COORDINATED INFORMATION RETRIEVAL FOR BUILDING CONTRACTORS' TENDERING

A THESIS SUBMITTED TO THE COUNCIL FOR NATIONAL ACADEMIC AWARDS IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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ABSTRACT

This thesis represents the results of a programme of research investigating the problem of the coordination of data used in the preparation of tenders for construction projects by building contractors.

The approach is one of using data modelling techniques to produce a relational database as a dynamic store whereby all data used and produced by tasks of tendering can be inter-related in a single source.

The database is tested for its ability to manipulate data from a construction project to enable retrieval of data for individual tasks in an interrogative form.

Interrogations or retrievals from the database are assessed for their flexibility in terms of the content and level of detail of what has been quantified and the format or structure of data presentation. This flexibility is compared with that attainable through current alternative methods.

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VOLUME 1

1. INTRODUCTION

This introductory chapter indicates the scope of the work through a summary of the contents before setting out the hypothesis upon which the work is based. This hypothesis is supported by specific objectives of the research. The chapter is concluded by a commentary on the restrictions that impinge upon the nature of the work itself.

1.1 SUMMARY OF CONTENTS

This thesis has been presented as a programme of research work where a problem has been identified, a description given of the background to the problem, a methodology presented whereby the problem is to be solved and conclusions drawn regarding the contribution that has been made by the programme of work.

Much of the application of the work has resulted in the production of detailed documentation which although fundamental to the work itself, is not considered essential for the assessment of the thesis. For this reason the thesis consists of two volumes. The first is the essential documentation of the methodology, rationale and conclusions of the research. Volume two consists of a series of appendices in which the detail of results have been fully documented without distracting from the nature and content of the thesis.

Volume one follows the course of setting out the hypothesis and objectives of the study together with a commentary on the nature and restrictions of the work in an introduction.

This is followed by a comprehensive background to the work where the nature of the problem being studied has been expanded and defined, a review made of previous and current work of relevance to the study, and a description given of the philosophy upon which the work is based.

A separate section has been assigned to an explanation of the research methodology in terms of the stages of work, their justification, their expected results, and their general method of execution. This section also contains a definition of certain terminology and concepts which it is felt is necessary for the placing of the research within its context.

The detail of the execution of the methodology together with summary documentation of results and conclusions is given in three further sections corresponding to the stages of data collection, analysis and synthesis. A separate section is then given to the testing and evaluation of the contribution made by the research.

A further section is allocated to conclusions that have been derived from the study together with a number of recommendations of further study that the work has identified as being necessary to enable further contributions to be made in this subject.

All other work referenced is then assigned a single section at the end of the thesis together with a separate bibliography of related literature.

1.2 HYPOTHESIS

The hypothesis that is being tested is that;

The Building Contractor's project data requirements for tendering can be satisfied from one source of coordinated data.

1.3 OBJECTIVES

The specific objectives that will directly result from the testing of this hypothesis are;

To produce and validate a coordinated data model which encompasses the data used and produced by building contractors in tendering.

This objective is therefore to find the relationships which exist between alternative project data classifications such that information which is quantified with a certain content and level of detail under one classification can be related to information quantified with a different content and level of detail under a separate classification. This should be distinguished from the relationships that are currently possible under a hierarchy of classifications using indexing or coding methods.

To measure the level of co-ordination that can be achieved through the use of an inter-related data store.

The resultant data model will enable a level of flexibility in the format and content with which tendering data can be expressed. Evaluation of the level of flexibility will provide a measure of the level of co-ordination that has been achieved.

To develop an efficient method for interrogating a source of data such that all relevant data will be retrieved to answer the users need.

In using such a fully related store of information and by testing its appropriateness to individual tasks, it will be possible to specify the interrogation rules for each task of the tendering process. Such a specification will be in the form of the stages of relational calculus necessary to retrieve data from the data model.

As a direct result of testing the above hypothesis it is expected to be possible to establish a means of measuring the extent to which transliteration is possible between alternative classifications of construction project data.

Transliteration in this context refers to the ability to directly translate statements between alternative classifications. It is not currently known how project data classified in one way can be transposed to another classification while retaining its meaning. The testing of the hypothesis will enable a means of assessment of the extent to which such a conditional transposition is possible and will therefore provide a measure of the level of co-ordination that is inherent within the data itself.

1.4 COMMENTARY ON THE NATURE OF THE WORK

The research is addressing fundamental problems involved in communicating information as it is currently performed. Because of this it has met with, and will be likely to continue to meet with restraints from within different branches of the construction industry.

The following is a description of the background to, the rationale for, and the nature of these restraints together with an explanation of the implications they have had on both the way the research has been executed and the acceptability of the research in the future.

1.4.1 Restraints of current industry practice

The execution of processes in general, and tendering in particular, has been influenced by evolutionary factors.
Competitive tendering has traditionally been based on an estimate of costs, the derivation of which is a separate and single function of contracting. There has been insufficient interaction with or feedback from those responsible for the execution of construction. Because of this, estimating techniques have been based on a method of pricing that 'seems to work' rather than on any evidence or monitoring of estimated costs and actual costs at a detailed level.

Similarly, those responsible for the preparation of tenders tend to be drawn from different organisational units of a contracting firm. Departments may typically include; estimating, tender planning, buying, insurances and legal, contracts management and surveying. This has meant that information prepared by each department has traditionally not been coordinated with or cross-referenced to that produced by others.

Finally, the thinking of those responsible for preparing tenders has been conditioned by the repetitive practice of pricing traditional tender documentation. This has meant that although inadequacies with

present methods are evident, the ability to specify improvements in information is restricted to current perceptions of practicability. In other words, those responsible for preparing tenders are unable to specify their methods of working or their information requirements beyond the terms of information with which they are familiar.

The implications of these restraints upon the execution of the research have been evident in three ways.

Firstly, the problems of assessing information required and methods of provision have not been possible to ascertain directly from the expressed opinion of practitioners. This is supported by a previous studies (1) which indicates the problems of current practitioners attempting to specify improvements to systems which are a radical change from those which are currently practiced.

Also, modelling of the process of tendering has had to be expressed in sufficiently general terms such that reference to particular organisational units or contracting firms can be eradicated from the general model. This is necessary because of the irregular pattern of demarcation between organisational units that has been found in different firms operating within the industry.

Finally, an implication of the current practices in estimating and tendering, has meant that methodology has, in systems terms, been based on systems examination rather than systems design, that is based on the way things are done rather than the way things should be done. This means that perceived inadequacies in current practice have been built into the modelling of the research rather than designing new practices. This has been necessary to incorporate both subjective assessment of modelling by practitioners and also to enable data in the form of current tenders to be directly of use within the study.

1.4.2 Professional restraints

In a similar way to the practices that have evolved in contracting practice as outlined above, the other construction professions have developed practices which are perceived as incompatible with the aims of coordination of tendering information. Construction professions, in particular quantity surveying, are centrally involved in the manipulation and generation of data that is used by contractors in tendering. There are additional barriers to the transfer of data between organisations over those that exist for transfer between different units of the same organisation. Such barriers relate to the coordination and cross-referencing of data stores, the purpose for which data generation is made, and the knowledge and experience which is used in data generation.

The professional restraints in themselves are further complicated by the concept of a temporary multiple-organisation (2) which is brought together for each project such that methods and techniques tend to be based on the perceived role of the profession rather than that which is particularly required by other members of that temporary team.

The nature of the professional conflict is being influenced by development and change that is taking place within the industry such that competition is increasing between professions as opposed to an enhanced level of inter-professional collaboration and cooperation.

The effect of the above professional restraints has again meant that both research modelling and industrial data have included perceived inadequacies with present methods.

The scope of the research would have ideally encompassed the activity of more than one professional role. This has been made impracticable by the above factors and therefore the research has been designed to encompass a single professional role, that of the building contractor.

The part of the building contractors role that has been studied does include a significant interface with other construction professionals.

1.4.3 Restrictions of other current research

In addition to the restrictions that have been identified within the industry itself, problems have been encountered in relation to other current research. The subject of coordination of construction project data has been debated and researched by industry and academic institutions for a considerable time. The pace of current work in the area has decreased although considerable resources continue to be devoted to the problem.

The approach of the majority of this research activity has been to attempt to classify data according to a single hierarchy which aims to be all-encompassing in its form. It is judged that this approach has inevitably led to the resultant classifications merely solving a part of the overall problem without any fundamental solution having been found.

The most significant current research in this area is that which is being carried out jointly by the professional bodies representing Architects, Quantity Surveyors and Building Contractors under the direction of the Coordinating Committee for Project Information. The approach is to derive a common arrangement of work sections by which drawings, specifications and measurements may be coordinated. This work is in direct conflict with the approach of this study where instead of an ideal classification or common arrangement hierarchy, a convention or framework of classifications is being taken directly from those currently used together with a mechanism by which such conventions may be interrelated. It is the testing of the above principle of coordination which forms the subject of this study.

It is felt that a problem inherent in much current and previous research has been its sponsorship by the professional institutions whose restrictions on the research have already been identified. The research has therefore consciously avoided any particular affiliation to a professional group. The scope and nature of the research has been accordingly influenced.

1.4.4 Summary

In summary, a number of restrictions have been identified to the programme of research which have been of importance in determining the scope and methodology. Such accommodation has been inevitable for the completion of the study.

The eventual application of the research is to be similarly restricted given a continuance of current industrial and professional practices. It is envisaged that the application of the research would make imperative a re-appraisal of organisational and professional procedures which would be made effective by enhancements to the efficiency and communication that would follow. The results and consequences of this re-appraisal have not been elaborated in the study but the intention has been to clarify the need for, and the benefits from, change.

Issues raised by Bryant (3) at a recent conference of researchers highlighted the point that these criticisms are often made and that they have served to distance industry from research. It is claimed that this has made dissemination and implementation of research ideas more difficult and less likely to be achieved.

This point is recognised and the above restrictions are only intended to place the research within its context and indicate the reasons for the research being executed in the way described. The restrictions are not felt to be prohibitive to the implementation of the results. A strong level of co-operation has been maintained throughout the programme of work with a number of large contracting organisations

whose representatives fully appreciate the problems at which the work is addressed.

The problem of the restraints to the rationalisation of construction industry information systems was recognised by a CIB group report.

> " Any rationalisation of the information system within the construction industry must be based on evolutionary principles, because the greater part of current practice is based on procedures which have evolved over a considerable period of time. The information system which has developed is therefore complex, based on convention and practical needs, and closely interwoven with ways of thinking prompted by tradition and professional and technical training. " (4)

With this in mind the thesis is presented as a staged improvement in the subject area of data coordination. In isolation it is unlikely to significantly influence the methods of industry. As an area of fundamental research which is to be continuously developed it will ease the process whereby further applied research can make this transition.

2. THE BACKGROUND STUDY

This chapter of the thesis forms the background to the work and consists of three sections. The first forms a precise statement of the problem which is being addressed which is then followed by a comprehensive review of previous work. The chapter then concludes with a statement of the philosophical approach adopted by the study as a result of this historical review.

2.1 STATEMENT OF THE PROBLEM

The study is concerned with the problem that information used by those responsible for the preparation of construction project tenders has certain inadequacies in the format in which information is presented, the content of information that has been quantified, and the level of detail in which information is expressed.

The need for re-grouping of measured work and for remeasurement itself, is evidence of both the lack of flexibility within project documentation and an inability to relate different sources of project information.

There is insufficient knowledge regarding the information requirements of construction project professionals such that a fundamental solution to the problem has not been found.

Before proceeding to examine in detail previous work in this area, further reference is given to the nature of the problem itself.

The many previous studies have identified the problem in different ways and reference to their description is of relevance.

A study commissioned by the RICS in 1966 (5) identified fifteen different occasions on which measurements of a project are made. Many of these measurements are performed by the same person but for slightly

different purposes. Other measurements are prepared by different people from the same contract documentation. Others are measurement for the purpose of updating but complete remeasurement is often necessary. Many of these measurements are only made necessary because the documentation of earlier measurement has not been either orientated towards other potential uses of the information or made sufficiently flexible in its format and content to allow use by others.

The Joint Working Party on Measurement Conventions set up by the RICS and NFBTE reported in 1972 in a similar vein suggesting that;

> " Regardless of the form in which it is presented the cost of producing original project data is not inconsiderable. It is therefore sensible to attempt to derive from any set of data the greatest possible use for related functions and purposes." (6)

and that

> ".. a high proportion of wasted effort is due to the lack of recognition by the original extractors of information, of the needs of subsequent users." (7)

A report that was produced as part of the D.O.E. sponsored data coordination study further identified a part of the problem in suggesting that;

> "The Construction Industry needs a comprehensive system of related classification to organise its information. The needs of industry can not be met by a single collection of unrelated categories." (8)

Finally, a report of a study carried out at Newcastle Polytechnic highlighted the problems of transfer of data between organisations;

"... difficulties arise from having to pass information through a number of professional boundaries, or interfaces, that have different data and information requirements with respect to format and content." (9)

and

"The basis of the information in all the systems (existing classification systems) is the same. The difference may be put down to context, structure and level of information detail required." (10)

The above sources have been used to indicate the nature of the problem which is being examined which draws upon measurement, classification, information requirements, coordination, communication and presentation of construction project data.

The problem can be defined as being that of the coordination of construction project data for the purpose of providing sufficient flexibility in its presentation such that a variety of information requirements can be satisfied from a single source.

Previous work in relation to this problem is now reviewed to further clarify the scope of the research and to indicate the course of action to be followed.

2.2 PREVIOUS WORK

In examining the problem area that has been defined, a wealth of publications have been found describing previous work that has been carried out. Such work has been undertaken by a number of types of sources or research models as described by Lansley (11). This includes; individual academics, groups of academics, combinations of academics and industrial organisations, industrial organisations in isolation, professional institutions, private research consultancies, government research bodies and international research bodies.

The work reviewed here has been undertaken over a period of nearly thirty years with variations in the degree of intensity of working within that period.

The work can be classified in terms of the approach taken and by aspects of the problem which have been addressed and in which a contribution has been made.

The remainder of this section consists of a comprehensive description of previous work classified by the aspects of the defined problem which have been addressed. Where appropriate, the position adopted by this study in relation to previous work has been commented upon.

2.2.1 Formats for Bills of Quantities

This represents the first category of previous work to be described because it was the first chronological category where significant conclusions and contributions were made. More fundamental contributions more central to the problem were made at a later stage.

Early attempts at improving the coordination of data focussed upon that which was contained within a bill of quantities. Attempts were made to reformat the document according to alternative classifications. The traditional form of classification had been to group measured items

under traditional trades that would be primarily responsible for carrying out the work.

The elemental bill (12) was aimed at making information within the document of greater use to quantity surveyors in design cost planning but was found to be inappropriate to functions of contracting. This is held to be due to the fact that an elemental classification was inappropriate to the majority of the work of building contractors. It was an early attempt, however, to make measurement information of wider and more general use.

The sectionalised trade bill (13) was an attempt at combining the formats of an elemental bill and a trade bill by the use of a faceted classification. Reordering of bill pages would be performed for alternative uses of the document. This particular development was not found to be popular within practice but is important to this thesis in that it recognises the need for alternative formats of information for different users and makes an attempt at providing such flexibility. This approach has been one that has been followed in the work as opposed to the alternative of attempting to derive an ideal classification which satisfies all potential users simultaneously.

The general trends in the thinking of bills of quantities at the time was towards a contractor-orientated document and the result of this trend was the proposal by Skoyles of the Operational bill of quantities (14) and its later amendment into a bill of quantities (operational format) (15). The first of these made an attempt to change the content of what was being quantified from a part of a building as it is fixed in position to an activity or operation that is to be executed by the builder in production. The bill of quantities operational format recognised the fact that to be able to quantify construction processes meant excessive assumption by the design team regarding the methods of construction and that instead broader operational categories should be used to classify items of finished work.

The important conclusion that can be drawn from the work on operational bills in relation to this study is to make the distinction between alternative formats and contents of data. Format refers to the classification system by which data is structured while content refers to what it is that is actually being quantified. The operational bill attempted to make construction activity the content of a Bill of Quantities. The Bill of Quantities (Operational Format) saw a reversion to the previous traditional content with activities becoming the format by which the document was structured.

A study carried out as part of an undergraduate course at the Polytechnic of the South Bank by Lee (16) also investigated the field of formats to bills of quantities and made the suggestion of a new format. The format was to be based on a hierarchy using construction elements, design and structural elements, descriptions and specifications, a locational analysis and units of quantification. Lee's work also addressed the content of data and its level of detail by suggesting a reduction in the number of items to be measured and a corresponding rationalisation of their description.

On the subject of alternative bill formats, reference is made to the work on civil engineering bills of quantities. Early research by Barnes and Thompson (17) led to the adoption by the profession of the 'method-related bill'. This used a system of classification that was based on locations and activities and also allowed alternative contents including the measurement of method, time, value, and quantity. The result is a single and specific hierarchy classification.

Annotated bills of quantities (18) are a form of locational formatting of traditional documentation. Notes indicating the location of measured work items appear next to individual items or in a separate cross-referenced schedule.

2.2.2 Reports on the presentation of Measurements

As a result of this varied activity in the formatting of bills of quantities, there followed a series of studies on the way measurement information was to be presented.

A study prepared by Higgin and Jessop (19) further emphasised the need for an alternative presentation of information. The common theme to these studies was the concern that was felt regarding the wider use of measurement information and the fact that variable requirements needed to be satisfied by a new approach.

The Royal Institution of Chartered Surveyors (RICS) established a working party (20) in 1965 to examine the standardisation of bill information and its use for purposes other than tendering. The use of locational bills was a further format suggested by the working party together with a standardisation of terminology and description. This area together with the agreement of a preferred vocabulary has resulted in a number of developments including standard phraseology for bills of quantities (21), standard specification clauses (22) and a construction industry thesaurus (23).

2.2.3 Theories and Methods of Measurement

Any analysis of the innovations in document formats should also take account of the corresponding developments that have taken place in the content of documents. As far as this study is concerned, this primarily relates to developments in the Standard Methods of Measurement. The first such standard was published in 1922 (24) and a succession of revisions have been made (25) primarily to reflect changes in the technology and organisation of construction. The most recent standard is SMM 6 (26) which was first published in 1978 and was designed to be a temporary revision paving the way for the radical changes to be contained within SMM 7. The responsibility for the development of these standards now rests with a development unit formed by representatives

of the RICS and the Building Employers Confederation (BEC). This unit has twice published proposals for discussion (27,28) relating to its developmental work and has also produced a draft version of the new standard (29) together with a draft practice manual (30) for limited circulation and comment.

One intention of the later standards has been to include the aim to widen the use to which measurement can be put and although such standards refer directly to the content which measurement should take, no guidance has been given on the format of the information produced. The contribution made on the content of measurements has been of a detailed nature with revisions having been made to take account of current trade demarcations and technologies. No fundamental change has been implemented or suggested in moving away from the concept of measuring construction work as though it is completed and as fixed in position.

Methods of measurement have been much used in practice as standards for the structuring and formatting of documents although this has never been stated as the aim or intention of the development unit.

