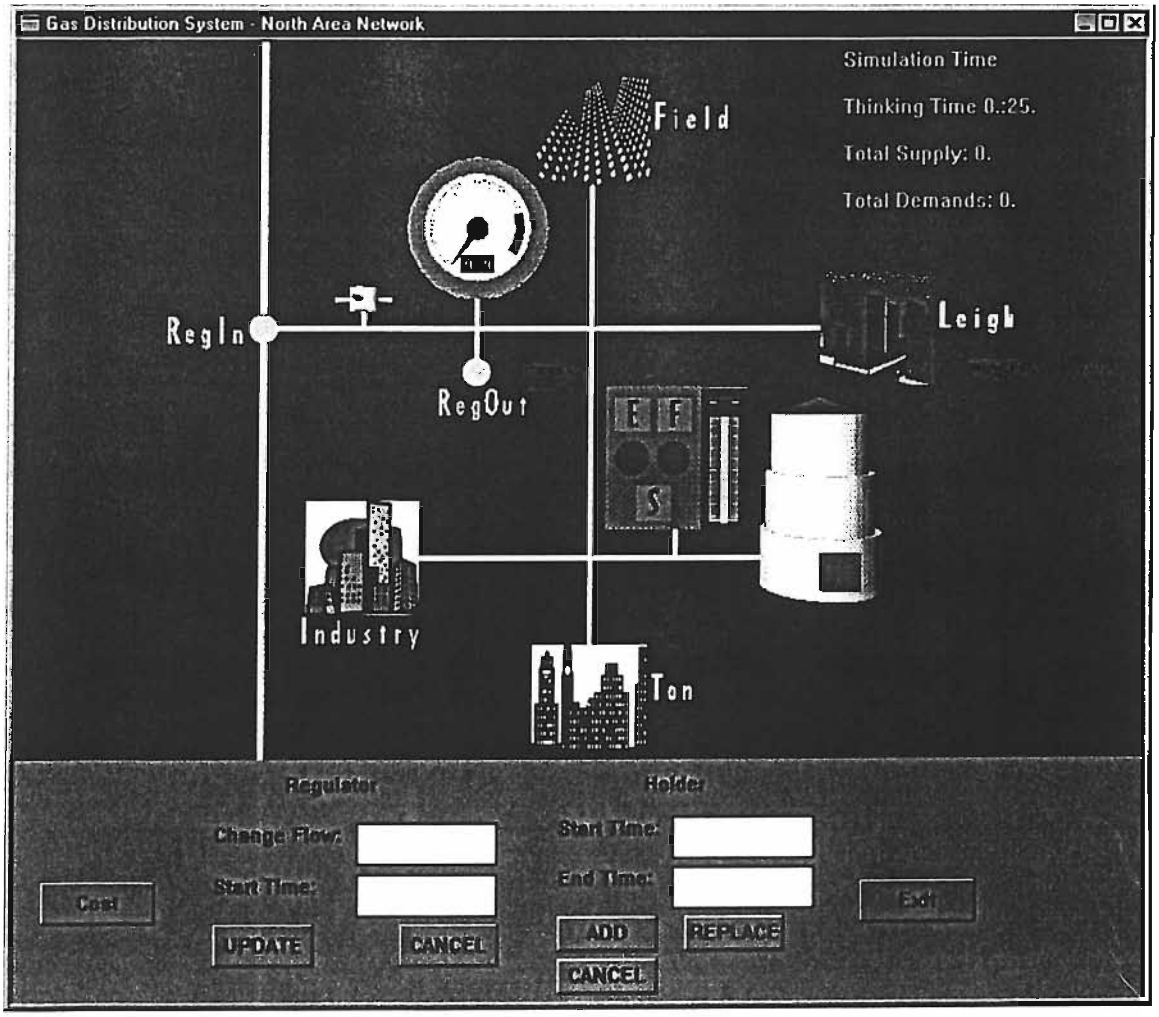

Figure 2 Virtual Interface

The Abstract Interface, (AI), (figure 3), was designed based on an abstract functional level of control, (Rasmussen, 1986). This interface provided end of day information on six functional parameters. In contrast to the virtual interface, the calculation of these parameters was done by the system and embodied the cognitive load that would have otherwise been required of the operator. Control functions were the same as the physical interface, through the regulator or holder, but no instantaneous or trended process measurements were given. If the system were in balance the polygon would keep its shape and stay green. When any parameters were out of balance - goals were not reaching optimum levels - the polygon would produce a different emergent shape in red to show a fault in control.

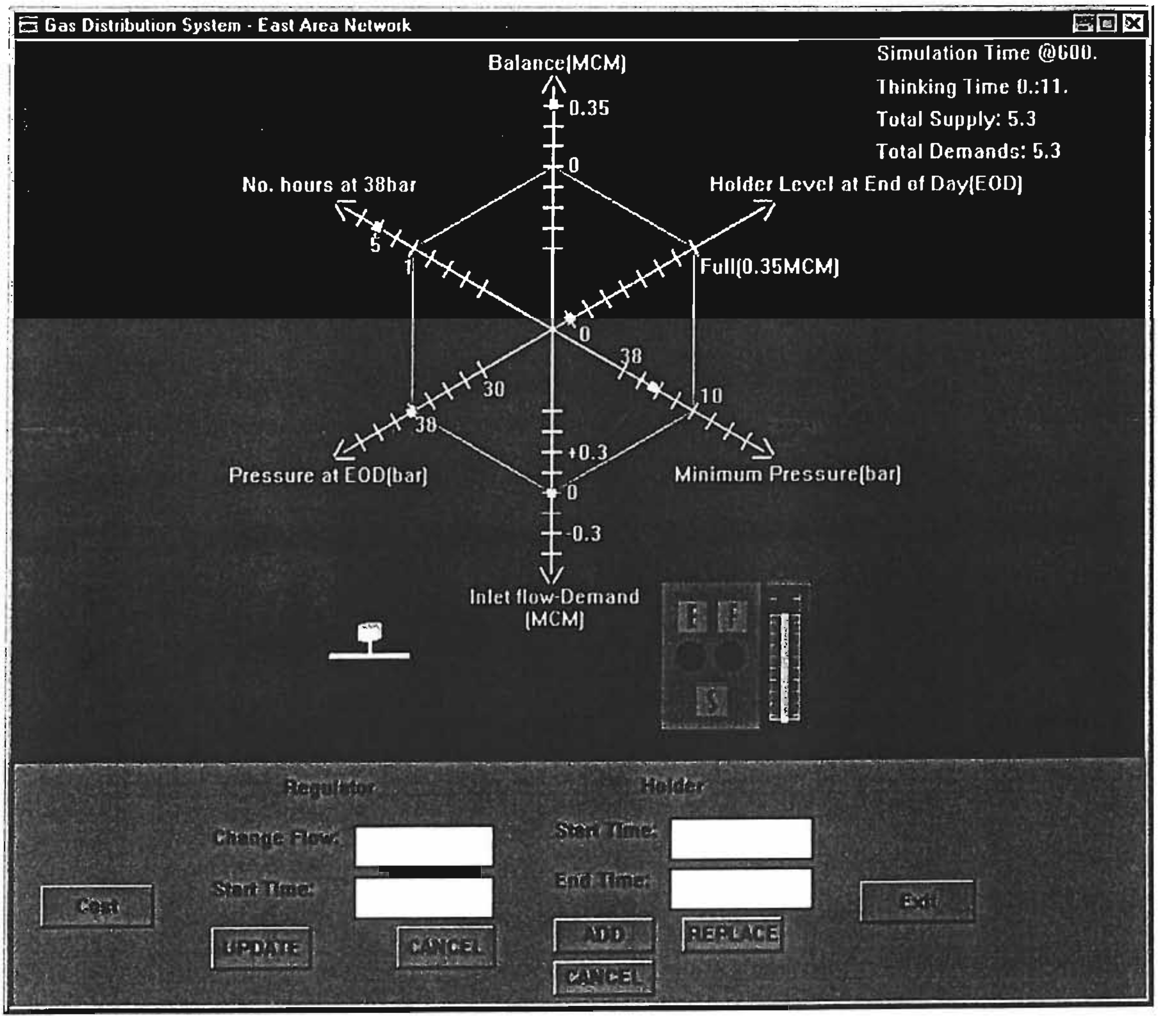

Figure 3 Abstract Interface

The perception of trust in technology was measured using a self-reporting questionnaire based on the trust construct of Cummings & Bromiley (1996) and completed by each volunteer.

Examples of the question structure are:-

I felt I could depend on the system to do its job – emotive

The interface helped me to make sense of the task – cognitive

The system was competent in its function – behavioural

The questionnaire data was collated in accordance with the four independent groups; (proximal-virtual, proximal-abstract, distal-virtual and distal-abstract). Each participant was asked about the degree of trust they experienced; scores of trust were from 1 = none at all to 5 = very high. Scores for each category of trust (e.g. emotive, cognitive & behavioural) were averaged to gain a mean score for each participant in each category

Transferable Lessons For Construction

The virtual interface replicated what engineers do in the physical sense, allowing the engineer to become involved in the actual decision making process, whereas the abstract interface carries out some of the engineering decisions before presenting that information, almost as a fait accompli. The virtual interface however, is likely to be the type of interface used in the future of construction. Although the virtual interface looks more like the real world, the cognitive load required to use it makes multidimensional problems difficult to solve in a holistic way. The abstract interface reduces the cognitive load but also removes the engineer from the decision making process, which they may find difficult to relinquish, hence debilitating trust in the system.