The work of the Standard Method of Measurement development unit is now closely allied to that of the Coordinating Committee for Project Information (CCPI) and it appears likely that what will emerge from their combined efforts is a prescribed standard content by which measurement should be made together with a prescribed standard format by which such measurement should be structured. Although the benefits of standardisation are acknowledged, it is felt that the flexibility required in data coordination will be missing from the resultant standards.

The problem of coordinating different formats of project information was identified by a team working at Newcastle Polytechnic. Their work (31) identified the problem of format and content of information with regard to its transfer between interfaces of design and construction

functions. It was important in recognising that a convention of formats was required rather than the use of a single classification system. The work suggested six formats which were fundamental to data transfer.

2.2.4 The Data Coordination Study

The most significant collection of work carried out within this area has been that which is known as " the data coordination study ". This was a series of related projects carried out by separate bodies over a period of more than ten years.

The origins of the work lay with the then Ministry of Public Building and Works which in 1966 set up a Committee for the Application of Computers in the Construction Industry. In 1967 a sub-committee for coding and data coordination was given the task of analysing these aspects of the problem and the Building Research Station was commissioned to undertake a 21 month study under the supervision of the sub-committee. It is the report from that study (32) which has formed the basis of data coordination and some attention is given to its derivation and contents.

The objectives of the study were;

> " To study the present characteristics and probable development of the information used in the design and execution of construction work; to determine the criteria for a coding system which would enable computer processed information to be used more effectively, both within the individual firms and offices and in communication between them, thereby leading to greater efficiency and economy; and to make recommendations." (33)

In the supporting argument for such an investigation, the report stressed inadequacies in information systems which have been identified both before and since this report. For example the report suggests that;

" .... data produced by one member of the building team may be independently produced again by others, either because they are unaware that the data already exists, or because the form is not right for their requirements." (34)

The general approach of the study has been to classify information in the following categories;

- general information
- product information
- project information
- management information

This illustrates the fact that the work was intended to be more broad in its application than that presented in this thesis.

The report also contains specific objectives some of which are of greater relevance here;

- to identify for various users, the ways in which information should be structured in order to meet their requirements.
- to establish a structuring for the documents used in the industry.
- to identify the categories of information relevant to each document
- to provide systems of cross-referencing between documents.

The methods used in the study were based on a system of functions of design and construction with constituent procedures . The execution of a function was defined as being marked by the achievement of an identifiable goal. A procedure was seen as a number of operations applied to a set of data that may be determinate or non-determinate. Such functions and procedures had then been related to the RIBA plan of work (35) and the study contracted out to parts of the B.R.S. and other research bodies on the basis of sections.

One of the main recommendations of the study was the separation of individual problems that were to be addressed within the overall domain of data coordination. These problems were described in terms of the following components of a framework to support information flow;

- a preferred vocabulary for use in documentation
- classification facets for different procedures
- conventions for classification of data
- a central commodity file for general and product information
- the specification of standard procedures and how they are to be executed
- the use of assigned codes in support of the above

Although not all of these areas are relevant to this thesis the above does indicate the scale and scope of the work undertaken in the data coordination study.

The main report itself then formed an analysis of the purpose of information systems, of the practical and technical considerations of data coordination and of the coding systems involved. It presented a set of criteria by which an information system should be measured for any scheme which claims to be comprehensive;

1. Classification of Information - in sufficient categories for the needs of information users , for the purposes of retrieval, search and selection.

2. Identification and description of resources - on the basis of a product catalogue approach.

3. Description of projects - on the basis of a coding system.

4. By fostering the development of procedures through the provision of categories for information retrieval, through documents structured for users, and by providing a means of coordinating conventions evolved for specialist procedures or groups of procedures.

5. By supporting information flow through user-orientated structuring of information, by industry document structuring, and by providing a system of cross-referencing between documents.

On the basis of these criteria and the analysis performed, certain suggestions regarding a framework for coordination were proposed. Those that are of relevance here would include;

- the use of a faceted classification system
- the use of a set of classification categories
- the use of a convention whereby categories are coordinated

The major conclusions from the study were therefore of the form of a set of criteria and recommendations for any future developments of information systems for the construction industry. The report recognised that any practical development of systems would be likely on a piecemeal basis with certain sections of development proving to be dispensable. The underlying framework was intended to be permanent in its application to all areas of development.

In relation to this thesis, the most consequential outcomes of the report were that the structuring of information was to be based on a set of classification categories which were to be coordinated by the use of a convention. This is the yardstick of information system development by which all other work of the data coordination study has been judged.

By 1969 the Department of Environment had taken on the responsibility for this subject and through the National Consultative Council a working party on data coordination was established to consider means of improving information flow in the construction industry. The work consisted of examining present methods of structuring project information to clarify principles and to suggest improvements. Two reports resulted from this stage of data coordination work which include a recommendation for information systems generally (36) and a specific extract which focuses upon structuring project information (37).

The approach here was to firstly examine current methods of structuring project information before taking a more fundamental view of project information needs. A detailed analysis was made of the information requirements of the building contractor which were classified in terms of separate functions of contracting. On the basis of these two parts of the study, a structure was proposed for project information which was based on two new concepts.

The first was by the use of six means of describing a construction project and its constituent parts in terms of WHO, WHERE, WHEN, HOW, ON WHICH, and WHAT is to be constructed. The final part of such a description was to be further classified according to a hierarchical structure of general characteristics of the purpose to which construction is made, the mode of working, the choice of construction method matched with the resource sets to be used. This structure would be based on the use of Construction Planning Units which were seen as an entirely new form of quantification which aimed to be based on the methods of the contractor.

The report went on to suggest how documentation should be structured and argued the relative merits of alternative hierarchies for alternative purposes and uses.

In the context of this research, this was an important study in that it exposed limitations of earlier attempts at solving the classification problem and presented an alternative solution. The framework or convention of classification categories that has been derived is vigorously defended by its authors as being appropriate for all project information requirements in isolation. However, the report itself, recognises that no satisfactory method has been found to coordinate the classifications of the study and some form of 'best' hierarchy is suggested.

> "Where only a single version of the documentation is available it is necessary to determine a single preferred structure which will tend to be a compromise between the requirements of the various parties and individual users." (38)

Other reports of the data coordination study have made similar contributions whose fundamental weakness can be exposed in the same way. They represent staged improvements in the field of classification and coordination of construction project data without attaining a fundamental solution whereby data is fully flexible in its format, content and level of detail.

The report entitled "A Classification Framework for the Construction Industry" (39) attempted to provide a convention whereby classification systems might be coordinated but although a fundamental re-appraisal was made of previous classifications and a new convention was suggested. Still no solution to co-ordination was found beyond the use of one of a series of alternative hierarchies and as the report says;

> " .. the only answer is to opt for the linear arrangement most likely to please a greatest proportion of users .." (40)

The final report of the data coordination study was published in 1978. This was a summary report which indicated the breadth of subjects to which groups had addressed their work.

The study has consumed between 100 and 200 man years as resources and although it has contributed significantly to the awareness and understanding of computing and data coordination, it has had very little practical impact. The study is continuing under the direction of a committee represented by the professions (CCPI) to the current time and a number of further reports have resulted which will be examined below. However, as Lansley states;

> "The generally held expert view is that the initiatives between 1966 and 1978 had little impact on industry. One research initiative simply led to another, a trend which is continuing with CCPI." (41)

2.2.5 The Coordinating Committee for Project Information

This committee represented the responsibility for data coordination being passed from the government to the industry itself in the form of professional institutions representing Building Contractors, Architects, Quantity Surveyors, and Consulting Engineers.

Their work followed on from that of the project information group of the data coordination study and over the seven years of their existence they have focussed upon the coordination of information contained within drawings, specifications and measurement. The fundamental nature of their approach has been to coordinate these separate sources of information and to attempt to gain maximum advantage from coordinated data through the use of a common arrangement of data that would apply equally to drawings, specifications and bills of quantities.

Therefore the aim of their work has been to derive a single faceted classification of data that will be of greatest benefit to those that use the information contained within the documents. The basis of this classification is expressed as the 'natural groupings of work' within the building industry. The work relating to specifications and

measurement has been documented in the form of a consultative document (42) which contains much detail of the resultant classification together with an account of how the study was executed.
Of much greater relevance are a series of committee working papers which were used in the production of the common arrangement. These were a series of reports on the relationship between the classification of the common arrangement and those of several other construction classifications namely;

- BCIS design and cost planning elements
- NEDO work categories
- classifications used as a basis for the arrangement of drawings
- the CI/SfB classification system

These illustrate the level of coordination that has been achieved by the work of the CCPI and have been examined in detail here.

Parts of this work were sub-contracted out to a private consultancy service with other parts being the responsibility of member(s) of the committee. All aims and objectives were set by the committee and these were to;

> " examine the relationship between the proposed work sections and the categories contained in the NEDO indices and the BCIS and CI/SfB design and cost planning elements to determine the nature and extent of the changes likely to be required for greater compatibility and to identify any problems likely to arise." (43)

The first report (44) relating to NEDO work categories highlights the point that ambiguity exists in allocation to categories and that because of differences between practices, no conclusions could be seen as being definitive.

This illustrates the fundamental problem of the approach of deriving a universal classification system and having this coordinated to other systems when users are liable to amend classifications for their own purpose and thereby destroy the coordination that has been designed for. The approach in this study is not to use rigid classification systems but that those classifications used for an individual project should be cross-referenced and coordinated.

The detailed analysis consisted of comparing NEDO categories with SMM 6 work sections, with Common Arrangement Work Sections (CAWS), with amended CAWS, and by using NEDO as a higher level grouping within the Common Arrangement hierarchy.

Each SMM work section was found to require sub-coding into an average of 4.72 NEDO categories whereas this was reduced to 2.08 for CAWS. This may be anticipated by comparison with a lower level grouping but the report states that;

> " In all it is difficult to conclude that the Work Sections we have proposed make any significant difference to the ease of application of NEDO indices compared to the existing position." (45)

this existing position was described by the report itself.

> "As things stand at present, an SMM work section may need sub-coding and monthly valuations sub-dividing between up to ten NEDO indices with the waste of time that this represents." (46)

The case for amending CAWS to fit with NEDO categories showed that in so doing, the classification would become less useful for other uses of the data.

The final alternative considered in the report was the use of NEDO categories as a classification within the hierarchy itself. This illustrates the problem in that to fully utilise a format as a structure for data it has to become part of the hierarchy itself. However, for other data uses, that hierarchy needs to be amended.

The conclusions that are drawn here are that, firstly, full flexibility is required by enabling individual hierarchies for the structuring of data to be specified for individual uses of data. Secondly, the attempt within the report to evaluate the relationship between the two categories showed that this would vary for individual projects and between individual practices and that any attempt to define a universal relationship would fail for this reason. When simultaneous relationships are required between a large number of categories, this problem would be compounded.

The second report (47) in the study considered the relationship between the CAWS and BCIS elements. The conclusions of the study are much the same as those reached on the NEDO categories study.

The final two reports (48,49) in the study looked at the relationship between the CAWS and the arrangement of drawings and that of the CI/SfB respectively. This illustrates the wider scope of the work of the CCPI which embraces general and product information together with drawn project information. These two reports are therefore not as critical to this thesis although the nature of some of the problems they have raised are similar to those described above.

In conclusion, the current work of the CCPI is highly relevant to this research. It represents the only published source of study of the relationship between alternative project data classifications. The conclusions regarding the nature of these relationships and the description of problems in their application are seen as completely vindicating the approach of the remainder of this thesis.

The CCPI have continued with their original concept of a common arrangement despite the conclusions of their reports and the difference in objectives and the time-scale of the horizons between their work and this thesis may be illustrated by a comparison of policy statements.

The RIBA as licence holder for the CI/SfB have commented on its relationship with the Common Arrangement and suggested that;

> " The cost and inconvenience of change should be fully recognised and ways of minimising them should be found." (50)

A previous publication arising from the research of this thesis commenting on the context of the work stated that;

> " The intention is that the need for, and benefits from, change will be made clear." (51)

2.2.6 Other Classifications

Other relevant previous work would include that represented in a series of other classification systems which are used for different purposes within construction and these are briefly commented upon.

The CI/SfB (52) is a faceted classification system which originated in Sweden over thirty years ago. The British version uses five facets of classification which are in the form of classification tables. The system is extensively used for product information but for the purposes of this study has no means by which facets may be coordinated to provide a flexible information store. A report by the RIBA (53) investigating its use for organising building project information identified the need for its combined use with other classification systems and a means of coordinating all of them.

The CBC classification system (54) is a computer-orientated development that was begun in Denmark and which builds a further facet onto tables of CI/SfB.

The Building Industry Code (BIC) (55) is a nine-faceted system which was derived by the Department of Education and Science for use on educational buildings. It was intended for classification of buildings and their constituent parts such that various formats may be produced.

The Greater London Council (GLC) system of structured drawings and bills of quantities (56) was again based on CI/SfB with additional facets for locations and work sections to make the system more applicable to project information.

The West Sussex system of drawings and bills of quantities (57) was computer based and worked on the basis of retrieving information according to a determined format. This was the first attempt to provide flexibility in the way information can be retrieved but was again restricted by a rigid hierarchy from which interrogations could be made.

The CUBITH system (58) was strongly orientated towards industrialised building with a link provided between standard formats of project documentation and a system of coded component catalogues. The system was sponsored by the Department of Health and Social Security but is no longer in use.

A more recent development in the structuring of project information is the work of Ormerod at Reading (59). The rationale was to orientate structuring towards constructionally significant operations thereby changing the content of what is measured. The approach of using work packages within a series of levels of an hierarchy was then taken as the approach to format. This work is new in recognising the different levels of detail and the different formats that are required as a project moves from the design to construction stages but still

represents a better solution for certain purposes rather than a fundamental change in terms of coordinating other recognisably valid classifications.

Current work being carried out under SERC finance by a steering group of the Chartered Institute of Building (CIOB) (60) is approaching the problem by examining the use of a schedule of activities as a means of estimating and controlling progress and costs of projects as an alternative to bills of quantities. This work is again an evaluation of an alternative content and format of project information for the purpose of part of construction management and is a different approach from that being taken in this thesis.

The conclusion that is drawn from this analysis of classification systems and from the review of previous work generally is that what is required is a way of coordinating those systems that currently exist rather than the further development of alternative classifications. The majority of these classifications are slight variations upon each other which change the appropriateness to a different set of users or for different project types. The majority of previous work has attempted to discover an ideal classification that would make all others \unnecessary. This study fundamentally differs in approach by exploring the ability to co-ordinate classification systems that currently exist.

A study carried out for the Building Research Establishment by ASLIB (61), the information consultancy, consisted of an analysis of a series of classification systems and current computerised information systems. The systems studied were CLASP (62), CI/SfB (63), Ann Plowdens classification (64), the CBC (65), the West Sussex bill of quantities system (66) and the Monk and Dunstone bill of quantities system (67). The systems were compared from the point of view of the categories used in their classification and whether any relationship could be established between them. The conclusion reached was that the only way that this could be achieved was by taking one system that was the most generic and simply translating to other classifications. No

satisfactory overall classification could be derived which then had a direct relationship to all or any of the other systems.

This is seen as further evidence that the ideal of a single classification hierarchy to which all other classifications may relate is one that will continue to be impossible to achieve and that a radical approach to the structuring of project information is required.

2.2.7 International Experiences

American practice in design and construction is not bound by the same restraints of institutional and professional allegiances as exist within the UK industry. The way that American design and construction is practiced is correspondingly different as is shown in an international comparison that has been carried out (68).

The approach to the structuring of project information in the US industry is, as a consequence, of a more ad-hoc nature with documentation being derived in ways that suit a particular organisations methods of working and the requirements of particular projects. A number of studies have been published (69) showing the approach of individuals in the field of information systems for contractors estimating but no fundamental piece of work appropriate to the problem of UK practice has been found.

The major international study in the field of information systems has been coordinated by the International Council for Building Research (CIB). An early congress in Rotterdam (70) examined the problems of information flow. The most relevant study to this thesis was that documented in report no 47 (71) which suggests a framework for the evaluation of information systems. This has been of use in the evaluation of the hypothesis rather than as a background to the study. Contributions to the CIB work on evaluating information systems included members from Hungary, Sweden, Norway, Holland, Israel, and West Germany.

The sixth congress of the CIB in Budapest (72) was largely devoted to data coordination problems and many different approaches to the problem were raised there.

Work done in the US by Brown (73) illustrated progress on a system for product information and the development of a standard library of specification clauses. This mirrors developments in this country at the time in these other aspects of data coordination. Of greater direct relevance is work done by Jackson (74) at Massachusetts Institute of Technology which makes the distinction between the structure of a classification system and the structure of data presented for individual users. It recognises the importance of information being structured in different ways for different people from a single coordinated source.

The approach of a Hungarian study (75) produced a mathematical evaluation of the interference to communication represented by its transference between sub-systems. There was, however, no examination of the level of interference within an individual sub-system which is the detail to which analysis is performed here.

A major piece of work prepared by Ruping (76) in West Germany was a further examination of the development and use of a standard specification library and the coding implications of its implementation.

Finally a paper by Tanabe (77) illustrated that the problem was one that had been recognised by Japanese industry and academics but for which no fundamental contribution had been made.

2.2.8 Measurement of the Appropriateness of Project Information

The above shows the considerable work that has gone into alternative means of classifying construction project information by a number of studies dating back to nearly 30 years ago and continuing at present. Much less has been done in assessing the usefulness of project information for various purposes and commenting upon areas of deficiency.

Work done by Skinner formed a comprehensive analysis of the ways in which bills of quantities were used for the different aspects of building contracting (78). Together with analysis of information used for different purposes, criticisms of data were obtained relating to the format that information takes, the adequacy of what had been quantified and the independence of information.

The conclusions that are drawn from Skinner's work are that different aspects of a contractor's work have unique requirements for information in terms of format, content and level of detail. This conclusion is made on the basis that unique criticisms were made of information provided within bills of quantities.

2.2.9 Industry Innovations

A number of contractors have initiated and in some cases implemented developments of their own in this area and although little of this work has resulted in published material, work done within the Tarmac group has been documented (79). In addition it is known that George Wimpey PLC and John Laings Construction have carried out significant internal studies and developments relating to the data used within their operations and systems to improve its appropriateness.

2.2.10 Summary

The analysis of previous work produced above illustrates the volume of literature that has resulted and attention that has been given to the problem. This indicates the importance of the subject to the industry and the fact that work is continuing by a number of approaches indicates that a fundamental problem remains to be solved. The remainder of this section consists of a description of how this background study has been interpreted in deriving the approach taken by this thesis.

2.3 EVOLUTION OF RESEARCH PHILOSOPHY

On the basis of the review of previous and current work that has been made, the following philosophy has been used as the foundation of the research.

The problem of the research has already been set within the confines of the classification, the coordination and the retrieval of project data.

On the subject of classification, many systems exist which enable information to be structured in a variety of ways appropriate to individual data requirements. Similarly, frameworks of classifications have been designed which enable particular hierarchies under which data may be structured.

Faceted classifications have been developed which enable a measure of coordination of information within classification systems. Other work has recognised the need for coordination between the various classification systems but no fundamental means has been established whereby such coordination can be achieved.

On data retrieval, it has been shown that different activities within the functions of design and construction have individual requirements for project information with regard to the content of information, the format by which it is structured, and the level of detail in which it is expressed. However, the precise specification of information requirements in terms of content, format and level of detail is not known for individual activities.

This represents the background to the research for which a philosophy has been developed as a means of fundamentally solving the problem of project data classification and coordination.
The approach is based on the rejection of the concept of single format documentation or the design of an ideal single classification system but acknowledges the need for a convention or framework of

classifications between which coordination is required. Documentation in a manual form is rejected in particular due to the problems of the dynamic nature of tendering data. Any vehicle for the transmission of such data must allow for regular updating of its contents rather than the provision of individual 'snapshots' at fixed points in time.

The concept of a computerised database as a means of information storage and retrieval is proposed as a means of providing coordination whereby information may be interrogated for and simultaneously expressed under alternative formats. This also represents a shift from the concept of using full and extensive reports as the source of information to the point where specific and limited information is interrogated for to suit the individual requirements of each task.

The task approach to designing and evaluating an information system is adopted on the basis that individual tasks or activities have unique requirements for information in terms of format, content and level of detail.

Most previous work has approached the problem by considering that people or users of information are the variables by which requirements differ. The approach taken here is that individual tasks or uses of information should be treated as the variable factors. This is adopted in the work and will allow it to be applied more widely to projects whose common tasks are executed irrespective of those responsible for their execution.

This represents the innovative approach being taken in this study and reference should be made to the hypothesis and objectives previously defined.

This concludes the background study to the research and the remainder of this thesis consists of the development and implementation of a methodology of research.

3. RESEARCH METHODOLOGY

Given the scenario of the problem described above a methodological programme of investigation has been designed whereby the hypothesis may be tested. The hypothesis states that building contractors' data requirements for tendering may be satisfied from a single source of inter-related data.

Before elaborating on the detail of the methodology, an overall description of the approach is given together with the definition of certain terminology and concepts upon which the methodology is based.

3.1 OVERALL APPROACH

A single inter-related source of data has been developed in the form of a model. This data model forms a prototype by which a principle is being tested.

The method of development of the data model has involved observation and examination of the practice of industry and has been classified according to the stages of; examining how tenders are prepared, establishing data used in preparing tenders, analysing the characteristics of such data, modelling data into an integrated database and physically implementing the database onto a particular configuration of hardware and software. This database has then been tested for the extent to which it provides a flexible and coordinated system of information retrieval for tendering.

The methodology involves the application of techniques of systems analysis, information science and computer science to tendering data for the purpose of establishing original knowledge regarding the properties of such data. Although the use of techniques has been similar to the way that they would be applied in a post-research, developmental study, this has been found to be the most appropriate means of executing the research whose contribution should be seen in the knowledge of data coordination that is derived.

The methodology is therefore the application of database design techniques to contractors tendering to evaluate the level of data coordination thus achieved.

Its component stages are as follows;

Functional Analysis	An examination of the means by which a tender is prepared by building contractors.
Systems Analysis	An examination of tendering methods to establish the data that is used by parts of the process.
Data Analysis	Examination of data used to establish its inherent characteristics.
Data Modelling	The application of database design techniques to enable a data model to be constructed.
Physical Implementation	The implementation of the data model on to a particular hardware and software configuration together with the use of data from a recently prepared tender.
Evaluation and Testing	Assessment of the performance of the database in relation to its objective of providing a coordinated source of data.

These six stages can be classified according to the recognised (80) phases of research in the following way;

Data Collection - Functional Analysis
Analysis - Systems Analysis and Data Analysis
Synthesis - Data Modelling and Physical Implementation
Testing - Evaluation and Testing

3.2 DEFINITION OF TERMS AND CONCEPTS

In order to classify the scope and nature of the research, certain terms which are in common usage need to be defined for their meaning within the context of this research. Similarly, concepts which are new to the research methodology itself have either been defined here or within the section of the thesis in which they first occur.

3.2.1 Information and Data

These terms occur regularly both within the analysis of the background to the study and within the methodology itself.
Information is regarded as a resource which is combined with other resources in the design and construction of buildings. It is a fundamental resource of decision making. Its importance is seen as being of an equally fundamental nature to all other indirect resources used within the process.

Information, in relation to an activity, can be defined as being composed of a combination of the 'knowledge' of those carrying out the activity, the 'experience' of the same people, and the data to which their knowledge and experience is applied. Knowledge has been defined as information acquired by the process of learning and experience as information acquired by the process of applying knowledge in practice (81). A preliminary definition of data is therefore that part of information which is not in the form of knowledge or experience.

A similar approach to defining data would be by it only encompassing that information which is recorded or committed to documentation if it is assumed that all knowledge and experience is un-documented but that individuals are unable to retain extensive memory of data.

The second stage of defining data for the purpose of this research is based on the dichotomy between that which is of relevance to the activity of design and construction generally as opposed to that which

is specific to a particular project. Examples of the former would include building regulations, local bye-laws, product information, etc as opposed to project-specific data which would embrace the specification and measurement of the resources and activities required in construction. This research is concerned exclusively with project-specific data.

The final stage of definition that has been used is based on drawing a distinction between data that is alphanumeric and that which takes a graphical form. This research does not include the latter category which would largely consist of the drawn form. Only data that is expressed in alphanumeric characters has been included in this study.

Therefore, in summary, data is defined as that aspect of information which is documented in an alphanumeric form and which specifically relates to a single construction project. Where digressions have been made from this definition, attention has been drawn to the fact.

3.2.2 Tendering and Tasks

As will be shown in the description of functional analysis, the approach to defining and describing tendering has been to analyse the constituent parts of the process. This can be done in many ways and alternative models are discussed later.

The approach within the research has been to allow representatives of industry to define parts of the process in terms of identifiable stages of work which independently use and/or produce data. These identified parts have been termed tasks and would correspond to more detail than is found within the procedures of the data coordination study (82).

The definition of tendering in terms of its scope has again been based on the views of representatives of industry and a consensus was established as being the range of tasks that are carried out between a decision having been taken to submit a tender and the point at which

such a tender is submitted. This would equate with a systems view that sub-systems should lead to the achievement of a specific goal, in this case the submission of a tender.

3.2.3 Interrogations and Retrievals

The approach taken within the evaluation and testing of the work has been to dispense with the concepts of documents or reports as being the vehicle by which data is produced, stored and transferred. In their place an interrogation is seen as being such a vehicle. An interrogation is defined as data retrieved from a database with a format, content and level of detail to be defined by the users of the data.

3.2.4 Systems Thinking

Much of the methodology of the research draws upon concepts of systems thinking and some explanations of aspects of systems relevant to the study are made at this point. For a fuller description of the theory of systems and their behaviour, reference is made to other sources (83).

Systems analysis typically consists of the two complementary stages of systems examination followed by systems design or improvement. Examination is applied to existing systems which allows analysis to identify potential systems improvements and the synthesis of new systems design. As the use of systems analysis techniques is being made here as a means to an end rather than an end in itself, not all aspects of systems analysis have been performed. More specifically, the work has only included the examination of current systems rather than the design of improvements or new systems.

The other aspect of systems thinking is the use of systems analysis in conjunction with functional analysis which is regarded as a parallel and necessary activity by others (84).

3.3 STAGES OF RESEARCH METHODOLOGY

Each of the six stages of methodology identified earlier are now examined individually in terms of the justification for and the results of their execution.

3.3.1 Functional Analysis

This formed the data collection of the research whereby a model has been constructed of the way in which tenders are prepared by building contractors within the UK construction industry under various methods of procurement.
Such a model is necessary to enable the data that is used in tendering to be analysed in terms of its point of derivation and the tasks that act upon it.

The model consists of flow charts indicating the point at which tasks are executed together with descriptions of methods of executing tasks.

The method of collection was on the basis of interview and questionnaire survey with contractors representing more than half of the industry.

3.3.2 Systems Analysis

The model of tendering tasks has been subjected to techniques of structured systems analysis which has enabled the data used by tendering to be established. This is an analytical process whereby material gained by observation and survey has been transformed into a specification of the data that is used.

The results of this stage of the work are a set of data flow diagrams which indicate the data that flows between tasks, together with a data dictionary in which all items of data are classified and defined.

3.3.3 Data Analysis

The term, as it is used here, should be distinguished from its more general usage within research methodology as a process of examination of collected data to enable the synthesis of relationships from the isolation of variables (85).

In the context of the methodology, data analysis is seen as the examination of the components of the data dictionary produced in the previous stage to ascertain and record inherent characteristics of these data elements.

The purpose of such analysis is to provide the detail which is necessary for the following stage of data modelling. Such detail would include the nature of data items, the points at which items are both derived and updated, the relationships between individual items, means by which individual items may be identified, etc.

3.3.4 Data Modelling

This is the first stage of the methodology whereby a synthesised solution to the problem of data coordination is being produced. Data items, whose characteristics have been established, are constructed into a model whereby all are inter-related in some form into a single database.

There are many alternative techniques that could have been used depending upon whether the database were to take the hierarchical, network or relational form. The techniques that have been used are relational normalisation and entity-relationship modelling.

The technique of cohesion analysis has been used to evaluate the conceptual database.

The result of this stage of the work is the design of a logical or conceptual data model. Logical or conceptual refers to the form of the model that is apparent to users of data rather than a representation of how data is physically stored.

3.3.5 Physical Implementation

This stage of the research has consisted of the translation of the conceptual data model into a series of physical databases. Proprietary database management system software has been used together with 16 bit micro-computing equipment to produce a database structure in accordance with the earlier data model.

The second phase of physical implementation has been to collect full documentation relating to project tenders. For detailed analysis, a tender for a commercial shed building, as compiled by a national building contractor in the summer of 1986, has been selected on the basis of its simplicity and fitness to test the principle of the research. All data within the tender documentation (86) that was made available has then been stored in relevant database files.

Earlier physical implementations of the database had been made using data from a fictitious project and an historical project. The rationale for the further use of a recently completed tender was that in the testing of the work, access could be made to those responsible for compiling the tender whose recall of the detail of the project would be recent.

3.3.6 Evaluation and Testing

The evaluation of the database has been to establish the level of data coordination that is achievable through its use. It has not been the intention to test the database as a working system in terms of its practical performance.

The hypothesis refers to a source of coordinated data for tendering and the approach of testing has been to concentrate evaluation upon the level of coordination achieved.

The primary aspect of testing has therefore been to measure the level of coordination that is made possible by the database and to compare this with that level of coordination that is possible by other methods.

The measure of coordination has been to test for possible combinations of format and content with which data can be expressed. This is the ultimate measure of the flexibility of data in terms of the structure with which it can be presented and given the stated hypothesis, this is taken as the primary quantitative measure of data coordination.

Evaluation has been made at different levels of detail for the three different implementations of the database which represent a progression from derived data to real historic data and then to real data of a recently completed tender. Final evaluation has then been made of how the database would perform generally based on the experience that has been gained in these three stages.

Measurement of coordination by this criteria has been on a proportional scale with end-points of full coordination and no coordination having been defined. The comparative levels of coordination achieved by the databases and other information systems have then been quantified.

This detailed analysis of coordination in terms of flexibility has then been assessed for its worth by establishing the relevancy of the combinations of format and content within the extra retrievals which the database has made possible. This assessment of relevancy has been performed by the estimator responsible for working on the third set of data used in testing.

The above represents the primary testing of the work of the thesis but supportive and supplementary evidence has been obtained in other forms. The currency of data has been taken as a measure of coordination whereby the extent to which recent updates and changes are reflected in the current database. This has been measured on an ordered scale. Measurements here are taken between currency of data in the database and the manual documentation. This analysis has only been performed for the third set of project data.

As a second area of supporting evidence, a measure has been taken of the cost of producing the coordination achieved by the database in terms of the relative activity required. This is felt to be of use in further studies to examine the cost effectiveness or cost benefit analysis of data coordination by this method as opposed to others.

Further evaluation has been performed to enable the extrapolation of the results of analysis of the three projects of testing into conclusions that are applicable to projects generally. This has been done by measuring the extent to which the database covers data used within tendering and here two methods have been used. The set of data items upon which database design was based were established through functional analysis as the data used in tendering. This set of data items has been compared with that set which was made available from the contractor for the tender of the third, commercial building.

Secondly. the database has been used to produce sample interrogations of data as required for individual tasks of the tendering model. Each interrogation has then been evaluated by comparison with that data that has been established as being used or produced through structured systems analysis. These two methods give a measure of the coverage of tendering data within the database.

3.4 SUMMARY

The overall progression of the methodology can therefore be seen to be an assessment of how tenders are executed, an analysis of what data is used, a study of what the characteristics of data are, the modelling of data into a schema which places data elements where they are logically related to each other. The data model is then implemented as a series of databases and tested for their level of coordination by the flexibility with which they can be interrogated.

This flexibility is measured primarily by how many combinations of format and content are possible in retrieving data, and by how relevant the data is. These measurements are then compared with those that are possible without the use of the database. Any improvement is to be seen as the contribution made by the research in providing a greater level of coordination of tendering data.

The remainder of the thesis consists of the detailed examination of each of these steps in the methodology in terms of how they are executed, results that have been produced and conclusions that have been drawn.

4. FUNCTIONAL ANALYSIS

This phase of the work represents the primary data collection of the research whereby the method by which tenders are prepared by the majority of UK building contractors has been established in detail through investigation and survey of practitioners.

The rationale for this stage of work is that in order to develop a coordinated system of data retrieval for building contractors tendering, an accurate representation of the method of preparing tenders is required. In addition to this, the data that is used in tendering needs to be related to individual tasks at which the data is derived and subsequently updated. A mere specification of data used as is available from previous studies (87) would not be adequate for this purpose. This is supported by the recommendations that any systems analysis should be supported by examination of functions and tasks as is to be found in other texts (84).

Previous assessment has been made of earlier attempts to model the methods by which tenders are prepared to confirm whether new data collection was necessary. An examination of these earlier tendering models follows in the next section.

The remainder of this part of the thesis then forms a detailed examination of the rationale, the methods, the results and the conclusions that have been drawn from the different stages of functional analysis.

4.1 EARLY TENDERING MODELS

Earlier studies have examined the tendering process in the form of its constituent tasks and models of the process are available in published form. The Chartered Institute Of Building (88) have produced a code of practice recommending the stages that are required in producing tenders. Similarly, a study undertaken at the Building Research Establishment (89) as part of the Data Co-ordination study has resulted in a model of individual tasks. This was used to derive a classification framework for construction data (90).

Some of the larger contracting organisations themselves have documented (91) the method by which tendering is to be carried out by their own staff in the form of models of the process.
Finally Skinner (92) has made a wider study of the work of the building contractor in both the tendering and post-contract phases of construction projects which highlights the extent to which a Bill of Quantities is consulted at each stage of these two phases.

The need for a further study was based on the following factors:

- not all of the above investigations sought to represent any commonality in the practice of the industry as a whole.

- only the BRE study modelled the tendering process from the viewpoint of the data that is passed through stages of tendering.

- all of the previous studies were specifically aimed at the process as executed under traditional selective tendering procedures and traditional contractual arrangements.

- all previous studies were carried out before the small but significant changes that have occurred both in the context within which tenders are prepared and the technology that is available for utilisation in their preparation.

Because of the above factors it was felt necessary to construct a detailed model in the form of individual tasks which illustrated data used and produced by the tasks. The study aimed to construct a model that was representative of the tendering process as executed by the largest international building contractors operating within the UK construction industry.

Finally, it was the intention that the model of tasks would represent fundamental stages in the process of compiling a tender for a construction project unrelated to the particular method of procurement that was being used or the particular organisational structure to be found within an individual firm.

In the process of constructing this model, the previous studies mentioned were not discounted but formed a useful foundation for model evolution.

4.2 STAGES OF ANALYSIS

The model that has been constructed has been based on three distinct phases of investigation:

- contextual study
- detailed model construction
- model validation

4.2.1 Contextual Study

Before commencing a detailed investigation of the ways in which tendering is carried out, it was felt necessary to carry out a contextual study to highlight likely problems of data collection and to provide a starting point for the model that was as far advanced as possible.

The contextual study therefore consisted firstly of an analysis of previous tendering models that had been produced as have been described above. The intention was to draw a degree of commonality between the alternative models and also to retain sufficient flexibility such that the model would be appropriate to different Contractors' organisations operating under alternative procurement methods.

The form of this early model was to group titles of tasks under headings of discrete functions of tendering and post-contract management. Details are to be found in the appendix. A limited survey was carried out with three Contractors' organisations which were specifically selected for their different organisation structures, use of procurement methods and organisation size. The survey aimed to establish whether tasks of the model were executed and to explore the information that was used by each task.

The results of the survey have not been fully documented as it was soon apparent that for meaningful conclusions to be drawn, a much more detailed investigation would be necessary on a more strictly defined area. However, the survey was of significance in illustrating three important factors that were incorporated into the approach taken in the detailed model construction:

- firstly that those responsible for executing tasks were only able to specify their information requirements in terms of currently used documentation.

- that it was possible to describe tendering tasks in sufficiently general and fundamental terms such that particular irregularities in approach and terminology used by individuals and between organisations could be accommodated within the model.

- that there was an observed criticism that information being out of data or having been superseded represented a major hindrance to the reliability and usefulness of that data.

4.2.2 Detailed Model Construction

As a second evolutionary phase in the development of the model a detailed study was made of the complete process of tender preparation as was executed by two of the UK's largest Contractors. The twenty largest Contractors (93) were all invited to participate in the study from which twelve positive responses were obtained.

The two selected for this phase of investigation were Costains and Higgs and Hill who were two of the firms that had contributed extensively to the contextual study. Their use in detailed model construction was therefore justified by acquaintance with their organisational and procedural characteristics and by their familiarity with the nature of the study. Two contractors only were selected for

detailed investigation as these particular firms represented a range of project sizes and procurement methods.

The development of the model itself was based on detailed and extensive discussions (94) with a large number of head-office and site-based staff of the two organisations over a period of four months. Discussions were carried out in the form of structured personal interviews.

The resultant model derived from this process was verified with staff consulted and formed the second stage of model development. The model consists of a series of process flow charts showing different levels of tasks and their inter-relationships. Each task has then been described with a guide as to its method of execution and reference to documentation used and produced.

This original model is fully documented within the appendix volume.

4.2.3 Model Validation

Before using the model further as a basis for design, the ten other contracting organisations that were willing to participate in the study were used to validate the two parts of the model that had been derived. An extensive personal interview based questionnaire survey was used with each of the nine organisations, one firm having felt unable to participate with the work.

A response was obtained from a representative of each organisation participating. The survey was attempting to validate the correctness of descriptions of tasks, their position within the model and also whether further tasks had been omitted. The results of the survey in the form of a summary of responses is reproduced here. In all cases, figures in brackets indicate the results when replies from a single contractor, whose practices and procedures were found to be most divergent from typical responses, were removed from the sample.

For all respondents in reply to questions relating to all tasks.

	Number of replies	% of replies
Agreement that tasks were executed.		
Complete	575	85
Partial	608	90
Agreement with description of task		
Complete	532	79
Partial	616	91
Agreement with position of task within model		
Complete	387	57
Partial	470	70
Agreement with completeness of model to this point		
Complete	550	81
Partial	596	88
Total number of respondents = 675		

Complete agreement measured as a reply of value 1 on a five-point response scale.