Although training was given in the virtual interface, system users were more concerned with understanding how the systems worked and how they would achieve the task rather than focussing on developing team relationships.

Specific training to develop and enhance trust in systems was therefore viewed as being essential. This would be particularly relevant where users had little or no knowledge of the actual process. If users were not confident in their own ability to perform the task, this often transferred into a lack of confidence in the system.

The amount and type of information presented in the virtual interface had a detrimental effect. It was certainly more complex, presenting trend plots and layered information, which needed to be accessed; hence creating more workload for the operator. It may have been that this detailed physical information presented in this condition, distracted members from the task, causing a *psychological remoteness* (Wellens, 1989), that ultimately reduced group performance and their perception of trust in the system. The *type* of information is more important than the amount of information capacity. In research of computer simulation studies for emergency services, Wellens & Ergener (1988) found that when controllers were given more information, teams became distracted, lost situational awareness and performance deteriorated.

The distal groups generally showed less trust, across all trust constructs. This may have been due to the fact that teams may have felt psychologically isolated as they were having to concentrate on a number of variables at once, e.g. control the system and communicate to each other at the same time.

When comparing interfaces however, measures of trust were higher in the distal-abstract group than in the proximal-virtual group for all dimensions of trust. This is a significant finding when considering the design of new systems especially for remote teams – it seems abstract functional interfaces are preferable irrespective of proximity, but physical detailed interfaces hinder teams who are remote. These results also indicate the need for consideration to be given to where humans are located in space as well as their communication and interaction patterns.

Physical proximity can not only influence communication methods and strategies but also when teams are separated, group situational awareness decays, which can cause a break down in collaborative decision making. Distributed decision making may be made easier if more abstract representations were presented where information could be quickly accessed on a generic level.

Within this experimental Human Supervisory Control domain, the abstract interface helped to trust to develop across all three dimensions, with cognitive trust scoring highest. This may have been due to experience increasing perceived understanding and knowledge of the system. This effect may be due to the abstract interface providing the user with information that directly relates to process goals, which validates Rasmussen's (1986) theory.

Distributed decision making may be made easier if more abstract representations were presented where information could be quickly accessed on a generic level as both performance and levels of trust were highest in the abstract groups.

Results indicate that holistic thinking with a more abstract functional display reduces the operator's cognitive workload and increases trust and performance, enabling more successful teamwork, which was independent of location.

The use of an abstract interface relies heavily on pre-existing knowledge of the users; they have to have gained real experience of the real systems that are being modelled by the new larger IT systems. Once this knowledge has been lost, either by redundancy, retirement or job changing this type of interface can be dangerous; it is little more than a computer game. This needs to taken into account when designing engineering and management training programmes.

Conclusions

This paper has proposed that the future of IT systems within construction will be so sophisticated that engineers and users will not be able to carry out immediate checks on the correctness of outputs. In addition the geographically distributed nature of decision making will increase. This will lead to problems of trust both between teams, working remotely and between engineers and their IT support systems.

The use of sophisticated computer control systems is gaining increasing prominence in construction. The outputs from these systems are such that engineers are unable to validate the outputs from the systems and must place total trust in the technology. In addition, the engineer will frequently be remote from the site of operations.

The construction of Kansai International Airport Terminal in 1990 required the use of an extensive and sophisticated system for monitoring and correction of differential settlement. This required the engineers to have confidence in the technology and jack up the columns as directed by the computer. In this situation it was not possible for the engineers to validate the instructions provided by technology; a similar situation as in the simulated control panel experiments. It required a considerable period before the engineers accepted that the system did indeed function correctly and that they could be confident in the outputs.

Distributed object environments offer the potential for a fully integrated design and management platform but has not, as yet, been widely adopted. Engineers still lack confidence in these systems, still preferring distribution of paper drawings. Even the use of electronic data interchange has gained little acceptance for the transfer of drawings and documents. Investigation of the causes for this reluctance to the take up of new technology found that compromise of quality assurance procedures was cited as the reason for retaining paper based systems. However, further investigation revealed that this was just an excuse, the problems identified are well within the present technological capabilities. The underlying message was that there are cultural barriers to the reliance in technology.

At the other extreme is blind faith placed in technology (Knapton 2000). Engineers, especially the younger ones, are allowing technology to replace their engineering judgement. In addition, technology is used in appropriately. Examples of this include a simply supported beam being designed using finite element software rather than simple bending moments. However, these engineers still place no reliance on the use of technology for integrating the overall design process, relying on technology only for individual elements of the design. This has resulted in lack of confidence in technology as many engineers consider that it has only succeeded in further fragmentation of the design process.

This indicates that for construction to benefit from greater reliance on technology some generic lessons need to be gained from the HSC domain and transferred to construction. The results from this experiment described above have been summarised and made appropriate for transfer to construction.

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The Application of BPR: A Case Study in Construction

D C Brown and M J Riley

Abstract

This paper reports on the successful application of BPR to the procurement of construction projects. The traditional construction procurement process is analysed and the failings and their causes identified. A case study of a Millennium project in the UK is described which was procured after re-engineering the procurement process. The resulting investigation of the project revealed significant savings in cost, reduction in delivery time and the highest quality of construction.

Keywords

Business Process Re-engineering, Construction Management, Project Procurement.

INTRODUCTION

The case study reported in this paper is an example of the application of Business Process Re-engineering (BPR) to support the worldwide drive to improve efficiency and reduce costs in the construction industry. The improvement targets set for the UK are shown in Table 1 and those for the USA are shown in Table 2. Many other countries are likewise setting their own targets. These targets are in line with the general thrust of the Latham report (Latham, 1996) and the Egan report (Egan, 1998) and are demanding but achievable as observed at the Hurst Spit Stabilisation Project (Brown and Riley, 1998) where these targets were exceeded.

Performance metric	`Improvement
Cost	30% reduction
Duration	25% reduction
Defects	Zero
User benefits	20% improved

Table 1: The key UK objectives of EPSRC IMI construction as a manufacturing process

However, it will not be possible to achieve any of these targets by simply forcing contractors to reduce prices even lower than at present with, the already, very slender profit margins. This price squeeze has, to date, resulted in comprises in quality leading to numerous defects and higher whole life cycle costs (Audit Commission, 1997). These improvement targets can only be achieved through major changes in the project procurement process together with changes in the relationships between client and contractor and contractor and designer together with integrating all major sub-contractors and suppliers in the project delivery process. This requires all parties to the project to adopt a holistic view of the project, looking beyond their individual horizons and objectives, to deliver a project which satisfies the client's expectations. The focus of all parties needs to move to best value instead of least cost.

Construction sector performance metric	Year 2003 target improvement	Ranking in importance*
Total project delivery time	Reduce by 50%	First
Operation, maintenance and energy lifetime costs	Reduce by 50%	Second
Productivity and comfort levels of occupants	Increase by 50%	Fifth =
Occupant health and safety costs	Reduce by 50%	Sixth
Waste and pollution costs	Reduce by 50%	Fifth =
Durability and flexibility in use over lifetime	Increase by 50%	Third
Construction worker health and safety issues	Reduce by 50%	Fourth
*Ranking in industry importance obtained from White House construction industry report workshop participants representing the residential, commercial, institutional, industrial and public works construction sectors.		

Table 2: US construction sector performance improvement targets to be achieved by year 2003

THE CONSTRUCTION PROCUREMENT PROCESS

The traditional project procurement process involves a highly sequential set of activities relying on competitive tendering for selection of the parties to undertake each construction activity. Contracts for these activities are awarded on the basis of lowest price with only limited attention being given to the ability of a given party to execute the task. In addition, there is no requirement for the parties selected to address how their individual undertakings will fit into the overall project and how they will interface between preceding and succeeding activities. The most common method for a client to obtain the lowest tender price for a construction project is by using a bill of quantities. In the context of civil engineering a bill of quantities is a list of the nature and quantities of all activities required to construct a project which is compiled using a standard method of measurement. These quantities are abstracted from the design drawings and the contractor is required to provide a rate for performing each activity. During construction the quantities actually used are measured and the contractor paid at the rate tendered but for the exact quantities used instead of the quantities estimated for the purpose of tendering. Therefore the final cost of a bill of quantities contract will invariably differ from the tender sum.

The major activities in the procurement of a construction project are illustrated in Figure 1. This highlights the area of the traditional project procurement process with the greatest potential for cost reduction. Research has estimated that 30% of project costs can be saved through better management of the design-construct interface (Brown 1994). In the traditional procurement process the project is fully designed and detailed construction drawings produced, after which the contract to construct the project is awarded to the contractor who submits the lowest tender for constructing the project. Two shortcomings are immediately evident in this approach. First, the designers, whilst able to produce elegant designs, have limited experience of how the project will be physically constructed and, second, there is no means for the design to exploit the particular abilities of a given contractor since the contractor is not selected until after the design is complete. In general, there is no mechanism for contracting knowledge to be fed into the design. This leads to two possible outcomes. Either the contractors submit tenders for constructing the project as designed (a conforming tender) which will reflect the added costs for construction difficulties or they will submit a tender based on their own design and construction methods for all or part of the works (a non conforming tender). Contractors will frequently submit both conforming and non-conforming tenders with the lowest price offered for the non-conforming tender. Whilst the non conforming tender is usually preferable to the client as a result of being the lower price, it must be recognised that costs have been incurred in employing designers to produce a design which is now to be discarded. Clearly, an even greater saving would be available had the original design not been commissioned in the first place.