Partial agreement measured as a reply of 1 or 2 on a five-point response scale.

As a result of the analysis of responses, certain patterns of criticism could be established and in these cases modifications were made to either descriptions of tasks and also more often to their position in the model. There were instances where both original tasks were deleted and newly defined tasks were added to the revised model.

The completed, revised model was then returned to the nine organisations participating in the validation survey and the two firms that were primarily involved in the development of the original model for final confirmation.

The responses gained and the details of the validation survey would suggest that the final model is a fair representation of the tasks that are carried out in tender preparation by these large national contractors.

The model that has been developed has been based on the practice of preparing a tender as encountered by the firms in the majority of their current work. Within the survey the opportunity was taken to further examine whether these firms adopted significantly different approaches for tenders executed under some of the newly established tendering procedures and contractual arrangements. Summary details of results are again reproduced here.

For all respondents for all tasks

Measures of whether tasks are executed in a similar way for a selection of alternative project procurement methods.

	Number of replies	% of replies
Negotiated Tenders		
Tasks executed in exactly similar way	664	98
Tasks executed in broadly similar way	669	99
Management Contracts		
Tasks executed in exactly similar way	412/525	78 (85)
Tasks executed in broadly similar way	413/525	79 (85)
Design/Build Contracts		
Tasks executed in exactly similar way	489/600	82 (93)
Tasks executed in broadly similar way	503/600	84 (96)
Total number of respondents = 675 (600)		

Exact similarity measured by a value of 1 on a five-point response scale.

Broad similarity measured by a value of 1 or 2 on a five-point response scale.

The percentage of tasks for which respondents expressed similarity between task execution under the original model and all three alternative procurement methods was;

Exact similarity	47%	(53%)
Broad similarity	70%	(79%)

These results indicate that the revised model that has been produced is seen to be of general application to the traditional method of project procurement and that for negotiated tenders a similar model of tendering is acceptable.

For procurement by management contracting and by design and build contracts, modifications to the model of tendering would be necessary. A large number of these modification consisted of the deletion of tasks that are only necessary where certain parties are inherent within the procurement method. Revisions to the model in this case would result in a simplification or reduction in the number of tasks.

Other modifications were of a nature that required amendments to definitions or descriptions of tasks to equate with terminology that is only to be found in alternative procurement methods. Such modifications would again be straight forward to achieve.

In conclusion, the tendering model that has been derived has been shown to be an accurate representation of the tendering procedure of the eleven firms included in the study when compiling traditional or negotiated tenders.

The types of changes or modifications that are necessary to the model for projects of a design build or management contract type are known and the principle has been set that a general model of tendering can be taken and amended for alternative project conditions.

There is scope for considerable further research here both in definition of modifications and in monitoring the actual tasks that are executed for alternative projects in the form of case studies which monitor the influences which the factors of; procurement method, size of project, time allowed for tendering, organisational structure of tendering firms, etc have on the nature of the set of tasks.

The version of the model of tasks that are included within a project that was used during the testing phase of the research has been included in the appendix relating to this section of the thesis.

Having validated a model for the eleven organisations participating in the study, analysis of these firms and the position they held within the overall UK contracting industry allowed certain assumptions to be made regarding how representative the model was of industry-wide practice. The following table contains full details of the analysis which is based on assessing the proportion of turnover, employed capital and workforce (95) of both the top twenty and top fifty construction firms which was represented within the study.

Proportion of industry represented within sample

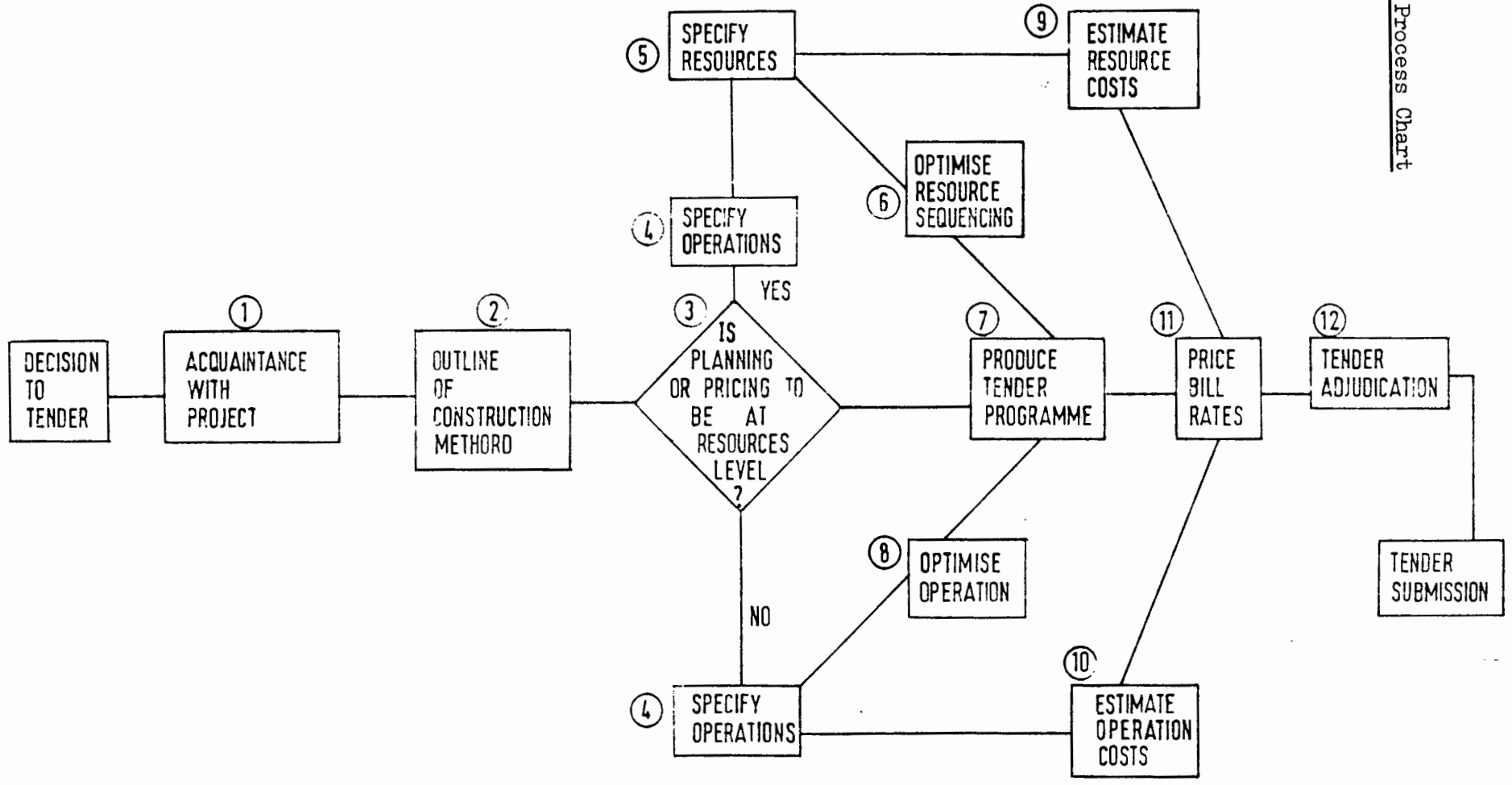
	% of top 20 firms	% of top 50 firms
By Turnover	69	52
By Employed Capital	60	51
By Number of Employees	60	50

By each of the three measures the survey included over half of the top fifty firms and it was felt reasonable to assume therefore that the model that has been derived is representative of this sector of the industry.

Experience gained during the contextual study also suggested that smaller firms within the industry operated tendering practices that were broadly similar in approach. Differences that had been established suggested that smaller firms executed similar tasks in generally less detail than that contained within the model

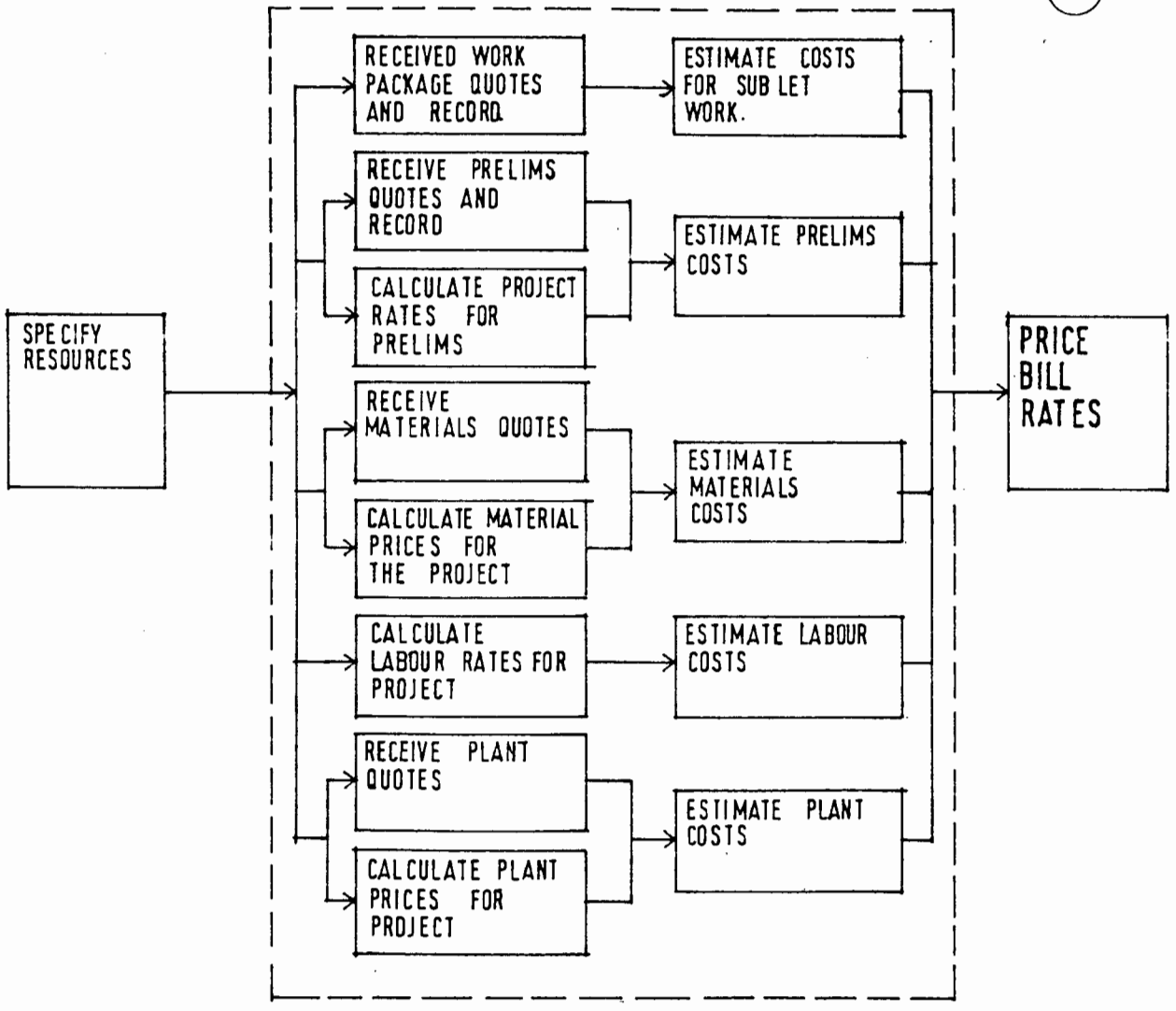
It is therefore suggested that the revised model of tendering tasks is representative of the way tenders are produced by large national and international contracting firms operating within the UK construction industry. Minor revisions would be necessary to apply the model to individual firms to take account of organisational factors and size. Details of the un-validated model in the form of process flow charts together with full definitions of tasks of the validated model are to be found in the appendix volume. The full details of the validating survey and statistical analysis are not reproduced here but are included within the appendix volume. The following are a selection of the flow process charts to indicate their nature and scope.

TENDERING SYSTEM - GENERAL PROCEDURES



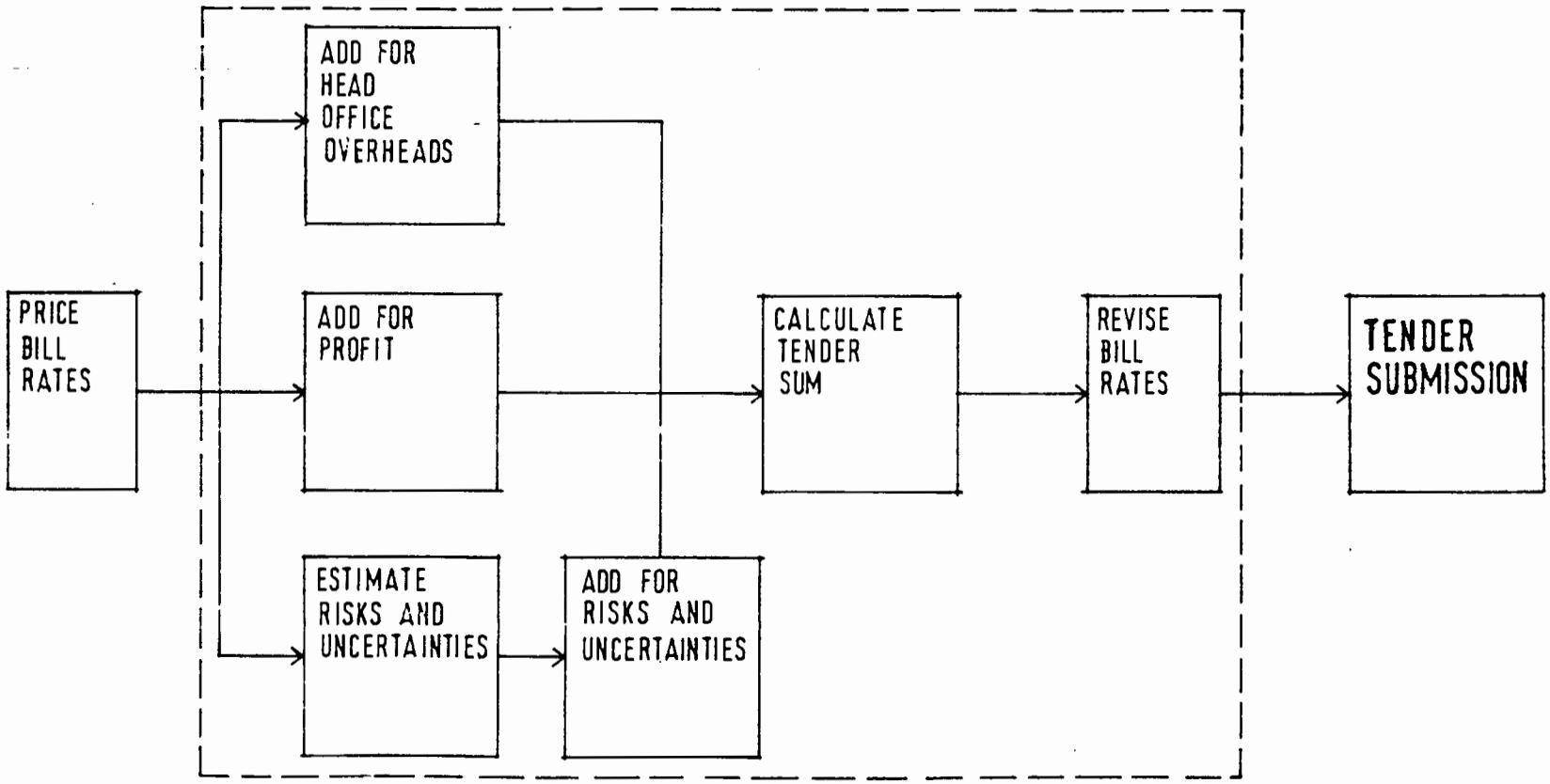
TENDERING SYSTEM ESTIMATE RESOURCE COSTS

(9)



TENDERING SYSTEM – TENDER ADJUDICATION PROCEDURE

(12)



4.4 Summary

This section of the work has therefore provided a specification of how tenders are prepared. This specification is in the form of a generalised model of tasks that are executed. The detail of the model consists of the definitions of these tasks together with an indication of their relative positions.

Such a generalised model has been shown to be applicable to large building contractors operating within the UK construction industry. An extract from the model would be necessary for its application to a particular construction project. The nature of this extraction would depend upon the size and organisational structure of the contracting firm, the form of procurement method used in terms of the tendering procedures and contractual arrangements, and the size and nature of the project itself.

5. SYSTEMS ANALYSIS AND DATABASE DESIGN

Having produced and validated a generalised model of tendering, the synthesis phase of the research consists of the design of a data model and implementation of a database. This has been achieved through the following stages of research.

5.1 STRUCTURED SYSTEMS ANALYSIS

This section of the thesis consists of the analysis phase of the research whereby the data collected in the form of a generalised model of tendering has been converted in to a basis from which a data model can be designed.

Structured systems analysis is a series of techniques for examining currently used systems in order to trace the flow of data. Previous examples of the application of these techniques to construction projects have been found in the areas of a Contractors monitoring and control system and in work for a Client's information control system.

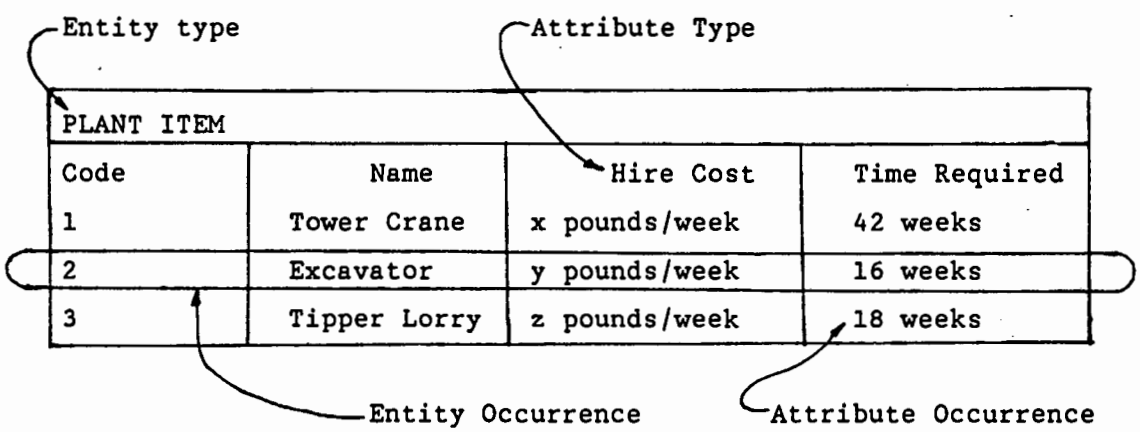
Fisher's work (96) takes a similar approach in basing analysis on a generalised model of tasks of project control as executed by broadly similar national building contractors. Work being carried out by Carter and Newlove (97) at Liverpool University applies the techniques to the systems operated by a single health authority client.

The approach taken here has been to use techniques of structured systems analysis (98) in order to construct data flow diagrams (DFD'S) and a data dictionary. The former is a series of charts which schematically represent the way in which different stages of a system are related in terms of data that is passed from one to another. DFD's also show the relationship between tasks and documentation and the links between data that is external to the sub-system being studied. A data dictionary is simply a schedule from DFD's defining the different data entities and attributes within a model.

The previously derived generalised tender model, the specified sub-system for this work, consisted of flow process charts together with definitions of individual tasks. This has made the process of drawing data flow diagrams straightforward. The full set of primary and secondary level diagrams have been repeated in the appendix with examples having been reproduced here together with a data dictionary which specifies all data entities and attributes within the model.

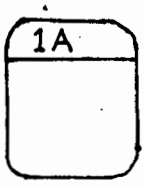
An entity has been defined as something about which information is stored in a database. An attribute has been defined as a data element which holds information about an entity.

An example of the occurrence of an entity would be a 'tower crane' of the entity type 'plant item'. Attributes of a plant item would include its hire cost, its name or description, and the number of units of time it is required for a specific project. Again these are attribute types for which each individual occurrence of an entity would have a series of values.



5.1.1 Data flow diagrams

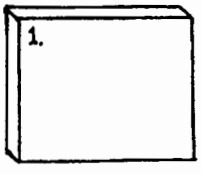
Two levels of data flow diagrams have been used in the analysis and the annotation follows that suggested by Gane and Sarson (99). The following key is intended to aid interpretation of the diagrams.



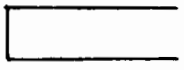
- A task or process which uses and/or produces data.

Entity

- A transfer of data entities between tasks.

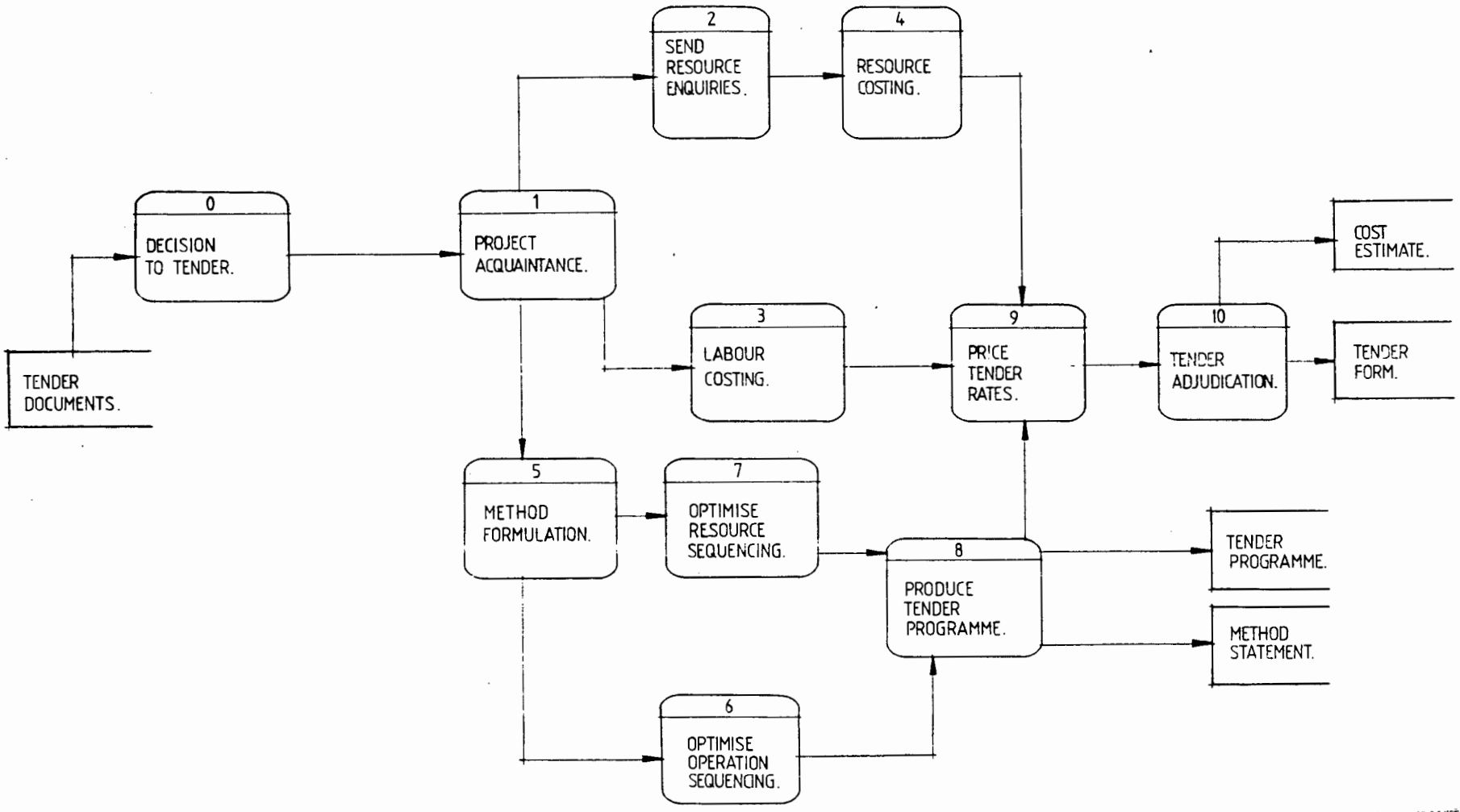


- A source or destination of data which is external to the defined sub-system.

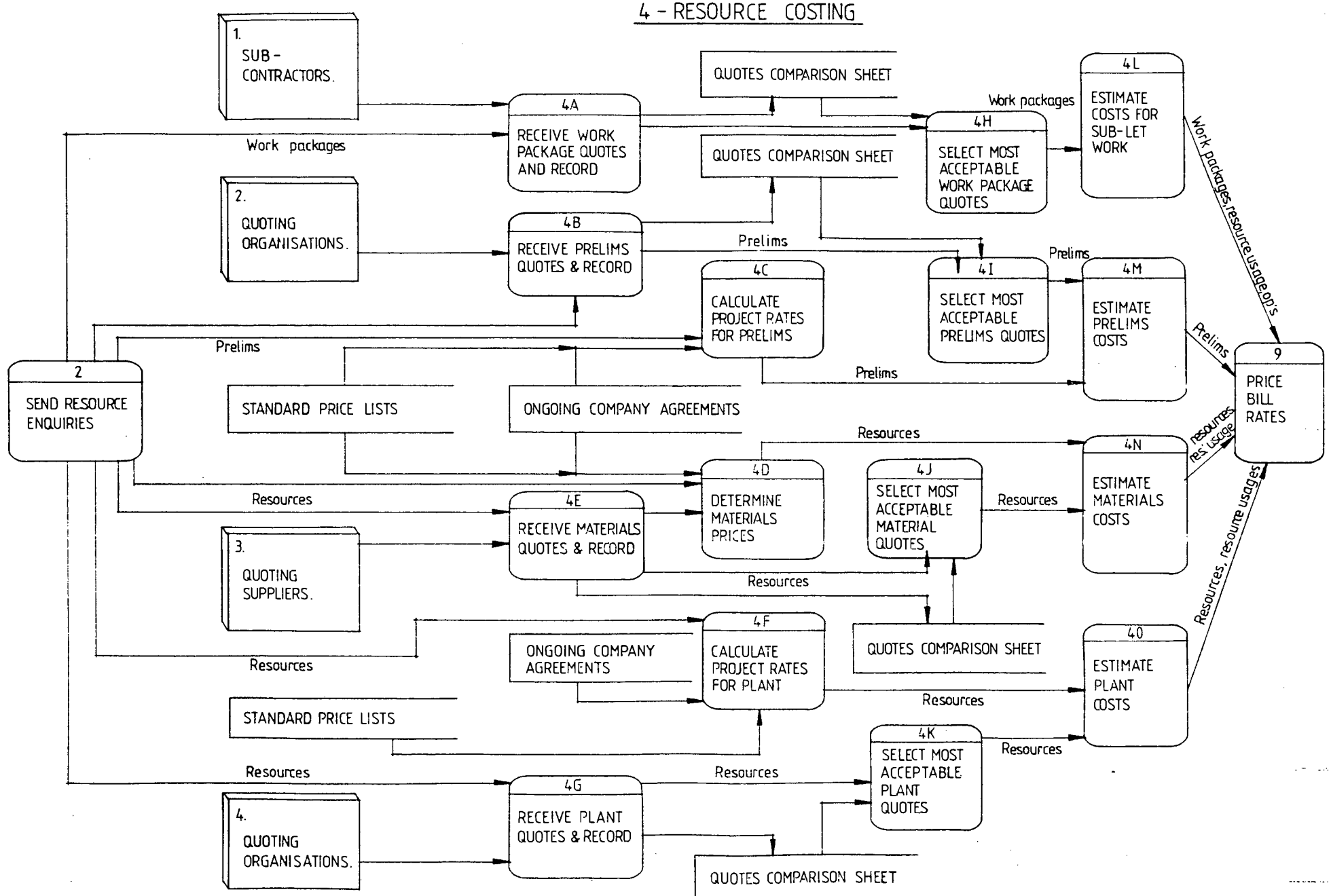


- A temporary store of data usually in the form of manual documentation.

TENDERING PROCEDURES



PRIMARY LEVEL



SECONDARY LEVEL

5.1.2 Data dictionary

This has been scheduled from the data flow diagrams with entities listed together with their associated attributes. Attributes include those to be found within the manual system together with extra attributes that have been added to enable data modelling. This latter category largely consists of identifying codes that have been assigned to all entities to ease the use and implementation of the model within the research. Such codes would be dispensable within any ultimate practical implementation.

ENTITIES	ATTRIBUTES
Bulk operations	Code, Name, Description, Unit of Measurement, Quantity, Start Time, Finish Time, Duration, Operation, Whether sub-let.
Contractors	Code, Tenders, Contracts, Name, Qualitative assessment of desire to win.
Contracts	Code, Value.
Tenders	Code, Value.
Elements	Code, Name, Description, Area, Unit of Measurement.
Parties	Code, Name, Address.
Bulk resources	Code, Name, Description, Unit of Measurement, Quantity.
Query	Code, Description, Specification of solution.
Answer	Code, Description, Query.
Increased Cost Categories	Code, Name, Forecast indices, Operation, Start index, Forecast cost increase.
Operation	Code, Name, Units of Measurement, Quantity, Bulk Operation, Whether sub-let, Type of Costing, Resource Usages, Unit rate labour component, Unit rate Sub-contractor component, Unit rate materials component, Unit rate plant component, Unit rate preliminaries component, All-in unit rate, Start time, Finish time, Duration, Preceding operation, Increased cost category, Forecast increased cost, total cost.

ENTITIES	ATTRIBUTES
Preliminaries	Code, Description, Related to, Amount, Unit of Measurement of amount, Whether quotes, Quoting organisation, Quote, Attendant costs, Total costs.
Work Package	Code, Name, Operations, Attendances, Sub-contractor, Quote, Attendant costs, Total costs.
Sub-Contractor	Code, Name, Work Package, Willingness to quote, Suitability to quote, Quote.
Quoting Organisation (Prelims)	Code, Name, Preliminary, Willingness to quote, Suitability to quote, Quote.
Quoting Organisation (Plant)	Code, Name, Resource, Willingness to quote, Suitability to quote, Quote.
Quoting Suppliers	Code, Name, Resource, Willingness to quote, Suitability to quote, Quote.
Corporate Resources	Code, Name, Quantities, Start time, Finish time, Specification, Unit of Measurement.
Resource Usages	Code, Operation, Resource, Resource Quantity, Operation Quantity, Wastage factor, Type of costing, Production constants/outputs, Prices, Costs, Unit rate, Resource unit of measurement, Operation unit of measurement, Resource gangs, Start time, Finish time, Duration.
Activities	Code, Name, Description, Units of Measurement, Operation, Start time, Finish time, Duration, Cost, Revenue, Whether subjected to detailed analysis.
Resources	Code, Name, Specification, Units of Measurement, Quantity, Whether quote, Price, cost, Quoting supplier, Quote, Attendant cost, Quoting organisation, Quote, Start time, Finish time, Duration.
Project	Code, Name, Estimated cost, Tender price, Tender documents received date, Tender submission date, Completion of estimate date, Tender adjudication meeting date.

ENTITIES	ATTRIBUTES
Location	Code, Name, Operation.
Cost Centre	Code, Name, Resource.
Bulk resource usages	Code, Bulk resource, Bulk operation.

The above two components of structured systems analysis therefore represent a statement of all data that passes through the tendering process. It is this range of data that is to be subjected to data analysis and data modelling and will form the contents of the coordinated information store.

This statement of data is directly comparable with those facets of data which were shown by the Newcastle Polytechnic study (100) to be fundamental to the transfer of information between interfaces. All of those facets appear as entities here.

Comparison with a more detailed schedule of data produced by a report of the data coordination study (101) is not possible due to the nature of the respective sources.

For the above reason and due to the fact that the form of the schedule is unfamiliar to those responsible for the preparation of tenders, it has not been possible to fully validate this data schedule.

As will be seen later, this is not considered to be critical to the testing of this research as both the tender model and the data schedule are intended as general models from which unique individual projects would differ.

The set of tasks undertaken for a project and the range of data used in preparing a tender would both be expected to be sub-sets of the general specifications presented here. This has been found to be the case in the project which was selected for the testing of the principle.

5.1.3 Summary

The use of these analysis techniques has resulted in the production of a specification of data that flows through the generalised model of tendering previously produced.

The specification of data for a particular project would be subject to the same variables that influence the nature of tendering tasks that are carried out.

The generalised specification of tendering data that has been produced is documented in the form of two-level data flow diagrams and a data dictionary which is a complete schedule of data entities and attributes.

5.2 DATA ANALYSIS

This section of the thesis has taken the results of structured systems analysis and applied analytical techniques that have been found to be necessary in providing the basis from which the synthesis of a data model is possible.

The above results represent the starting point for database construction. The second phase of design has been to study in some considerable detail the data elements that form the model. This has been done for both entities and attributes to provide information that is both necessary to execute some of the later stages of modelling and also to provide a better 'feel' for the data being handled.

Much of the application of data modelling techniques is ambiguous in that the interpretation being given to the data and assumptions regarding its use will determine the optimum way in which the data is to be stored from a practical point of view. For this reason the following extensive examination of the data being used is made necessary. It should also be pointed out that the following analysis refers to the data as it is used in the present system rather than its anticipated use within a future coordinated information system. The analysis forms part of systems examination rather than systems design.

5.2.1 Entity Analysis

Entities and attributes have been analysed separately as an entity type or occurrence may exist independently of attributes having been assigned to it. The form of analysis also differs in line with the use to which such analysis is put. Entity analysis is primarily used in entity-relationship modelling whereas attribute analysis provides information necessary for relational analysis in later stages.

All entities have been analysed to firstly identify candidate keys (attributes which are potential unique identifiers of an entity). An entity will have a number of attributes which describe its state and condition. Not all attributes will uniquely identify that particular entity occurrence but may be conditions or attribute values that are common to more than one entity occurrence e.g. more than one item of plant may be required on a project for a period of 12 weeks. Therefore the period of time for which an item of plant is required would not be a candidate key of the entity 'plant item'.

Those attributes that are unique identifiers of the entity to which they relate are termed candidate keys one of which will be selected as a primary key.

Other types of key that are considered here are foreign keys where an attribute of one entity is a unique identifier of a second entity. A concatenated key is where a combination of more than one attribute forms the only means of uniquely identifying an entity occurrence. Although concatenated keys are permissable within the methodology being used, they have been replaced by imposed codes in the testing of the research for the ease of implementation and use that this has allowed.

The second aspect of entity analysis has been to define the stage in the tendering model where the entities first occur as data, to examine whether additions or deletions are made to the list of entity occurrences during tendering and finally if so whether deleted occurrences are required to be retained.

This aspect of analysis is important to later modelling processes in establishing links between entities and attributes that relate to the dynamic nature of the data being analysed.

5.2.2 Attribute Analysis

In a similar way all attributes have been analysed for the nature of occurrence values and ranges within which such values fall. The nature of values indicates whether data is of a character, numeric, logical, monetary or date type. Ranges are presented as maximum space allocations that are expected and refers to the length of character strings, the numerical precision of data, etc.

This is primarily for the purpose of physical allocations at a later stage but also helps in understanding the nature of the data being handled.

The analysis also allows identification of points at which values are updated and if so whether old values are to be retained. This is important in deciding upon multiple files and protection to data that is to remain unaltered. Considerations such as authority of individuals to amend data also require such knowledge.

Finally an indication has been given of means by which values are derived where this is through the use of other data attributes within the data model. This is important in helping to identify possible relationships between data and has been used as an aid to entity relationship identification and in the assignment of attributes to skeleton tables in later aspects of modelling.

The results of data analysis are therefore a detailed specification of the inherent characteristics of the entities and attributes of data that are potentially used in the preparation of tenders.

Such an analysis of tendering data has not been produced before and therefore no comparison with previous studies is possible. In addition, the nature of the analysis has again been found to be inappropriate to validation by industry.

The results of this analysis have not been reproduced here due to the volume of material produced. Full details are to be found in the appendix volume.

5.2.3 Summary

The contribution that has been made by this stage of the methodology can therefore be summarised as being the supplementing of the schedule of data entities and attributes with full details of the inherent characteristics of both of these elements of data. Such characteristics are analysed for the purpose of enabling data modelling techniques to be applied where knowledge of the nature of entities and attributes is both explicitly and implicitly required.

5.3 DATA MODELLING

This section of the thesis forms the beginning of the synthesis of a solution to the problem of data coordination. This is done through the design of a logical or conceptual data model.

A logical or conceptual model refers to the way the structure of a database appears to those who access it (102). A physical model refers to the manner in which data is physically allocated to a storage medium and is not a consideration here.

The objectives for the logical or conceptual model are both, that it should encompass all data entities and attributes previously established, and that it should enable full coordination of all data entities in the specification of the format and content with which retrievals are possible.

The translation from a schedule of data items to a physical database is achieved by first constructing a logical or conceptual model which places parts of the database in their relative positions according to certain rules and principles.

There are a number of alternative approaches to modelling which have not been fully explored. The main alternatives are network, hierarchical or relational storage. The first two of these are to an extent dependent upon detailed knowledge of information access paths and present certain limitations to the structure and format with which information may be presented. As the rationale behind this research project lies in the development of an information retrieval system where the final form of retrieval is not known, any such restrictions would be undesirable and for this reason the use of a relational database has been selected.

A hierarchical database would have a certain priority order of entities by which the format of retrievals should be structured. This would approximate to the approach being taken in other research in the design of an ideal single hierarchy of classification.

A network database has a less rigid order of priority and would allow certain pre-defined links between separate branches of a hierarchy. This would approximate to the approach of a complex faceted classification which has a single hierarchy as its basis.

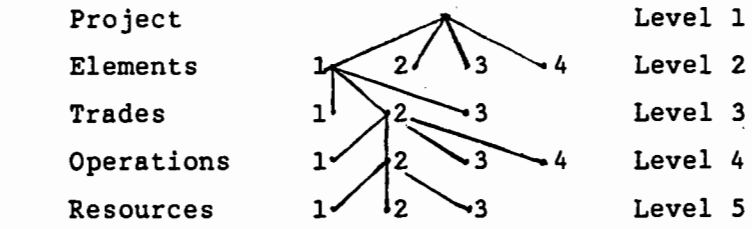
A relational database has no set hierarchy as its basis but would allow retrieval of data on the basis of any two entities between which a relationship can be established within the conceptual model. A parallel with other current work being carried out can not be contemplated for this level of complexity.