Changes in the procurement process can, therefore, lead to savings in project cost and greater focus on the client's expectations. Partnering has been strongly promoted as a better mechanism for the procurement of construction projects and has produced encouraging results in both the UK and US (Larson, 1995). Partnering is a long-term negotiated association between a contractor and a client or a designer and a client, lasting typically four or five years, in which the client offers repeat work to the companies in the partnering agreement for the duration of the agreement. However, some 60% of construction projects are procured by the public sector (Harvey and Allan, 1993) where competitive tendering is required to satisfy the issues of probity. In addition, more than 85% of construction projects in the UK are still one-off projects (Brown and Riley, 1998) offering no opportunity to establish long term relationships between client, designer and contractor to reap the benefits of partnering.

This paper reports on a case study in which re-engineering the project procurement process resulted in the construction improvement targets being achieved. This was accomplished while still maintaining competitive tendering and with no long-term agreements or repeat work being on offer.

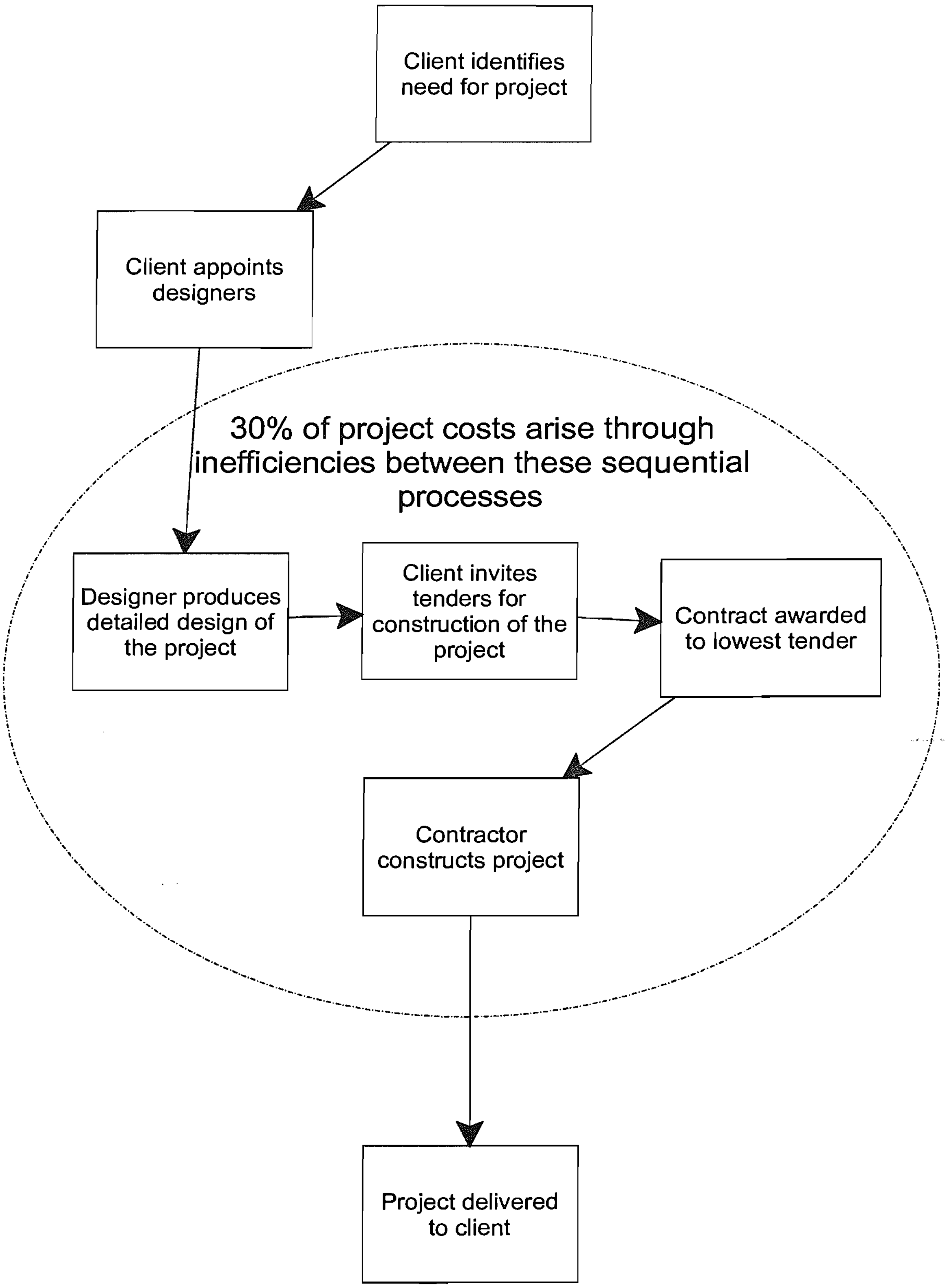

Figure 1: Traditional construction procurement process

CASE STUDY

The situation described above was recognised by Gosport Borough Council, a local authority in the south of England. Gosport Borough Council had been awarded a grant from the Millennium Commission to construct a Millennium Bridge over water, approximately 150m long, with an opening section over a navigable channel (details available at http://www.m4i.org.uk). The Millennium Commission is a central Government organisation which allocates money raised by the National Lottery to projects throughout the nation which enjoy public support and which will be lasting monuments to the achievements and aspirations of the people of the UK. The grant made available £1.4 million for the construction of the bridge subject to the conditions that the budget could not be exceeded, the bridge was to be completed by the millennium and the bridge was to be of millennial quality.

Following award of the grant, visits were made by Gosport Borough Council officers to recently constructed opening bridges in the UK and interviews with their owners carried out. This revealed several major problems with procuring opening bridges. In all projects studied there had been either a cost or a time overrun and in many cases both. Of even more concern than this was that a significant number of bridges exhibited problems with the opening mechanisms. Bridges failed to open, failed to close and jammed in operation. The road surface on one pedestrian bridge was so slippery that it had to be closed to pedestrians while a new surface was designed and installed. Investigation of the causes for these problems revealed that the main reason for these failures was the absence of integration of design and construction. The structural design was completed by the designers with little consideration being given to the construction methods, the mechanical and electrical installation were not designed but merely a performance specification produced and then finally a contractor was appointed to undertake the construction. The general approach can best be described as build something that is not perfect first and then put it right later on.

Gosport Borough Council and the authors decided that in order to meet the criteria laid down by the Millennium Commission and to avoid the pitfalls described in the introduction, the whole project procurement process would need to be completely re-engineered. In particular it was desired, first, to create a procurement mechanism whereby the contractor who was going to physically build the project could make an input to the design and, second, to ensure completion on budget the client would require a fixed price for construction of the bridge before contracts were awarded. The development of the re-engineered construction process was therefore carried out in close collaboration with the Council's auditors. The solution finally arrived at was to introduce a design workshop phase into the tendering process. The re-engineered procurement process developed is illustrated in Figure 2.

The architect, consulting engineers and mechanical and electrical designers were appointed using a new selection process which is outside of the scope of this paper. However, part of the design team selection criteria was their desire to work closely with the contractor during the design stage for the benefit of the project. The designers were initially required to produce an outline design for the bridge together with a bill of quantities. Four preferred contractors were then invited to submit a tender based on the bill of quantities. From the four tenders returned three contractors were selected to go through to the next phase of the procurement process. The three contractors selected at this stage had all submitted tenders for just over £1.8 million. Each contractor was now required to spend one day working with the designers to modify the design to improve its quality and buildability. Thus each contractor made modifications to the design to suit their own particular expertise and capabilities and used their construction knowledge to ensure the design maximised the quality of the final product. Each contractor was now required to submit a new tender based on the design that they had jointly produced with the designers. This tender was required to be a fixed price tender as opposed to the first tender which was based on a bill of quantities.

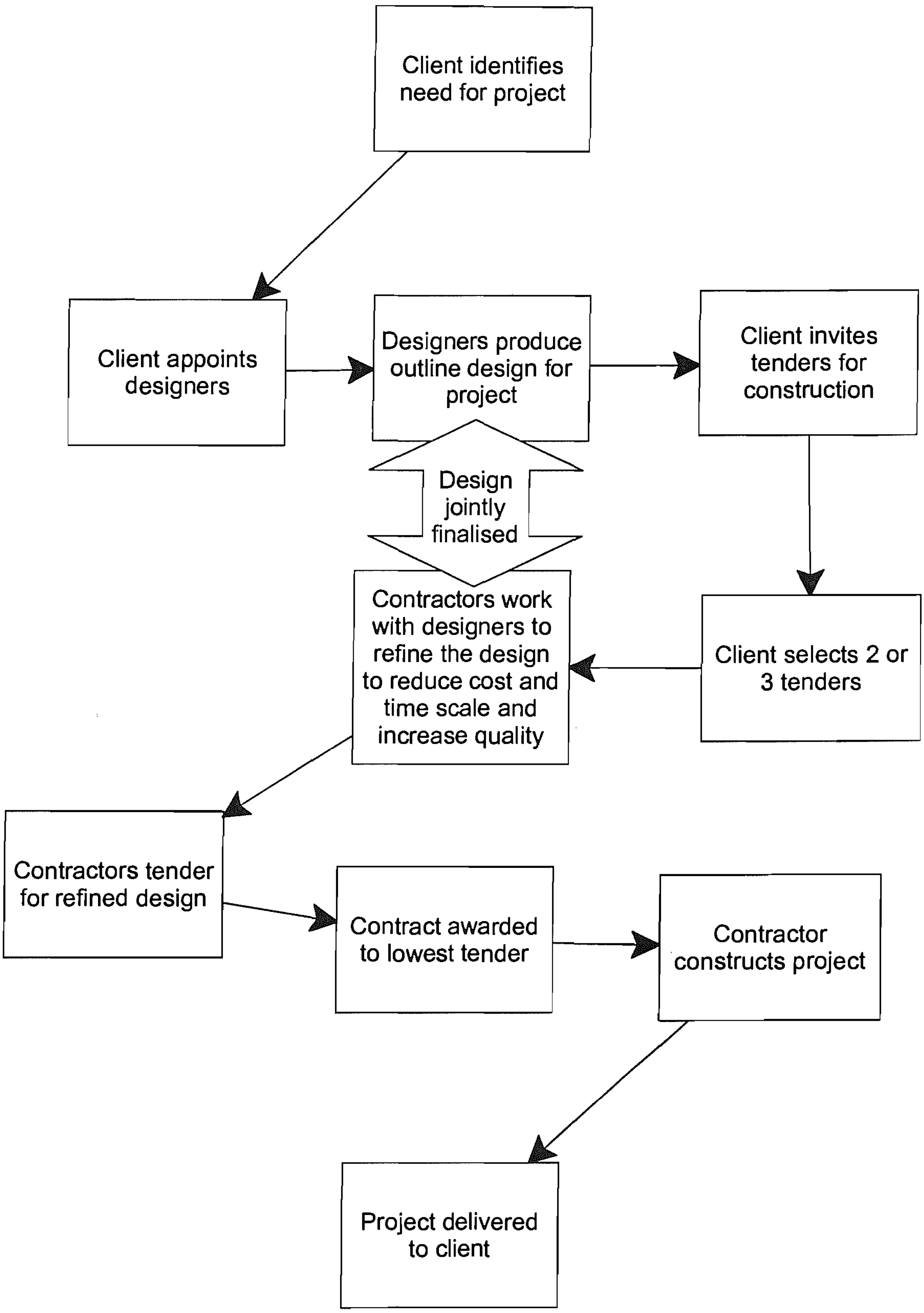

Figure 2: Re-engineered Construction Procurement Process

It was appreciated that this process would result in the contractors incurring costs during the time spent with the designers. Gosport Borough Council therefore decided that, on request, they would reimburse unsuccessful contractors for their time. No requests for reimbursement were received. Analysis of the reasons why neither of the unsuccessful contractors had sought reimbursement yielded some interesting findings. First, the contractors acknowledged that tendering incurred expenditure whether by the traditional route or by the re-engineered process adopted here and there was no significant difference in level of expenditure. Second, as there were only three contractors left at the final stage the chances of winning the contract was one in three; considerably better odds than for most tenders. Finally, the contractors wholeheartedly embraced the process of contributing to the design and felt that adoption of the new process by the wider construction industry should be encouraged. In particular it was considered that the process fostered a greater feeling of ownership of the project by the contractors and that they were now more than slaves to the whims of a designer.

The contractor who submitted the lowest tender after this stage, namely £1.4 million, had thought of a very innovative solution to a problem which had been anticipated would cause difficulties with quality but was considered essential to minimise environmental inapt. Both the architect and client wished to have a white concrete bridge but recognised the difficulties of maintaining colour consistency using white concrete in site conditions. The successful contractor proposed prefabricating white concrete shells for the bridge deck in a controlled factory environment where colour consistency in the concrete was easily maintained. In addition, these shells would then form the mould for the main *in-situ* structural concrete for the bridge thus reducing the quantity of temporary works required to support the wet concrete over a tidal lake adding to the cost saving and reducing the delivery time.

THE OUTCOME

The start of construction of the project was delayed by six months as a result of delays by central government in issuing an order under the Transport and Works Act. This Act requires an order to be made by the Secretary of State authorising any works which interfere with the rights of navigation. The Secretary of State is obliged by law to consider any objections to the works before issuing the order. The delay was beyond the control of Gosport Borough Council or any of the parties involved with the project and the delay was even more surprising since the application for authorisation for the project under the Act was completely unopposed. This potentially could have been catastrophic for the project with the start of construction not only being delayed by six months but also construction would now commence at the start of winter instead of the beginning of summer.

Furthermore, in spite of the delay being caused by central government the Millennium Commission, another government body, would not permit any slippage of the completion date. In the traditional procurement route this delay would have resulted in either the client incurring considerable additional costs in order to compress the construction programme if this was possible or the project being completed late thereby jeopardising the Millennium Commission funding. It is a demonstration of the success of the re-engineered procurement process that time compression of the construction phase of the project has been achieved leading to completion on time with no additional costs being incurred by the client.

The quality of both the design and the construction are considered by the client to be of the highest standard, considerably better than the majority of previous projects commissioned by Gosport Borough Council. This was principally due to the early involvement of all parties to the project which brought about a design in which buildability and attention to quality had been considered right from the outset. This high standard of quality was still achieved in spite of a significantly compressed construction programme.

An important feature of this project was the degree of co-operation between the parties to the project. This was in sharp contrast to the traditional construction industry where conflict and adversity are the norm (Brown *et al* 1999). This co-operation arose as a result of the early involvement of the contractors in the project which gave time for a culture of trust and co-operation to build within the project team.

This re-engineered procurement process has achieved the targets of improved quality, reduced costs and reduced project delivery times but has also offered two other benefits. Firstly, the client benefits from a fixed price tender giving confidence that the project will be completed on budget and, secondly, the contractor is involved with lower risk since the design has been produced to suit the contractor's expertise and experience and the contractor knows in detail before tendering the exact method of construction and scope of the works. It is also anticipated that because of the reduced risk incurred by the contractor as a result of the design and construction method being bespoke to the contractor's preferences and capabilities that greater certainty for the contractor's expected profit will result. This is fundamental as this procurement process will only continue to be successful if it can be seen that all parties to the project benefit from its use and not just the client.

In the project described in this paper the interaction between the client, contractor, designer and sub-contractors brought about an innovative method of construction. Whilst this may have come about through the traditional procurement route as part of a non-conforming tender this would have resulted in Gosport Borough Council paying for an initial detailed design of which the majority would have been discarded. Furthermore, other alternative construction methods were discussed between the contractor and designer some of which were considered to be of sufficient merit to be incorporated into the project. This forum for innovation only arose as a direct result of the procurement process used.

The re-engineered process brought about a culture change in all the parties to the project. The general approach adopted throughout the project was for the designers to describe their requirements to the contractor, the contractor would then suggest their preferred means of construction and the detailed design would then be produced. This is an almost unique process and yet another spin off from re-engineering the project procurement process. Furthermore, the change in culture between the parties enabled individuals from all parties involved to make suggestions for the benefit of the project without fear of ridicule and all suggestions thus made were objectively considered.

CONCLUSIONS

The case study reported in this paper is just one example of how the application of Business Process Re-engineering can produce significant benefits. In this example a saving of over 20% of project costs was achieved together with a significant compression of the construction programme. The project described has now been nominated as a demonstration project by the Movement for Innovation as an example of construction procurement best practice. Whilst the savings in cost are less than the 30% thought possible this project represents only the first trial of a new procurement process and further refinement of the process should lead to greater improvements.

The re-engineered procurement process addressed the shortcomings in the traditional process but, in addition, brought about a change in the cultural relationships between the parties to the contract. Further refinement of the process is needed to ensure that this change in culture occurs for every project and becomes the norm rather than the exception. Furthermore, the benefits of the culture change needs to exploited for the benefit of the project and for the benefit of all those involved.

The case study reported in this paper focused on the construction industry but the process is transferable to other industrial sectors. Considerable interest in the re-engineered procurement process has been expressed by the aerospace and ship building industries in the UK and the authors hope to investigate its application in these industrial sectors in the near future.

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A NEW PROJECT PROCUREMENT PROCESS

D.C.Brown, M.J.Ashleigh, M.J.Riley and R.D.Shaw

Abstract

Partnering has been proposed as a means of achieving 30% cost savings in a suitable organisational climate. How this is achieved within the construction industry involves not only a mutuality of purpose between project personnel, but appropriately applied methods of process. This paper addresses the issues surrounding the way forward in partnering. By applying systematic processes to selecting partners on a short-term construction project, a case study demonstrates that co-operative working can be developed and conflict avoided. Using a unique and rigorous selection methodology known as the Project Delivery Process (PDP), this millennium project, although still ongoing, evidences how significant improvements may be achieved in line with world-wide improvement targets.

Keywords: partnering, concurrent engineering, construction procurement, designer selection, contractor selection, project delivery process, construction management.

Introduction

Over the last decade the partnering philosophy has been a major vehicle in the world wide effort of creating significant improvements in the construction industry. Since the US Construction Industry Institute report "In Search of Partnering Excellence" (1991) and the initiatives for change in construction set out in the "Joint Review Of Procurement And Contractual Arrangements In The United Kingdom Construction Industry" (Latham, 1994) and the "Construction Task Force" (Egan, 1998), partnering has begun to have some effect on change of practice in some engineering and construction industries.

To this end targets have been established to drive this process forward. Although the improvement targets being set are ambitious, they are considered to be achievable (Brown and Riley, 1998). Table 1 shows the USA construction sector performance targets to be achieved by year 2000, (Wright et. al, 1995).

Construction Sector Performance Targets	**USA Government**	
	Target	Rank
Total Project Delivery Time.	Reduce by 50%	First
Lifetime Costs (Operation, Maintenance Energy)	Reduce by 50%	Second
Productivity and Comfort Levels of Occupants	Increase by 50%	Fifth =
Occupant Health and Safety Costs	Reduce by 50%	Sixth
Waste and Pollution Costs	Reduce by 50%	Fifth =
Durability and Flexibility in Use Over Lifetime	Increase by 50%	Third
Construction Worker Health and Safety Costs	Reduce by 50%	Fourth

Table 1: Construction Sector Performance Improvement Targets for the USA

Table 2 sets out the construction performance improvements targets for the UK that the government report recommended delivering, (Egan, 1998). These targets are measures of expected percentage annual improvements across the industry.