The following diagrams may aid the illustration of the distinction between these three database types.

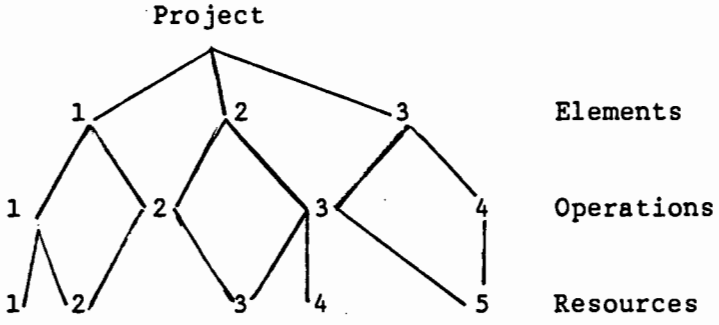
A relational database is the only currently known method by which such a conceptual model can be achieved. For a full description of alternative database forms, reference is made to Martin (103).

In designing a relational database, two techniques of data modelling have been seen as being most applicable, relational normalisation and entity-relationship modelling.

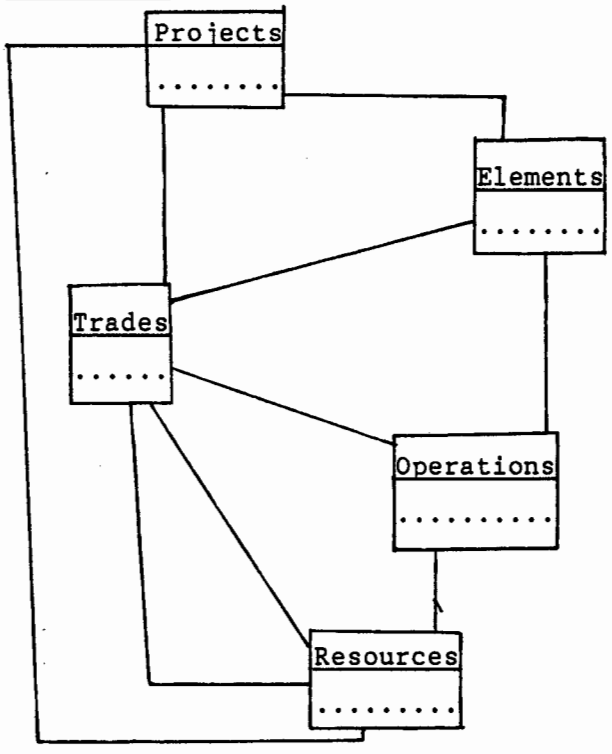
Hierarchical



Network



Relational



Relational normalisation is a bottom-up approach where all individual data attributes relating to a single entity are examined in relation to each other to establish data independence. A set of dependency rules have been defined which equate to a number of normal forms as defined by Codd (104).

The approach is basically one of decomposing files that contain all attributes of an entity to a point where all files contain data attributes that are fully dependent on each other.

Entity-Relationship (ER) modelling is a top-down approach which is based on examination of fundamental relationships between data entities. These are analysed for any complications in the form of the relationships and extra entities that are required before assigning attributes once the model is largely complete.

Much published information is available relating to the theoretical background to Entity Relationship (105) and Relational Normalisation (106) modelling together with current developments in modelling theory (107).

E-R modelling is judged as being the most suitable method by many for database design of high complexity and on this basis has been selected as the principal modelling technique within the study. Relational normalisation has then been applied to the conceptual model produced as a secondary technique and a refinement to database design. Howe (108) has illustrated the application of the two techniques in combination as used here. A case study of the application of E-R modelling techniques is also available in published form (109).

The remainder of this section represents the application of E-R techniques to tendering data the results of which are given in detail. Details of the application and results of relational normalisation analysis are to be found in the following section.

5.3.1 Entity-Relationship Modelling

The first stage of E-R modelling has been to identify all relationships that exist between entities and as a result of such analysis the following list was obtained.

5.3.1.1 Relationship Identification

Bulk Operation, Operation
Contractors, Tenders
Contractors, Contracts
Parties, Queries
Parties, Answer
Operation, Element
Bulk Resources, Resources
Query, Answer
Query, Operation
Increased Cost Category, Operation
Increased Cost Category, Preliminary
Operation, Preliminary
Operation, Work Package
Operation, Activity
Operation, Resource
Operation, Location
Preliminary, Work Package
Preliminary, Quoting Organisation (Preliminary)
Preliminary, Activity
Preliminary, Resources
Work Package, Sub-Contractor
Sub-Contractor, Resource
Quoting Organisation (Preliminary), Resource
Quoting Organisation (Plant), Resource
Quoting Supplier, Resource
Corporate Resource, Resource
Resource, Cost Centre

In deciding upon relationships that exist the results of earlier data analysis were extensively used. A potential criteria for relationship identification lies in the existence of formal messages which contain more than one entity. This criteria has been used in part although not exclusively in that formal messages presently only relate to documentation available through what has been defined as an inadequate manual information system. Details of formal messages or documentation are contained within data flow diagrams.

At this stage of design it is only possible to define entities between which it is envisaged a relationship would be desirable. Further desirable relationships will be possible to include in later refinements to database design. It should be pointed out that omitting desirable relationships would only limit the speed and ease with which information can be interrelated and therefore does not invalidate the testing of the principle.

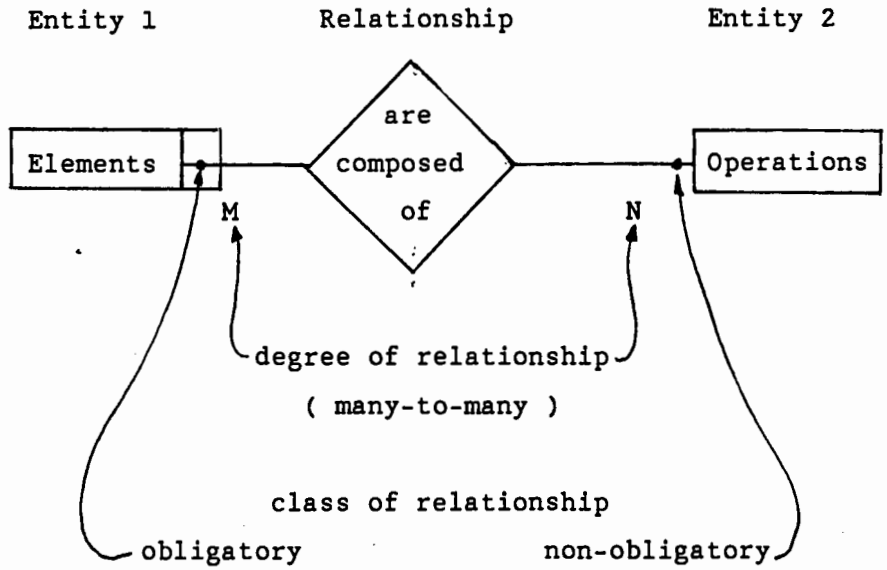
A relationship between two entities will still be possible through a more indirect route where a specific direct relationship has not been defined.

5.3.1.2 Entity Relationship Diagrams

The identified relationships have been analysed in detail through the use of entity relationship diagrams. Such diagrams enable specification of certain characteristics of all relationships which determine how the conceptual model is to be constructed. These characteristics include the degree and membership class of a relationship together with enterprise rules and determinacy constraints.

The degree of a relationship refers to the number of entity occurrences that may participate and with a binary relationship the alternative would be one-to-one, one-to-many and many-to-one. The membership class of a relationship is either obligatory or non-obligatory. This defines whether all or only some of the occurrences of an entity must participate in the relationship. Enterprise rules and determinacy constraints simply document the above two characteristics in a structured way.

An example E-R diagram has been annotated to give an example of these concepts.



Enterprise Rules:

Elements may be composed of more than one operation.

Operations may be composers of more than one element.

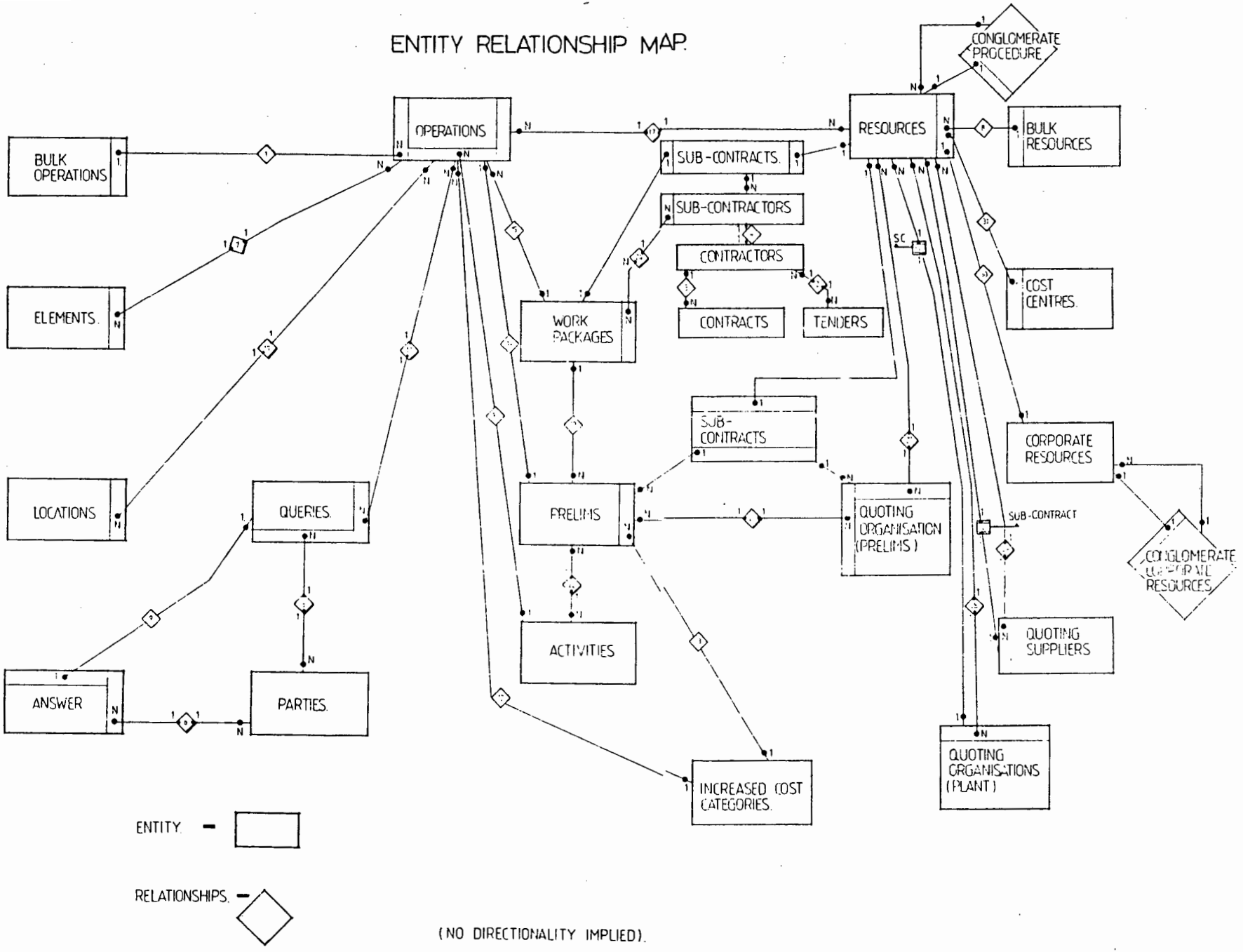
Determinacy Constraints:

An element does not determine an operation.

An operation does not determine an element.

Individual E-R diagrams together with the accompanying analysis has been performed for all relationships identified above. An overall E-R diagram has been reproduced here as a summary of the full analysis which is to be found in the appendix volume.

ENTITY RELATIONSHIP MAP.



5.3.1.3 Decomposition of Many-To-Many Relationships

The state of the data model at this stage is that all relationships have been analysed to the point were conceptual modelling can begin. The first stage of this modelling has been to decompose many-to-many relationships which it is being assumed are not permissable within this model. Some database management systems are able to handle many-to-many relationships but to avoid restricting the conceptual model they have been decomposed here. The process has simply been to form new entities of the relationships which were originally of this ineligible form. All many-to-many relationships simply become two separate one-to-many relationships with the old relationship becoming a new entity in itself. Details including revisions to relationship diagrams are reproduced in the appendix.

5.3.1.4 Elimination of connection traps

Modelling continues with the identification and elimination, were applicable, of connection traps. These take the form of either fan traps or chasm traps and again are ineligible for the physical model.

Potential Fan Traps

Fan traps potentially exist where two relationship occurrences of the same type fan out from the same entity occurrence. This could give rise to ambiguity in the determinacy between three linked entities. If entity A has a Many-to-one relationship with entity B which in turn has a one-to-many relationship with entity C there is potentially an incorrect assumed dependency between entities A and C. The problem only arises where there is a many-to-one-to-many chain which is best converted into a one-to-many,one-to-many chain.

i.e. M-1 1-M becomes 1-M 1-M

All instances where such a chain exists within the current model have been examined.

Operations ——→ Work Packages ——→ Prelims

Here there is a more direct relationship between Operations and Preliminaries which removes the trap.

Operations ——→ Increased Cost Categories ——→ Prelims

Here there is a more direct relationship between Operations and Preliminaries which removes the trap.

Operations ——→ Work Packages ——→ Sub-Contractors

Here there is no direct relationship between operations and sub-contractors until a quote has been selected at which point there will be a relationship between them through a sub-contractor being a resource.

Prelims ——→ Work Packages ——→ Sub-Contractors

Here there is no direct relationship between prelims and sub-contractors and therefore there is a danger of misinterpretation of the model. An amendment to the model has been made to account for this.

Potential Chasm Traps

Chasm traps exist where the existence of a relationship is suggested by the model between entity types where no such relationship exists between entity occurrences. An example would be the situation where the model suggests that entity A determines entity C indirectly through entity B whereas in effect there is a direct relationship between entities A and C. The trap is most likely to occur where there is a one-to-many-to-one chain and again the solution would be to remove the non-existent determinacy.

i.e. 1-M M-1 becomes 1-1

No potential chasm traps have been identified between entities within the model.

5.3.1.5 Other Complications

A series of other complications with the present data model have to be examined and dealt with before conceptual modelling is complete. These complications include complex, double and recursive relationships.

Complex Relationships

A complex relationship is defined as one that exists between more than two entities in a situation where they can not be broken down into binary relationships without losing determinacy information. That is knowledge of how the three or more entities interact with each other jointly would be lost and only information relating to individual pairs of entities would be retained.

Complex relationships should be used under the above conditions only when binary relationships are inadequate as they detract from the simplicity of the model. Potential complex relationships have been examined and where amendment to the conceptual model is necessary, revised E-R diagrams have been included.

1. Contractors, Sub-Contractors, Contracts, Tenders.

This is not a situation of a complex relationship in that the relation of contracts to tenders is one that is time related and therefore membership of the two entities is mutually exclusive.

2. Parties, Answers, Queries, Operations.

Again this situation is one where the relationship between the entities is one that is related to time and therefore the use of a complex relationship does not remove the nature of the situation.

3. Increased cost categories, Operations, Prelims.

The three relationships are made necessary by the optional nature of the membership between operations and prelims. Again the use of a complex relationship would not simplify the situation.

4. Operations, Activities, Prelims.

The rationale is as for 3.

5. Operations, Prelims, Work Packages.

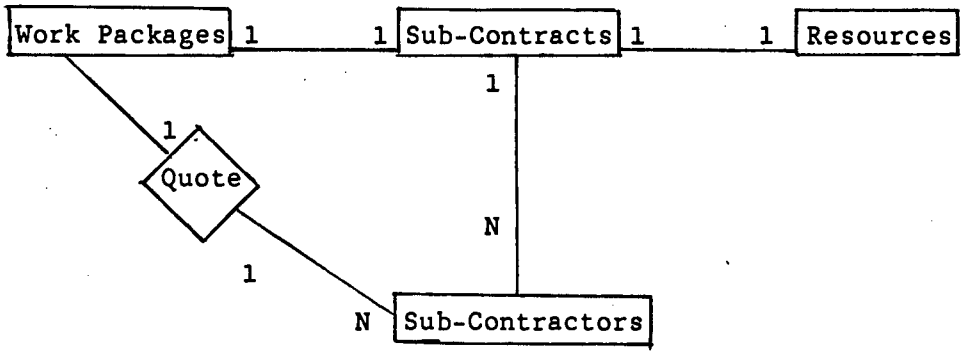
The rationale is as for 3.

6. Operations, Resources, Resource Usages.

The need for a complex relationship here is made unnecessary by the assumption that any relationship between operations and resources is made a subject of the resource usage entity.

7. Work Packages, Sub-Contractors, Resources.

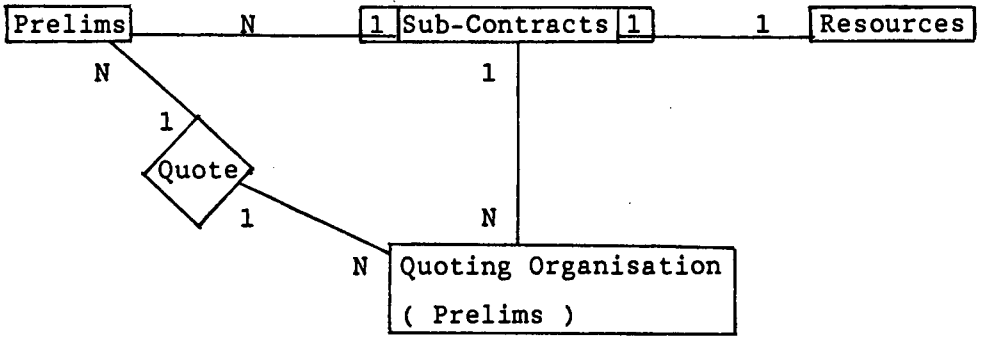
Here a complex relationship would lead to simplification and a three-way relationship between work packages, sub-contractors and resources is specified with the name of sub-contract being given to the relationship. The new entity relationship diagram for this relationship is as follows:



The necessity for a retained independent relationship between Sub-Contractors and Work Packages is again time-related and exists for the situation where enquiries have been sent but sub-contracts have not been awarded.

8. Resources, Prelims, Quoting Organisation (Prelims).

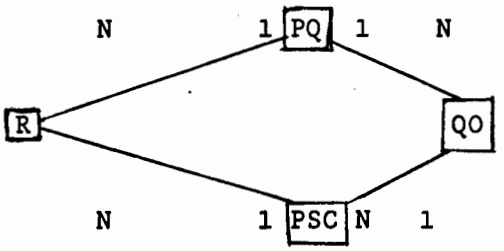
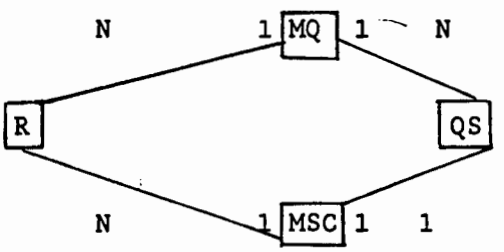
Here a complex relationship would lead to simplification and a three-way relationship between resources, prelims and quoting organisation (prelims) is specified with the name of sub-contract being given to the relationship. The new entity relationship diagram for this relationship is as follows:



The necessity for a retained independent relationship between Prelims and Quoting Organisation (Prelims) is again time-related and exists for the situation where enquiries have been sent but sub-contracts have not been awarded.