Scope for Sustained improvement Indicator	**Improvement Per year**
Capital cost – All costs excluding land and finance	Reduce by 10%
Construction time – Time from client approval to practical completion	Reduce by 10%
Predictability – Number of projects completed on time and within budget	Increase by 20%
Defects – Reduction in number of defects on handover	Reduce by 20%
Accidents – Reduction in the number of reportable accidents	Reduce by 20%
Productivity – Increase in value added per head	Increase by 10%
Turnover and profits – Turnover and profits of construction firms	Increase by 10%

Table 2: Construction Sector Performance Improvement Targets for UK

To try to achieve these targets, considerable emphasis has focused on transferring improved processes implemented with success in the manufacturing industries to the construction industry. It is acknowledged that some business process methods pioneered in manufacturing such as just-in-time (Riley and El-Hajjar 1999) and business process re-engineering (Brown & Riley, 2000) are beginning to produce benefits in the construction industry. Simply transferring technology or processes from manufacturing will not, however, achieve quantum improvement targets set for the construction industry. Significant improvements can only occur by drastic culture changes, which need to be endogenous to the industry. Companies need to be dedicated to moving along the continuum from adversarial towards co-operative culture.

The Construction Industry

Construction projects are executed by the formation of temporal virtual organisations. These virtual organisations are characterised by being composed of organisations with widely varying objectives and expectations. A feature of these organisations is that they are made up of designers, constructors, architects and other professionals in a formalised structure, for the express purpose of delivering a project on behalf of a client. Traditionally, however, the client has had little or no control over the cost, quality or final outcome of the project. The wishes of the client have been completely obscured by the adversity created within the virtual organisation through absence of co-operation. Successful projects are characterised by a focus on client requirements and co-operation replacing adversity, and inclusion of the client in the virtual organisation. (Brown et al, 1999).

Even the simplest of construction projects involve many different participants assembled into a once only team. The generic organisational structure of the construction industry is shown in Figure 1 (Riley & Brown, 2000) and illustrates the range of contributors that are required for a construction project.

The highly fragmented nature of construction has resulted in an industry blighted by the problems of adversity, poor quality, cost escalations and schedule overruns. It has been recognised (Table 2), that construction costs need to reduce, together with construction schedules and generally better value for money needs to be provided. The reasons for these problems can be directly attributed to a lack of co-operation between the parties to a construction project (Brown 1994).

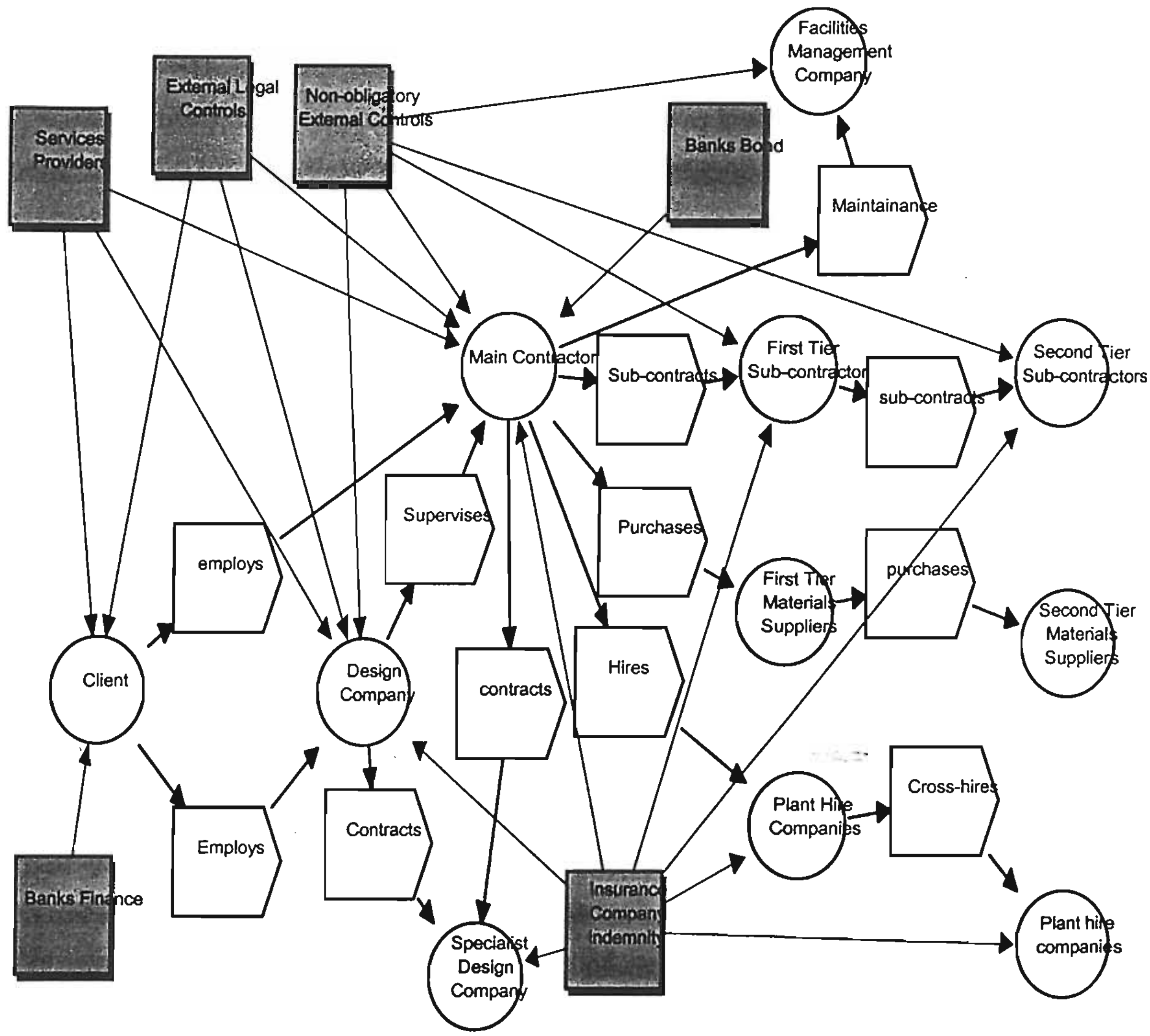

Figure 1: Construction Project Network

The fierce competition generated by competitive bidding based on lowest price has led to contractors bidding as low as possible to get work, but looking to contractual aspects of the work to obtain additional payment to create an acceptable profit margin. Pursuing these objectives leads to adversity. The level of adversity in the construction industry is reflected in the anecdote that by the 1980s, the two main products of heavy construction were claims seminars and new attorneys firms specialising in construction litigation (Lazar 1997). In the UK in 1995 the top ten law firms specialising in construction litigation made higher profits than the top ten construction companies but with less than 0.1% of the turnover, (Brown et.al, 1999).

There is a tendency for clients and contractors to assume an adversarial posture with each other as a result of the conflict between clients' costs and contractors' profits. This is essentially a no win situation since one party's gain is another party's loss (Larson 1997). This dynamic is further complicated since it permeates the supply chain between contractor and sub-contractor and contractor and supplier.

In 1992 Tarricone maintained that designers and contractors were traditionally adversarial, inefficient and resistant to innovation. It is estimated that 30% of the cost of a project can be attributed to failures in the design - construct - manage process (Brown & Beaton, 1990). A significant proportion of these failures can be attributed to incongruent goals and the consequent divergence of the various organisations participating in a construction project (Nam & Tatum 1992).

Management of the trade-off between the goals of cost, quality and schedule has been one of the central concerns of project management (Puddicombe 1997). Prioritisation of cost, quality and schedule between clients, contractors and designers, as well as non-congruent success criteria will cause conflict as to the definitions of a successful project. This can lay the foundations for conflicting courses of action and adversity between the project participants. The need for a new contract strategy to remove this bipolar attitude is clearly evident. Adversarial working is now being replaced by new ways of working in other industries (Towill 1992) and has led to great improvements. The scenario for a paradigm shift in the culture of the construction industry proposed by the Latham (1994) and endorsed by Egan (1998), has started the change process but there is still a long way to go. For non-adversarial working to become a tangible reality, there need to be principles and processes that are driven down the organisation as well as extended throughout the supply chain.

Past research has recommended what these principles should include, (e.g. Bates, 1994; Lusk Brooke & Litwin, 1997). Examples such as shared goals arrived at through consensus, mutual trust and respect, new attitudes and behaviour, new means of communication and commitment are all positive factors. These new trust-based attitudes, however, cannot be initiated contractually unless they involve cultural, structural and system changes. In their meta-analysis over twenty years of multi-national companies, (Lusk Brooke & Litwin, 1997) reported changes could not occur until systematic processes were implemented throughout the industry. They further claimed that these processes had to be driven by a set of critical management practices and influences that were mutually shared by all parties concerned. Lazar, (2000) substantiates this by maintaining that development or growth of any trust-based relationships can only be achieved by a set of behavioural strategies that are implemented, communicated and monitored consistently over time.