Double Relationships

A further complexity that has to be examined is the situation where more than one relationship type exists between the same two entities. In the first example below there are two relationships that exist between resources and organisations that submit quotes for plant resources. The originally identified relationship is that of providing a quote whereas the second relationship of being awarded a sub-contract has now been identified.

Entities	New Relationship	New Diagrams
Resources, Quoting Organisation (Plant)	Sub-Contract	
Resources, Quoting Suppliers	Sub-Contract	

Recursive Relationships

Here the problem exists that an entity may have a relationship with itself which is not manifested on the original diagrams of the model. The examples shown indicate that some resources are composed of a combination of other resources and to avoid problems such as double-counting of resource totals, etc this fact needs to be specified in the conceptual model.

Entity	Explanation of Relationship	New Diagrams
Resource	Some resources are conglomerates of other resources e.g. mortar being a conglomerate of sand, cement, lime, etc.	Resource N | | 1 1 | | | | 1 Conglomerate Resource
Corporate Resource	Some corporate resources are conglomerates of other corporate resources e.g. mortar being a conglomerate of sand, cement, lime, etc.	Corporate Resource N | | 1 1 | | | | 1 Conglomerate Corporate Resource

5.3.1.6 Construction of Skeleton Tables

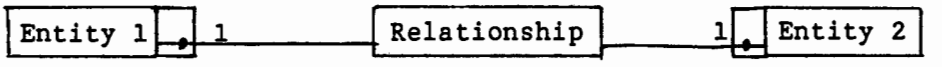
The analysis at this point enables an initial set of skeleton tables to be constructed. A skeleton table is one that is based on an entity or relationship without having its associated attributes assigned to it. The rules and principles of skeleton table construction are outlined here. The application of these rules requires knowledge of the degree and membership class of relationships between entities. This is available from the individual E-R diagrams previously referred to which are to be found in the appendix.

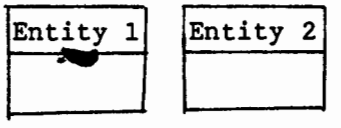
These rules are set out in the form of seven alternative cases which embrace all circumstances encountered in the analysis.

Case 1

Degree: One-to-One Membership: Both obligatory

Both entities and the relationship can be a single table.

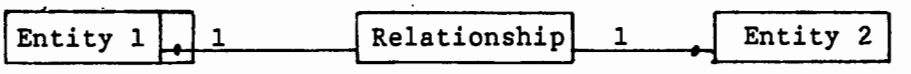
E.g. 

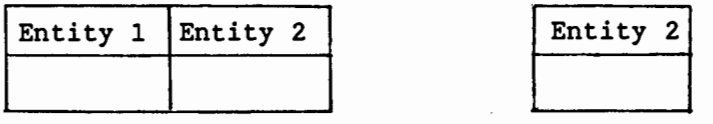
Resultant tables 

Case 2

Degree: One-to-One Membership: One obligatory, one non-obligatory

Both entities as separate tables with the obligatory table having the identifier of the other as a field.

E.g. 

Resultant tables 

Case 3

Degree: One-to-One Membership: Both non-obligatory

Separate table for each entity and a third for the relationship itself.

Resultant tables

Case 4

Degree: One-to-Many Membership: Many membership obligatory

As for case two

Case 5

Degree: One-to-Many Membership: Both non-obligatory

As for case three

Case 6

Degree: Many-to-Many

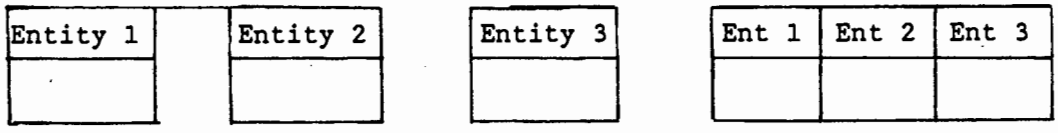
Regardless of membership class separate tables must be constructed for both entities and for the relationship.

Case 7

Complex relationships

Regardless of degree or membership class, separate tables must be constructed for each entity and a single table for the relationship.

Resultant tables



The above principles have been applied in deriving full skeleton tables for which table name, type, table identifier and posted identifiers have been defined. A posted identifier is a table identifier that also exists in a remote table and is the mechanism by which all tables are able to be inter-related in providing a coordinated system of information retrieval within a relational database. Full details of the construction of skeleton tables are found in the appendix volume.

5.3.1.7 Attribute Assignments

The skeleton tables are so called in that at this stage tables have been defined in terms of entities and by other tables to which they are related. A table is a component of a conceptual model which will become a database file when physically implemented as a database. The skeleton tables produced can now have all other attributes within the model assigned to them to give full table design. The principles upon which such assignments are made are now outlined before considering the results of attribute assignments.

Rules

1. The final set of tables must be relational normalised with no repeating groups and with every determinant being a candidate key. (As full relational analysis is to be performed later the only consideration being considered here is the avoidance of repeating groups i.e. only a single occurrence of an attribute being possible for a single entity occurrence)

2. If there is a choice in placement, null values should be avoided. This will normally mean placement with an entity whose membership is obligatory.

3. If no suitable table exists then further entities or relationships may need to be defined or alterations made to existing definitions.

The attribute assignments that have been made are again to be found in the appendix and not reproduced here due to the volume of material.

5.3.1.8 Summary

The procedural application of entity-relationship techniques has been fully described here but the summary of its contribution can be seen as being the transposition of a schedule of analysed data entities into a logical or conceptual data model of a relational database. This the top-down approach to database design which at this point forms the first part of a hybrid design methodology being used within the research.

Entity relationships have been identified and specified in terms of enterprise rules and determinacy constraints. Data traps within the relationship map have been eliminated and unusual relationship types identified. This has enabled skeleton tables to be constructed and attributes to be assigned to them.

These tables are the forerunners of the ultimate database files and form the starting point from which relational normalisation may begin. Relational normalisation is the second or bottom-up approach of the hybrid design methodology.

5.3.2 Relational Normalisation

The technique of entity-relationship modelling produces a conceptual model where all entities and relationships may be translated into relations or tables within a relational database. At this stage all relations derived this far have been analysed for the existence of repeating groups the removal of which places the model in first normal form (1NF) according to the Boyce-Codd rule (110).

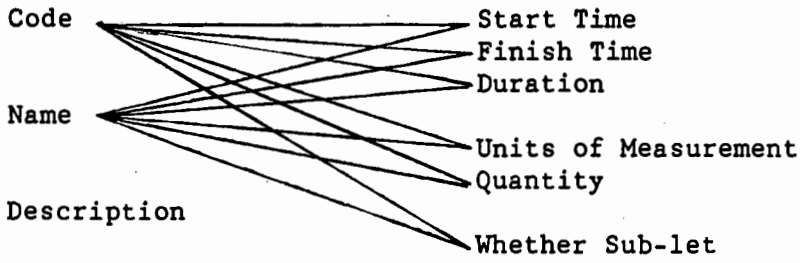
Other normal forms are now examined in further refinement to the model. In order to do this full determinacy diagrams have been produced together with their decomposed forms. These diagrams indicate where one attribute is an identifier of other attributes and the second normal form requires that all attributes within a single relation should be dependent upon all parts of an identifier that is in a concatenated form.

The third normal form requires that all attributes within a relation which are neither the identifier, nor a candidate identifier which has simply not been chosen through convenience, should be mutually independent from all other non-identifier attributes. This is simply stating that there must only be a single level of determinacy within a single relation rather than having such determinacies nested within a relation. This is the non-transitive dependency rule by which the third normal form is defined.

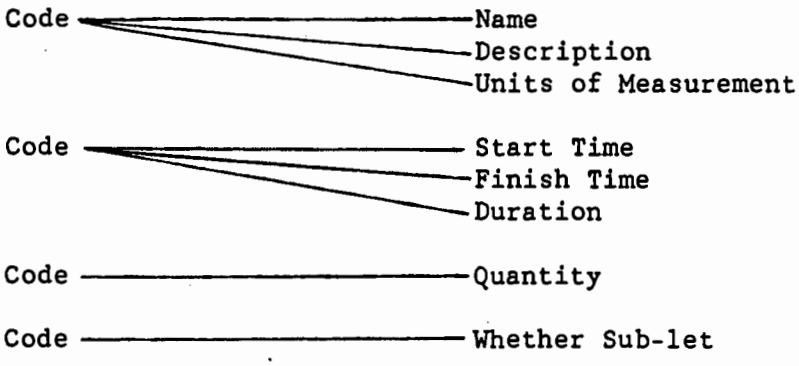
Relational normalisation techniques may be continued by the examination of further normal forms. These have not been considered at this stage as it is felt that they would not significantly contribute to the testing of the principle of the database in coordinating construction project data. Further enhancement in development of a database to a practical system may need to examine higher normal forms. For a description of the nature of higher normal forms and the method by which they are measured, reference is made to other sources (111).

The determinacy diagrams together with their decomposed forms show the transition of the conceptual model into one that satisfies the requirements of relational normalisation and are reproduced in full in the appendix. A sample determinacy diagram for the Bulk Operation entity is shown here.

This satisfies the second level of data modelling referred to earlier where the primary design technique of entity-relationship modelling has been refined and enhanced with the bottom-up approach of relational normalisation giving a combination of the two design approaches whereby the requirements of both have been satisfied.



becomes:



5.3.2.1 Second Normal Form Analysis

Such analysis ensures full functional dependency between all attributes and the relation's concatenated key. This rule requires that attributes must be determined by both components of an identifier that is of a concatenated form. All concatenated identifiers have been examined in detail for possible contravention of the rule.

Relation Name	Key	Non-Key Attributes
Operation / Element	Operation Code + Element Code	Operation quantities in Elements
Operation / Location	Operation Code + Location Code	Operation quantities in Locations
Increased Cost Categories Forecast	Increased Cost Categories Code + Period	Forecast Index, Forecast cost, Forecast cost increase.
Activity Sequencing	Activity Code + Preceding Activity	-
Sub-contracts (Work Packages)	Work Package Code + Resource Code	Sub-contract Code
Sub-contracts (Prelims)	Sub-contract Code + Resource Code	-

All of the above meet with the full functional dependency rule which is necessary for a relation to be in second normal form (2NF). This rule is met if all non-key attributes (column 3) are fully dependent upon both components of the concatenated key (column 2). Examination of the decomposed determinacy diagrams will confirm that this is the case.

5.3.2.2 Third Normal Form Analysis

A relation is in third normal form if it meets the non-transitive dependency rule. This refers to all non-key fields being mutually independent. This is achieved by the removal of nested determinacies referred to earlier. The following relations have been examined in depth for possible contravention of the rule.

Relation Name	Key	Non-Key Attributes
Prelims Quantities	Prelims Code	Amount, Related to, Units of Measurement.

The above relation is a potential violator of the non-transitive dependency rule in that the attribute 'related to' is a determinant of the attribute 'units of measurement'. However, upon closer examination it can be shown that this is only the case with a part of total occurrences and for this reason no further relations are necessary.

Combination Resource	Combination Resource Code	Resource Set, Resource Code
Combination Corporate Resource	Combination Corporate Resource Code	Corporate Resource Code, Resource Set

The above relations are all potentially violators of the non-transitive dependency rule as in both cases the resource code/corporate resource code are determinants of resource sets. For this reason they have both been sub-divided in to the following relations:

Relation Name	Key	Non-Key Attributes
Combination Resource	Combination Resource Code	Resource Code
Combination Resource Sets	Combination Resource Code	Resource Sets
Combination Corporate Resource	Combination Corporate Resource Code	Corporate Resource Code
Combination Corporate Resource Sets	Combination Corporate Resource Code	Resource Sets

5.3.2.3 Relation Design

Having subjected all relations that were directly taken from E-R modelling to relational analysis to the point that they are in third normal form, the full specification of relations has now been achieved. This is the final conceptual model and the relations defined here simply remain to be converted into database files of the physical model.

The design of all relations has been reproduced in the appendix. The name of the relation is given together with its primary key. All non-key attributes have been scheduled of which those that are candidate keys or identifiers are highlighted.

5.3.2.4 Summary

This forms the conclusion of the application of the database design methodology. The above specification of relations forms a generalised conceptual model of a relational database applicable to the coordination of tendering data.

As with previous generalised models, any individual project is likely to draw upon a sub-set of the relations scheduled above. These relations that are to be included would become the individual files within the database.

5.4 EVALUATION OF CONCEPTUAL MODEL

Having completed the process of conceptual modelling through the use of techniques of E-R modelling and relational analysis the resultant database design has been evaluated through the use of cohesion analysis. By this process, all relations are examined and classified into one of four types. These are listed here in descending order of strength.

Functional cohesion where files cover data used by a single task

Communicational cohesion where all fields relate to a single entity.

Procedural cohesion where a file covers more than two tasks.

Coincidental cohesion where fields have no inter-relationship.

Cohesion analysis is one of few means by which conceptual models can be evaluated and has been included here for that reason. The best measure of the efficiency of a database lies in its use as an information retrieval system. This to an extent is also evaluating the components of physical implementation i.e. hardware and software which is not the intention. No entirely satisfactory independent means has been found of objectively evaluating a conceptual model and therefore cohesion analysis, despite its limitations, has been adopted. The only true measure of the conceptual model lies in the correct application of the design techniques that have been used.

The primary weakness of cohesion analysis to the testing of this particular conceptual model is that the analysis is based on relating model structure to current information usage. This is contradictory to the expressed intention of the research in attempting to devise a means of structuring information which is unrelated to individual tasks that are being executed.

The following is a summary of the analysis of all relations by their class of cohesion. Full details of this analysis are again to be found in the appendix volume. For a fuller description of the principles of cohesion analysis, reference is made to other sources (112).

	Number of Relations
Functional cohesion	0
Communicational cohesion	63
Procedural cohesion	36
Coincidental cohesion	0

The classification of all relations of this study according to cohesion analysis illustrates that no relations have functional cohesion. This is seen as justification for the methodology given the argument above, despite the fact that functional cohesion is classified as the strongest form.

This represents the conclusion of this section of the thesis whereby a hybrid methodology of E-R and relational normalisation modelling techniques have been applied to the schedule of data entities and attributes derived from the tender model. This represents the significant synthesis phase of the work in that a conceptual model has been produced which form the foundation for the implementation of a physical database.

The work at this stage also meets with the first objective that had been set in support of the testing of the hypothesis. A coordinated model of data, encompassing that used by building contractors tendering, has been produced by the application of a sequence of methodologies.

5.5 PHYSICAL IMPLEMENTATIONS

This section of the thesis contains a description of the way in which the logical model derived above has been implemented in the form of a series of computerised databases.

This includes a description of the configuration of hardware and software that has been used together with an indication of the limitations this places upon the logical model. Alternative configurations are examined and a commentary given of the current and future trends in development.

The next section then forms a description of the tenders that have been used as the data sources for the research together with the limitations imposed by their use.

The final section consists of a commentary on the nature of the database system that has actually been developed and modifications that are necessary in translation to a working system.

5.5.1 Configuration

For the purpose of this research, a combination of hardware and software has been used which represents recent developments in the technology within the field of micro-computing. Alternative micro-based combinations are available which would enable the information system to be tested in a similar way.

More advanced database management systems are now available on mini-computer or a mainframe set-up. The advancement of such systems lies in the efficiency and speed with which data can be handled rather than the flexibility given to data retrieval. It is for this reason that the limitations imposed by the hardware and software used in the research are not considered to be of a nature that invalidates the testing of the principle of data coordination.

The particular configuration used was that of an IBM PC XT microcomputer together with Ashton-Tate's DBase III database management system (113). Earlier implementations were based on the DBase II system (114) which again was only inferior in terms of the efficiency and speed of retrieval rather than the flexibility allowed.

Current trends in database management systems, the availability of random access memory and the possibilities of mass storage of data are leading to the situation where it is felt that the principle being tested by the research will be capable of development to the position of a system of data retrieval for industrial application.

5.5.2 Tender Data

In the implementation of the logical model, data has been obtained from three sources including one from a national building contractor pertaining to a recently completed tender.

This project is a commercial shed building for the storage of salt with the client being the highways department of a local authority. The tender submission date was 24th June 1986. The project was based on a single-stage selective competitive tender with clients representatives having prepared drawings and bills of quantities. The approximate value of the project was £130,000.

Permission was given by the contractor to have access to all available tender documentation together with the opportunity for personal contact with those responsible for preparation of the tender.

The project was specifically selected for use within the research on the basis of its simplicity for the testing of the principle of the research. This refers to the fact that the quantity of data is of a manageable size rather than the range of types of data being small.

It is felt that all individual construction projects would have been deficient in some aspect of data and that attempting to discover a project which included all entities and attributes would have proved a fruitless search. This view was supported by the contractors from whom project data was sought.

Full details of a comparison between the set of data entities and attributes that was included for this tender and that upon which modelling has been based is given in the evaluation and testing of the research.

5.5.3 Nature of the Database

The system of data retrieval that has been produced as a means of testing the research is far from being a practical system of use in tendering. The intention of the research has been to test the level of data coordination that would be possible with such a system. However it is felt that the opportunity exists for post-research development work to take place in developing a practically orientated system which would be tailored to the requirements of an individual contractor. Negotiations on this subject are proceeding with a number of firms that have contributed to the work.

It is felt that such development would build upon the methodology of research used within the thesis but with a significant input from the building contractor concerned.