Contract Strategies for Co-operation

Recently, various new contract strategies have been proposed and tried in an effort to achieve co-operation between the participants in a construction project. Within the UK, these include design and build, management contracts and private finance initiatives (Construction Industry Board, 1996). For nearly a decade, partnering has been strongly promoted within the UK as the most beneficial way foreword. The Construction Industry Institute (1991) initially defined partnering as: -

> 'A long-term commitment between two or more organisations for the purpose of achieving specific business objectives by maximising the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organisation boundaries. The relationship is based upon trust, dedication to common goals, and an understanding of each other's individual expectations and values. Expected benefits include improved efficiency and cost-effectiveness, increased opportunity for innovation, and the continuous improvement of quality products and services'.

This approach would appear to provide a panacea for the construction industry's problems. However, although this describes what partnering should involve, this singular global viewpoint fails to address how to 'maximise effectiveness of participants resources' (CII, 1991). Too frequently, companies enter into partnering arrangements without any change from the traditional adversarial stance and thus still result in project failure through non co-operation. It is often difficult, however, to implement new practices and principles into an organisation unless fundamental changes are made to the actual processes in how contracts are initially formed and subsequently maintained.

This definition presents other problems. Firstly, the majority of construction projects are one off which often means no long-term business relationship can be established. Secondly, any relationship that is based on trust has to be developed from consistent patterns of behaviour rather than enforced contractually; which is an inevitable recipe for disaster. As Lazar, (2000) states 'there is substantial evidence that excessively "tight" contracts deter trust development and encourage a relationship based on "opportunism'. He goes on to argue that although collaborative behaviour may be enforced or coerced, it becomes costly and the relationship usually terminates in a low-trust/high cost conflict. Rather, real trust is a voluntarily entered state of mind based on consistent strategies of co-operative behaviours.

The partnering philosophy has been successfully implemented throughout the motor industry, retail trade and offshore industry (Towill 1997) for some years and yet there still exists a certain amount of scepticism throughout the construction industry, as many are only paying lip service to the principles of partnering. Even though endorsed by government bodies and pursued by some companies with success, there have been some extreme casualties of the partnering philosophy approach (Lazar 1997), with many companies still failing to make partnering a tangible reality. In a recent review in New Civil Engineer (Ibell, 2000), a director of a major construction company was questioning whether the industry had the 'understanding, courage and openness required to make partnering relationships work'. As Wilson et al (1995) maintain, for partnering to work there has to be a change in an organisations culture, belief in the ideal is not enough; rather there has to be a mobilising process that is driven down throughout the whole organisation, (Lusk-Brooke & Litwin, 1997). In order for this philosophy to become an actuality, a partnering culture has to be endogenous to each company before it can be shared as an inter-organisational relationship. How this could be successfully cultivated within the construction industry, was seen as an enigma.

A New Project Delivery Process (PDP)

A new Project Delivery Process (PDP) was developed by the Business Engineering Group as a way of promoting continuous improvement and innovation within the construction industry by selecting parties to a contract with the culture for co-operative working. It is a process that arose through observations of a highly successful project which, in spite of seven month delay in granting of licences by Central Government, was completed by the original finish date and considerably under budget with no defects; a reduction in schedule of 45% and cost saving of 30% (Brown & Riley, 1998). As a result of a the time-lag between selection of contractor and commencement of works together with the co-operative culture of both parties and the recognition of the need to complete by the original deadline, an opportunity arose for the contractor to become involved with the design. As a direct consequence, the buildability improved and project duration was reduced with no extra cost to the client. When all parties were ready to begin construction, a non-adversarial and co-operative team had already developed and continued to grow throughout the project. Subsequently, the authors considered that if this process of mutuality between the client, the designers and contractor could be built into the selection process before the start of a contract, it could prove to be a method of optimising quality of design, reducing costs and enabling a more co-operative project team.

Gosport Borough Council (GBC) is a local authority in the South of England. GBC had been awarded a grant from the Millennium Commission to construct a Millennium Bridge over water, approximately 150m long, with an opening section over a navigable channel (details available at http://www.m4i.org.uk). The Millennium Commission is a central Government organisation which allocates money raised by the National Lottery to projects throughout the nation which enjoy public support and which will be lasting monuments to the achievements and aspirations of the people of the UK. The grant made available £1.4M for the construction of the bridge subject to the conditions that the budget could not be exceeded, the bridge was to be completed by the Millennium and the bridge was to be of Millennial quality.

The project was further complicated by being in a Site of Special Scientific Interest (SSSI). SSSIs are sites designated by Government because they contain some of the UK's most important habitats and provide homes for many of the rarer indigenous species.

In 1997 the Audit Commission published the findings of its study of capital expenditure and acquisition by Local Authorities and the National Health Service in England and Wales. The findings of the Audit Commission (1997) convinced GBC that the traditional procurement route presented too great a risk of failure but the GBC auditors felt that partnering had the potential for conflict with probity. Essentially, some hard-hitting facts from this report were:

- 'In two out of five projects, the difference between the tender sum and the scheme design estimate was more than 15%'.
- 'Two thirds of projects surveyed were completed late and half of all the projects were 15% or more behind schedule.'

Furthermore, GBC had a finite amount of funding, there was high public expectation attached to this project and they were cognisant that the public sector generally had a poor track record of project procurement. From the client's perspective, therefore, their overall rationale for seeking a new procurement route, was about identifying objectives and recognising their own limitations; they wanted to be realistic about their expectations. GBC were also fully aware that they had to work within the constraints of a publicly accountable body. They therefore needed a process whereby they could identify partners who would understand these problems and who would work with them towards mutual objectives. There were several factors that GBC felt were crucial to the success of this project which were:

- To select organisations that would embrace their own cultural values.
- To select organisations that would work in a co-operative manner.
- To select consultants who would recognise the value of the other participants being involved with the design process.
- To select contractors that would wish to make an input to the design process.
- To achieve total integration of the project objectives.

GBC, therefore, enlisted the help of the Business Engineering Group to develop a selection process which would ensure that all of their potential problems were avoided and their expectations realised.

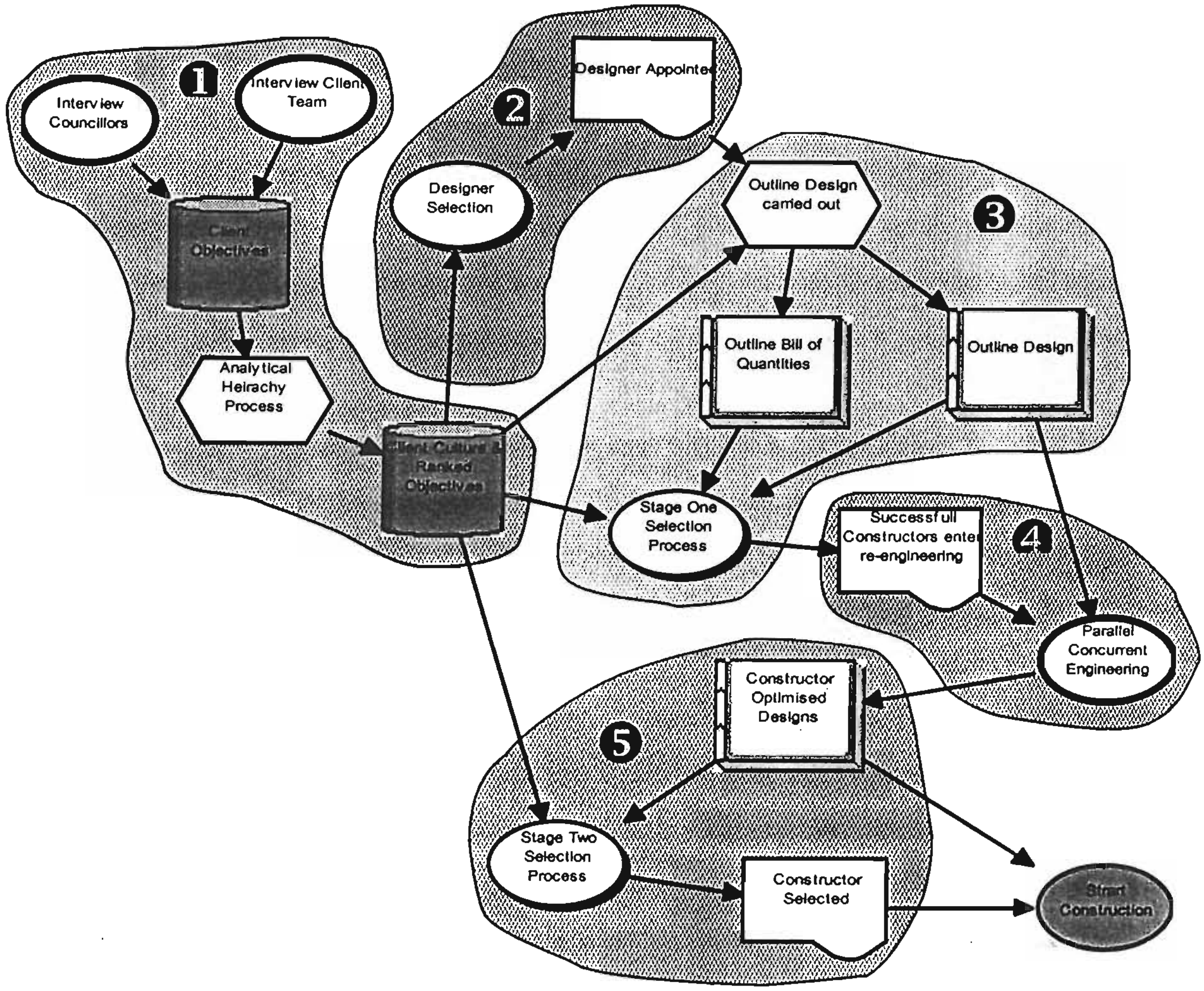

Figure 2: Overview of Procurement Process

Details of the PDP Methodology

The new PDP involves five key stages namely:

1. Analysis of client's objectives
2. Designer selection
3. Stage one constructor selection
4. Concurrent engineering phase
5. Stage two constructor selection

Within each of these stages, there are further integrated levels of analysis, measurement, evaluation and feedback. The PDP therefore involves an intrinsic co-operative method of working which also embraces some of the most crucial elements that multi-partner projects need to agree on. According to the latest report from government agency Construction Industry Council 'Guide to Project Team Partnering' (CIC, 2000), these success factors are namely; openness, clearly articulated mutual objectives, problem resolving structures, and commitment to continuous improvement. Adopting a structured pre-selection process has enabled companies that share mutual objectives and embrace a co-operative working culture to be identified. Consequently the project is more likely to achieve or exceed the performance targets.

The five stages of the process, mentioned above, will be described as they were developed for GBC's Millennium Bridge. A process map of this methodology showing each key stage is shown in figure 2. A general overview of each key stage will be explained followed by details of the mechanisms involved.

Analysis of Client's Objectives

This stage allows the true expectations and objectives of the project to be determined. For the project in question the council officers, the elected council members and the Millennium project team all had individual aspirations for the project. To identify the objectives the Delphi method (Linstone & Turoff 1975) was used and all interested persons were invited to respond. This process identified 32 objectives, which were assembled into a hierarchy with 8 super-objectives. The next step was to prioritise the 8 super-objectives. To achieve this the analytic hierarchy process (AHP) (Saaty 1977) was used with the respondents being the Millennium project manager and the engineering advisor. The final ranking of the objectives was taken to be the average of the two respondents and is shown in table 3.

Undertaking this process caused the client to investigate the exact expectations and objectives of the project. This enabled all parties subsequently engaged on the project to be provided with a clear statement of the client's expectations and objectives.

Designer selection

A detailed process map of this stage in the process is shown in figure 3. Only designers with an established track record of designing bridges were accepted onto the pre-qualification list.

Super Objective	Importance	Sub-objective
Quality	33%	To ensure that design quality translates effectively into physical quality To provide a structure with low maintenance and operating costs To engage designers with formal QA type procedures To provide a structure that will be of a quality worthy of being referred to as a "Millennial structure"
Design	29%	To engage designers who have a proven record of flair and initiative To engage designers who are able to show a grasp of a Millennial brand and concept To produce a structure that is sympathetic to environmental and planning issues To produce a design that is both individual and intellectually challenging
Cost	16%	The need to ensure that budgets are not exceeded or significantly underspent The need to balance capital expenditure against operational and maintenance costs of the structure The desire to examine options to enable choices to be made about costs The need to ensure a balance between the cost of any solution and its effectiveness
Culture	8%	A desire to work with organisations which understand the local government culture including issues such as probity A willingness to embrace new ideas and concepts A desire to work with others in a co-operative manner The need to work with others who are for flexibility in thinking and working methods
Political	6%	To meet the valid expectations of Bodies such as English Heritage and English Nature To meet the requirements of the Millennium Commission To reconcile the potentially different needs of the County Council and the Borough Council To recognise that any Gosport project is part of an overall Portsmouth Harbour wide scheme
Time	3%	The length of the overall design and construction period including any period required for a Public Enquiry Ability of Designers to forecast programmes accurately Completing works by dates agreed with the Millennium Commission The desire to examine options to enable choices to be made about the length of the overall programme.
Working Relationship	3%	To engage designers who will be able to communicate easily and effectively with the Council To engage designers who will be able to assist the Council throughout the project in its dealings with various parties To engage designers who are sympathetic to the Councils requirements To engage designers who are compatible with the Councils culture
Experience	2%	To engage designers who are able to demonstrate a record of building structures of proven quality To engage designers who can demonstrate a successful record at Public Enquiries To engage designers who have a proven record of producing structures that are adopted by the Highway Authority To engage designers who have been proven to produce designs with flair and imagination

Table 3: Ranking of Objectives

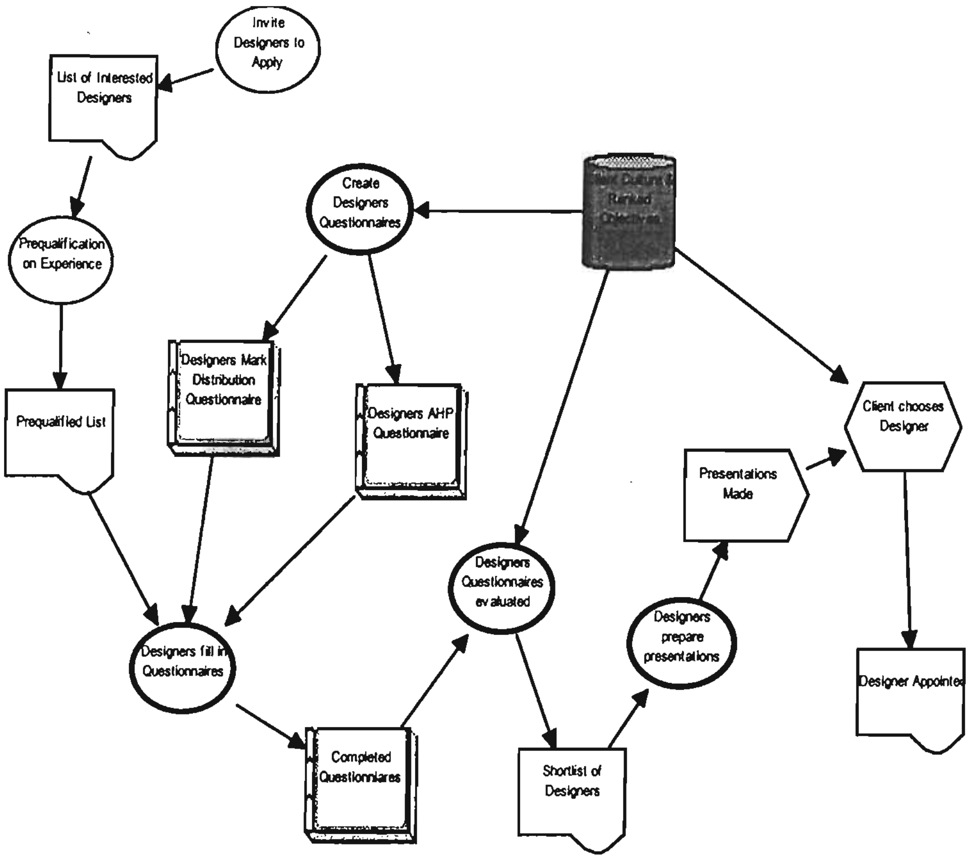

Figure 3: Designer Selection Process

Two questionnaires were designed in order to investigate four issues which were ranked in the order shown:

1. The attitude towards the involvement of contractors in the design process.
2. Areas of concern for the client.
3. The organisational culture of prospective designers.
4. The long-term benefits to the client.

The two questionnaires were in the form of an AHP questionnaire and a mark distribution questionnaire. The AHP questionnaire was used to validate the responses to the mark distribution questionnaire. This was to ensure that the responses were the genuine views of the organisation and not simply responses that it was thought the client might like to hear. It was clear from the responses that of the sixteen organisations responding to these questionnaires, two considered that contractors had nothing to input to the design process. Four organisations were shortlisted and asked to make a half-day presentation of their scheme design to the council. They were instructed that the presentations should be made by people who would be involved in the project and not by marketing departments. The successful company had assembled a team consisting of a structural engineer, an architect, an environmental consultant and a mechanical engineer. This proved to be the most balanced team presenting their scheme and were able to address all the concerns of GBC. The designers were then asked to prepare an outline design and bill of quantities.

Stage one constructor selection

This process is shown in figure 4. The initial part of the process is similar to that of the selection process for the designers. Analysis of the responses revealed that three of the thirteen contractors responding to the questionnaires felt that they had nothing to contribute to the design process. The contractors shortlisted by this process were required to submit a tender based on the bill of quantities and a quality submission. Contractors were obliged to satisfy the quality requirement for the project before their cost submissions were evaluated. One contractor was rejected for the project based on their quality submission alone without their cost submission being opened. Contractors who were successful were then invited to enter the second phase of the selection process.

Concurrent engineering phase

This process involved each of the contractors working independently with the designers to improve the buildability of the project, improve the quality and reduce the risk to all parties. This results in a bespoke design for each contractor suited to their own particular expertise and preferred method of working. GBC agreed that unsuccessful contractors could claim reimbursement for the time spent working on the project once the final selection had been made. However, no applications for payment were received.

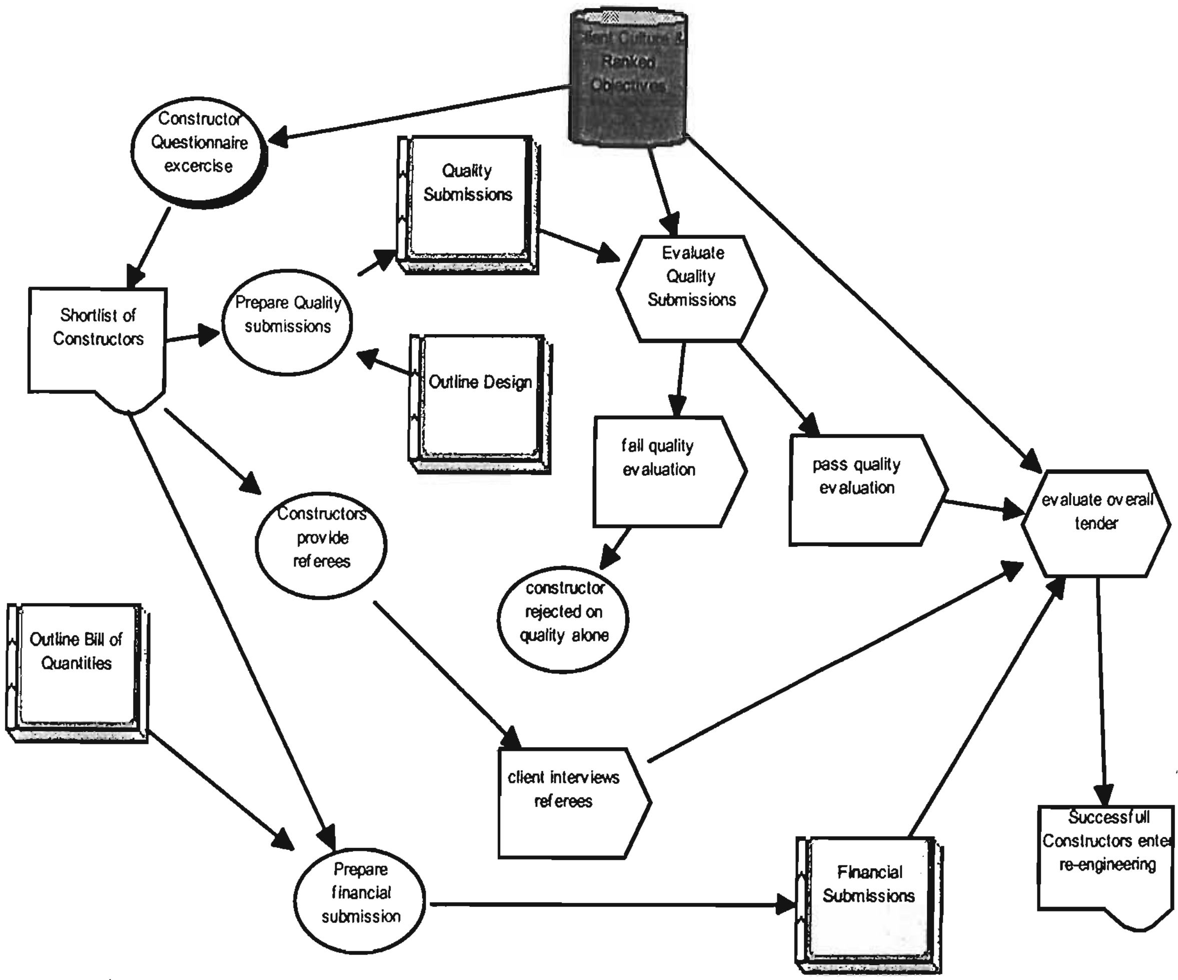

Figure 4: Stage 1 Constructor Selection

Stage two constructor selection

The overall process is shown in figure 5. Following completion of the previous task the contractors were required to make a revised quality and price submission. The final selection was made on the basis of 60% cost and 40% quality.

The Benefits

Adoption of this selection process has resulted in benefits to all parties involved. For the client there has been a 25% reduction in cost, a project that is on time and of excellent quality. The cost savings arose principally as a result of the concurrent engineering phase. The design was modified to improve buildability and hence reduce cost. The major savings, however, came as a result of minimisation of risk through clarification of design requirements allowing contingency sums to be removed.

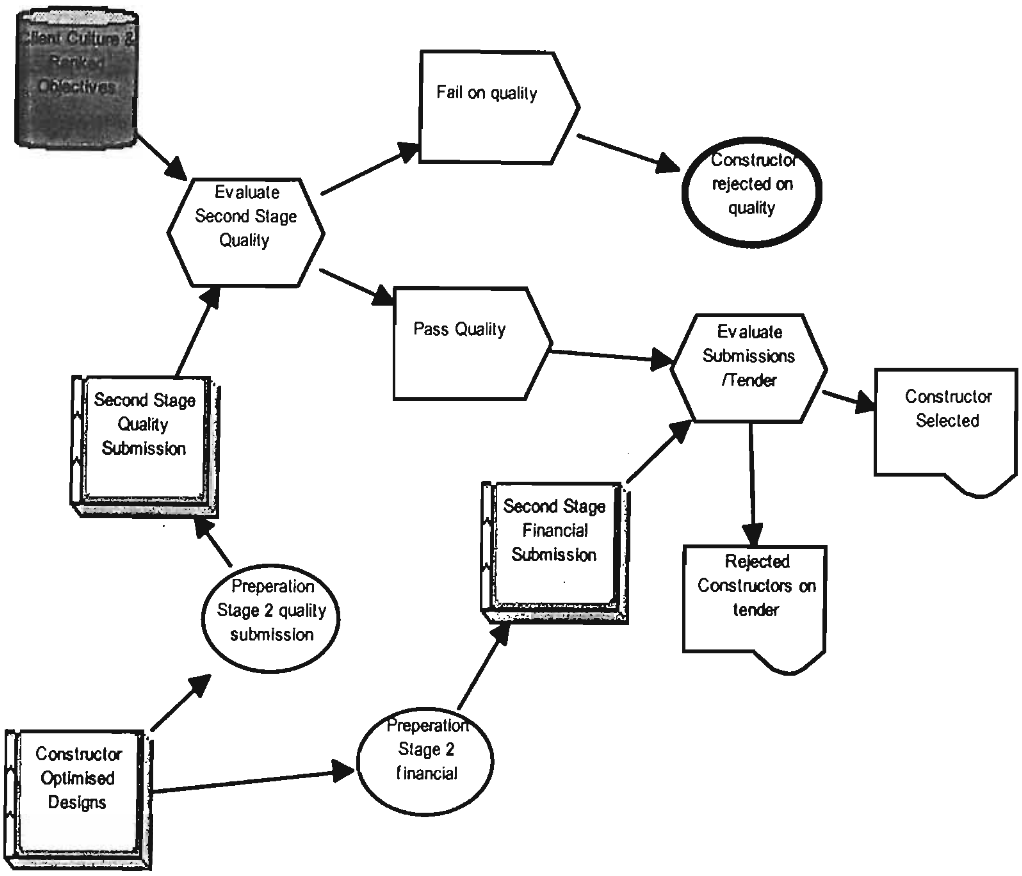

Figure 5: Stage 2 Constructor Selection

Certainty of quality was achieved through a major design change proposed by the contractor. The bridge design required the approach viaducts to be built in white concrete, which posed potential problems of maintaining colour consistency. The contractor proposed that pre-cast side panels be constructed using white concrete in a pre-cast factory where quality could be assured. These panels could then be used as permanent formwork and infilled with grey concrete. By significantly reducing the quantity of formwork and volume of white concrete required, this considerably reduced the overall costs. It also ensured a quality product; particularly the quality of the completed viaducts, which far exceeded the client's expectations.

The finish to the circular concrete columns supporting the viaduct was also a cause for concern. The contractor had originally allowed for the fabrication of circular steel shutters for casting the columns to ensure a quality finish. At the suggestion of the designers however, a mono-tube lined with Zem drain was used giving a cost saving with no compromise in quality.

The most important benefit to the contractor was greater certainty of profit. This was as a direct consequence of the concurrent engineering phase of the process. The designers considered that the greatest benefit to them was the elimination of abortive work. The co-operation that has arisen between the client, the designers and the contractor has in general resulted in elimination of wasted effort by all parties.

Conclusions

The methodology for the procurement of a construction project described in this paper exploits the philosophy that; if parties to a construction project are selected such that they have the culture for co-operation and a framework where every party that is able to contribute, is enabled to make a timely contribution to the project, then the probability of overall success of the project will be greatly enhanced. The process relies on having clearly identified objectives, which are clearly articulated and communicated to all parties involved in the project. It requires that all parties respect the contributions that others can make to the project.

The client considers that the new procurement method used for procuring the project has enabled all the objectives shown in table 3 to be achieved. In addition, the project has far exceeded the Egan targets shown in table 2. The client, contractor and designers have all reported that this has been the most harmonious and co-operative project team that they have been involved with. The contractor stated "this is the first project in which we have been able to use our experience to influence the design of the project".

Recently the Construction industry Council (CIC), June 2000) launched the latest 'Guide to Project Team Partnering'. The document is a template for multi-party partnering contracts. It emphasises stages of systematic processes that should be engendered into the project contract from the very beginning and offers a practical five-step selection programme based on quality. This endorses what the authors have already tested with success on a high profile project; that is to employ standardised procedures that can be applied to all stages of the project. This involved initiating a rigorous methodology based on quality 'where the whole process starts and ends with the needs of clients and users' (CIC, 2000, p4), which can in the future be employed all the throughout the supply chain. In an attempt to meet legislative procedure as well as to produce a non-adversarial co-operative project team, the authors re-engineered the project procurement process, which involved a unique selection procedure. Although this project is ongoing, it is believed that valuable lessons can already be drawn from methodology used to procure this Millennium project.

The Movement for Innovation (M4I) was established with Government funding following publication of "Rethinking Construction" (Egan 1998), with the task of driving forwards innovations in construction. Further evidence of the success of the project can be drawn from the fact that the project has been adopted by M4I as one of its demonstration projects as a result of the innovative procurement route adopted.

The PDP has now been enhanced and developed into a systematic methodology that can be applied to long or short term construction projects, allowing all partners to share experiences, decisions and goals. PDP can be described as being completely client centred as it was designed to try and reduce the risk of selecting team members who did not share the same ethos as the client. This process is considered to be unique, as it can be adopted by repeat or occasional clients and also acknowledges constraints such as issues of probity and public accountability associated with the public sector.

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