5.5.4 Results of Implementation

The results from having implemented the data to the data model has been to produce a system of database files whose structure and contents are shown below:

Filename	Records	Date of Creation	Size (bytes)
OPAC.DBF	357	10/06/86	3312
OPCOST.DBF	357	10/06/86	6525
OPQTY.DBF	357	10/06/86	6525
OPSL.DBF	357	10/06/86	2241
OPTIME.DBF	357	10/06/86	5161
OPSEQ.DBF	357	10/06/86	3312
OPCT.DBF	357	10/06/86	2241
OPUR.DBF	357	10/06/86	27648
ACTP.DBF	36	10/07/86	315
REQO.DBF	54	10/09/86	585
BKOPTIME.DBF	16	10/06/86	371
BKOPQTY.DBF	16	10/17/86	371
EL.DBF	6	10/06/86	997
BKOPSL.DBF	16	10/06/86	179
OPEL.DBF	357	10/07/86	12301
LO.DBF	5	10/06/86	249
OPLO.DBF	357	10/06/86	12658
ACTIME.DBF	36	10/06/86	667
BKOP.DBF	16	10/06/86	2627
AC.DBF	36	10/06/86	4123
OP.DBF	357	10/07/86	50143
ACCOST.DBF	36	10/07/86	1247
ACPR.DBF	46	10/06/86	513
PR.DBF	46	10/06/86	2629
PRWP.DBF	46	10/06/86	513
PRSL.DBF	46	10/06/86	375
PRQUL.DBF	0	07/31/86	131
PRQU.DBF	0	07/31/86	163
PRST.DBF	0	08/01/86	99
OPPR.DBF	46	10/06/86	513
STPR.DBF	0	08/01/86	99
QOPR.DBF	0	08/01/86	99
QOPRASS.DBF	0	08/01/86	131
PRQTY.DBF	46	10/06/86	1911
RU.DBF	400	10/09/86	5331
RE.DBF	85	10/09/86	6931
RURATE.DBF	400	10/09/86	18563
RUOTPT.DBF	400	10/09/86	8099
RUWF.DBF	400	10/09/86	4899
RUGANG.DBF	400	10/09/86	4499
RETIME.DBF	85	10/09/86	1353
RUTIME.DBF	400	10/09/86	7395
WP.DBF	9	10/10/86	851
REUNIT.DBF	85	10/09/86	1374
RERATE.DBF	85	10/10/86	2766
REPRIC.DBF	85	10/09/86	1629
RESL.DBF	85	10/09/86	609
REBKRE.DBF	85	10/10/86	864
RECC.DBF	85	10/09/86	864

Filename	Records	Date of Creation	Size (bytes)
RECR.DBF	0	08/01/86	99
RECOR.DBF	0	08/01/86	99
WPCOST.DBF	9	10/10/86	261
WPQUL.DBF	55	10/10/86	846
WPQU.DBF	55	10/10/86	2583
OPWP.DBF	82	10/10/86	837
SC.DBF	55	10/10/86	1749
SCCO.DBF	0	07/31/86	99
SCST.DBF	9	10/10/86	512
SCASS.DBF	55	10/10/86	516
REQTY.DBF	85	10/10/86	1629
SCQU.DBF	0	08/01/86	99
STWP.DBF	7	10/10/86	512
BKRE.DBF	19	10/10/86	1651
BKREUNIT.DBF	19	10/10/86	384
BKREQTY.DBF	19	10/10/86	441
OPQRY.DBF	7	10/14/86	512
QRY.DBF	5	10/14/86	1024
ANS.DBF	5	10/14/86	880
ANSPTY.DBF	5	10/14/86	134
PTY.DBF	2	10/14/86	289
PTYQRY.DBF	5	10/14/86	134
OPBKOP.DBF	357	10/10/86	1024

6. TESTING AND EVALUATION

This chapter contains a number of sections relating to the evaluation of the research. Evaluation is made in relation to the stated hypothesis that the contractors data requirements in tendering can be coordinated within a single store. The remainder of this chapter forms the assessment of the extent to which this hypothesis has been proved or disproved.

The chapter begins with a section analysing general theories of evaluation and the extent to which they relate to the research. On the basis of this analysis, a methodology has been designed for the testing of the research and this is presented as a separate section.

The primary testing of the research is then shown in accordance with this methodology. This forms the full evaluation of the hypothesis.

The final two sections of the chapter are extensions to this testing firstly in the form of further supporting evidence. Secondly, the chapter concludes with an indication of the consequences of the results of testing being applied to construction projects generally.

6.1. THE THEORY OF EVALUATION

Testing is aiming to establish quantitatively whether the database design allows coordination of construction project data. Before describing the detailed methodology of how this is to be done, an analysis is made of the background to the evaluation of information systems (117).

6.1.1 Stages of Evaluation

Evaluation stages can be summarised as:

- identification of potential comparative criteria
- examination and selection of relevant criteria
- measurement of performance of alternative systems with regard to relevant criteria
- comparison of relative values of criteria measurements

The above is a means of evaluation which can be applied widely but will form the method of evaluation of the database in the testing of the hypothesis.

6.1.2 Bases of Evaluation

In examining the detail of the application of these evaluation methods, certain principles have been highlighted which influence the form such application will take. These again have been derived from previous studies (118).

Evaluation is seen as consisting of both a description of systems which are to be evaluated followed by more detailed measurement. Description in this case is necessary to facilitate a superficial comparison of the function, scope and objectives of different systems.

The method of description that has been used here is that recommended by the C.I.B. study (119) of using tables from the Construction Industry Thesaurus (120) to classify:

- for whom the information is intended (Table F)
- which documents the system uses (F)
- which project processes the system assists (G)
- which categories of information are dealt with (F-K)
- which properties and measures of data are used (E)
- which times / phases of a project are relevant (G)
- which places are relevant (E)

Description of the application of the database in this form is repeated in full in the appendix.

In addition, evaluation is held to be only relevant if alternative courses of action are possible. In the case of the database, evaluation will compare its performance in relation to the performance of currently used manual methods. A second benchmark will be provided by seeing the database as a description of the actual level of coordination compared with a non-existent desired level of coordination. The first benchmark of existing manual performance will enable relative evaluation. The second benchmark of a desired level of coordination will allow absolute evaluation.

The purpose of evaluation is to set a value on a system which is the measurement of the extent to which a system's objectives have been met. In the case of the database this can be done by measurement in one or all of three areas:

1. Information results - what information is produced ?

2. Information activities - what activities are to be performed in producing the information results over an above those activities required by the benchmark system ?

3. Information stores - what activities are required in converting an information result into a secondary information store ?

6.1.3 Identification of potential evaluation criteria

The testing of the hypothesis requires a detailed quantitative measure of the extent to which the database is a coordinated store. The method of testing has been designed with the need for coordination as the paramount requirement.

From previous studies (118) it is concluded that criteria used for comparative evaluation must be equally relevant to both the database approach and the current manual system. In addition, all criteria used in evaluation must be quantifiable. Non-quantifiable criteria or subjective judgements will form part of the description of the two systems. However, non-quantifiable criteria may be replaced by quantifiable criteria of a finer detail which give pointers towards higher level non-quantifiable criteria.

Criteria should approximate to performance specifications of systems if possible and can be derived from system objectives that are described in terms of desired outputs.

Finally all measurements of criteria can be based on various types of measurement scales. Nominal scales are mere classifications of performance with no indication of value. Ordered scales give an indication of relative values but no measure of the differences between values. Interval scales give an indication of relative value that also measure the difference between values. Finally, proportional scales show relative value together with measurements of different values but also measure absolute values against a scale whose end points are known and defined.

Examples of three measurements of weather and temperature would be:

Nominal	Sunny, cloudy and raining
Ordered	Warm, Hot and Very warm
Interval	17 degrees C, 31 deg. C and 26 deg.C
Proportional	288 deg Kelvin, 302 deg K and 297 deg K

The form that testing is to take is of the nature that detailed measurements are being made. For this reason these measurements should, wherever possible, be based on proportional or interval scales. The evaluation of the performance of the two systems will then be possible on the basis of quantitative analysis.

6.2. EVALUATION METHODOLOGY

The previous section sets out the theoretical framework within which evaluation will take place. In this section the methodology of evaluation is shown in its stages of development. This takes the form of the identification of potential evaluation criteria, the selection of criteria to be used, and a description of how performance will be measured and compared.

6.2.1. Identification of criteria

Potential evaluation criteria are identified and examined in accordance with the above principles. What is being sought is a set of criteria that will enable measurement of the level of tendering data coordination in comparison to that achieved by alternative systems.

The derivation of each of these potential criteria has been as a result of extensive examination and analysis based upon: the criticisms made by practitioners, the philosophy of database design and also the contribution made by others. Skinner's work (121) is of particular relevance here, as is that work relating to the evaluation of information systems (118).

The table examines each potential criteria in turn and identifies those that are to be used in testing including a description of the rationale for their use.

Where appropriate, criteria that are of a similar type have been grouped and collectively analysed. This explains the multiple entries within the first column. Although differences are possible to define within these criteria groupings, this summary table indicates general descriptions of the rationale for their use in or omission from the methodology.

CRITERIA	USED	RATIONALE FOR USE
Necessity	No	The necessity of information does not measure the level of coordination but is a potential measure of information utility.
Currency/ Timeliness	Yes	The point of derivation can be measured on an ordered scale and shows whether the most recent information is being coordinated.
Ease of access/ speed of provision/ cost of production	Yes	The activity required in producing information is measurable in a number of ways and is a measure of the relative cost of performance of systems in their coordination.
Format/ Content/ Adequacy/ Level of Detail	Yes	The information provided does in itself measure the level of coordination by the specification of entities and attributes which it draws upon.

Usability/ Independence	No	The work is specifically precluding certain aspects of information namely that which is drawn, that which is experience, that which is knowledge, etc which combine with data to form a complete specification of information requirements. Testing of this criteria would only be measuring the level of other aspects of information needed which is beyond the remit of the hypothesis.
Coverage/ Scope	No	The coverage of information possible through coordination is largely a measure of the coordination of the data in itself rather than the system which is producing it. This would give a proportional measure of the level of coordination of the data itself.
Benefit/ Value of information	No	Measuring the value of information or attempting to specify ideal information requirements is beyond the remit of the hypothesis but is important in any cost/benefit evaluation of systems. Cost effectiveness is being measured here.
Quality/ Fitness for purpose/ Relevancy	Yes	A survey of the relevancy of data retrievals from the database has been made based on the perceptions of the estimator responsible for producing the data for the third project used in testing.

6.2.2. Selection of evaluation criteria

Therefore the criteria that will be used in evaluating the level of coordination that is provided by the database will be:

A. Currency	- the point at which data is derived or updated.
B. Cost of production	- activity required in providing coordination over and above activity required in the benchmark system.
C. Format and Content	- the measurement of the possible formats and contents against those possible within benchmark systems.
D. Relevancy	- a measure of how relevant data retrieved is to the carrying out of tasks.

A. is a measure of the extent to which data is updated further than is possible under existing systems. This aspect of coordination is measured on an ordered scale.

B. is a measure of the resource cost of producing the achieved level of coordination in principle and is therefore of use in assessing cost effectiveness against alternative systems.

C. measures the level of coordination of information produced. This is done against benchmarks of existing, ideal and zero measurements. Measurement is therefore made on a pre-defined proportional scale.

D. is a measure of the fitness for purpose of data in the form of a survey of the perceptions of an estimator.

From this analysis of the criteria that are to be used, it is concluded that criteria C is the fundamental measure of data coordination within a database system. The flexibility of data presentation is being taken as the indicant of the degree to which the components of the data store are inter-related. Criteria A, B and D are measures of other characteristics of the data store in providing this coordination. Criteria C is therefore the basis of primary testing with measurement of the other criteria being a part of supporting evidence.

6.2.3 The Vehicle for Evaluation

Having established criteria of data coordination together with criteria of the cost of coordination and criteria for the value of data, the following forms the detail of how measurement of the criteria will be made between the two systems.

The vehicle of measurement will be by interrogating the databases by all potential combinations of data entities as formats and contents. Matrices will be constructed of information interrogated by all combinations each of which is defined as an interrogation specification.

Matrix of data interrogations

Interrogation Format	Operations	Resources	Locations Etc
Interrogation Content			
Operation	Possible	Possible	Impossible Etc
Resources	Impossible	Possible	Impossible Etc
Locations	Possible	Possible	Possible Etc
Work Packages	Possible	Impossible	Possible Etc
Queries	Impossible	Possible	Impossible Etc
Etc			

6.2.4. Measurement of Performance

The four selected criteria are now examined in detail for the method by which measurement of performance will be made.

In doing so a clear distinction is drawn at this stage between criteria that contribute to primary testing and those that form part of the supporting evidence.

6.2.4.1. Primary Testing Criteria

Measurement of format and content will provide assessment between systems on a proportional scale. This is the case because end points of a scale are defined and relative measurements taken between these end points. Full coordination in this context is measured by all combinations being possible. Zero coordination being measured by interrogations only having interrogation contents and formats based on the same entities.

e.g. Zero coordination allows x1 interrogation specifications
Manual system allows x2 interrogation specifications
Database systems allow x3 interrogation specifications
Full coordination allows x4 interrogation specifications.

Relevancy of data retrievals has been measured by seeking the judgement of the estimator responsible for producing the tender for the third testing project. Examples of all combinations of format and content that have been found to be possible only with the use of the database have been shown to the estimator who has assessed their relevance in accordance with a questionnaire.

6.2.4.2. Supporting Evidence Criteria

Measurement of currency of information will be made where both systems allow interrogation with the same format and content specifications. In such instances measurement will be made of the most recent point of updating of information between the two systems allowing comparison on an ordered scale. This ordered scale is represented by the model of tendering tasks established through functional analysis. This model includes flow process charts which indicate the relative order of execution of tasks.

e.g. For interrogation specification (i,j);
Manual system point of updating is point x
Database system point of updating is point y

The cost of producing coordinated data will be measured by the relational algebra procedures that are executed in retrieving information from the database in accordance with each interrogation specification. Relational algebra procedures include; selections, updates, joins, counts, summations. Each of these procedures will be enumerated. The relative importance of different relational algebra procedures can not be measured as it is dependent upon both hardware and software used and the quantity of data being handled. For this reason the measurements will be on a nominal scale.

e.g. For interrogation specification (i,j);
Requires x1 selections, x2 updates, x3 joins, etc

6.2.5. Points for Comparison of Values

Despite only two systems being evaluated, analysis will take place for three conditions to take account of the characteristics of the experimental data. These characteristics arise from the fact that the tenders being studied, as would be the case with any projects that had been selected, do not use every data entity and attribute nor execute every task that has been used in designing the databases. All projects will use a particular sub-set of both. The three conditions are:

Condition 1 - the existing manual information systems applied to project data of the third testing project. Measurements were ascertained from existing documentation together with interaction with the project estimator.

Condition 1A - the database system applied to the data of the first and second testing projects. Measurements were produced by the example operation of the database.

Condition 2 - the database system applied to the data of the third testing project. Measurements were produced by the destructive operation of the database.

For criteria A and B, evaluation will be performed between conditions 1 and 2 only. Testing on these criteria is to be seen as part of the supporting evidence of the work.

For criteria C, evaluation will be performed between all three conditions to illustrate the evolution of the database in its development over time and to indicate the coordination that may be achieved for different types of projects. This is the primary testing of the research.

For criteria D, evaluation will again be performed between conditions 1 and 2 only. This aspect of evaluation aims to establish the value of the contribution that is being made by the research and is based upon the assessments made by an estimator. This is seen as the validation of part of the primary testing.

6.2.6 Evidence to Support Extrapolation of Results

The results that will be produced as a result of the methodology described above will enable conclusions to be drawn about the level of coordination and its worth in relation to three specific sets of project data.

In order that the conclusions drawn may be extrapolated in a statitically valid way to apply to construction projects generally would require much more extensive analysis than that which it has been possible to include in this study. This point is addressed in more detail in the section of the thesis in which extrapolation is made. However, to place the research and its conclusions into context, evidence has been gained regarding how representative the sample is. This evidence takes the form of a measure of the range of data to be found in the three testing projects compared with the range of data to be found in construction projects generally. This has been measured in the following ways.

1. By analysis of data entities and attributes that were used as a basis for database design compared with those that were available for database construction. This compares the project data that was available for the construction projects that are being used in testing in relation to the data that the earlier model of tendering had established as being used. There are certain differences here which reflect the fact that the projects being studied have not been tendered for in the precise way that the tendering model would indicate. The model of tendering tasks was designed to reflect the highest level of complexity that would have been used on tenders generally. The process of functional analysis was based on extensive survey's of current practice which specifically aimed to establish the most complex procedure of tender preparation whilst recognising that individual projects would involve the execution of a smaller range of tasks drawing upon a sub-set of the complete tasks of the model.

e.g Database model uses set A of entities and attributes
Projects being tested use set B

2. By analysis of individual tasks. This is to assess whether data that was used in tendering has been accommodated within the database. This testing has been performed by attempting to produce sample interrogations from the database in accordance with every task of the previously derived model of tendering. The agreement that information produced from the database does relate to all individual tasks has then been obtained through cross-referencing with the specifications of data contained within data flow diagrams of structured systems analysis.

e.g. Manual system uses/produces document set A for task A
Database system uses/prod.s document set B for task A

The detailed analysis of testing has been undertaken on the basis of evaluation of the database for three separate sets of construction project data. It is not argued that these represent the full range of complexity and size of projects or that conclusions drawn from their analysis would be applicable generally in a statistically valid way. However, the analysis of the extent to which the projects embrace the tendering process is presented as evidence in support of any future extrapolation or broader study and places into context the conclusions that have been drawn. The point is reiterated that the tender model that has been constructed is based on survey work which aimed to establish tasks potentially executed for any particular type of project. The model is not therefore typical of an individual tender but is a representation of the tasks that would be executed and the data used for all construction projects. This is held to significantly contribute to the extrapolation of results in itself in that any study of further projects would have simply led to a different sub-set of tasks and data entities being studied and would not have added to the work or its conclusions.

6.3 PRIMARY TESTING

This section represents the fundamental evaluation of the research whereby assessment is made of the full flexibility of the database with regard to data coordination. The presentation consists of a description of and a rationale for the use of the three projects used in testing. This is followed by the results of detailed analysis of testing with regard to the formats and contents of data. The final aspect of primary testing then takes the form of the assessment of the relevancy of the coordination achieved by the database.

6.3.1. Testing Data

The primary testing of the research is through measuring the flexibility with which data can be retrieved from a database. This flexibility has been defined in terms of the format and content of data.

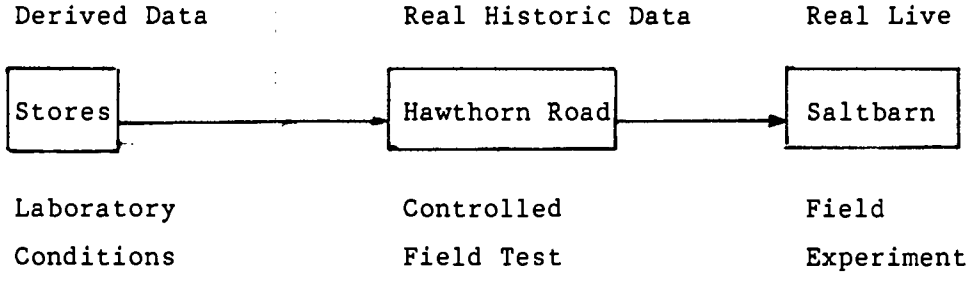
The detail of how this has been performed has been through implementing the database design with three different sets of project data from three discrete projects as follows.

Project 1 — Derived data from a fictitious project which has been used as an experimental implementation of the database under 'laboratory' conditions. This project will be referred to as "Stores".

Project 2 — Historical data of a real design that has been used as a controlled field test in the evaluation of the database. This project is referred to as "Hawthorn Road".

Project 3 Current data of a project under construction that has been obtained from a contractor. This has been used as a full field experiment for the application of the database. This project has been extensively used in the detailed analysis of testing as well as in providing supporting evidence. As access was also available to the project estimator, whose recollection of detail was recent, this project has also been used in the validation of the work through the relevancy survey. This project is referred to as "Saltbarn".

The above is presented as a logical sequence in which project data has been used as a means of testing within the research. The depth of analysis has evolved in accordance with the data used. The following diagram summarises the progression of the use of the three projects and their place within testing.



The problem is recognised that testing on the basis of three projects does not enable conclusions to be drawn for the industry as a whole. However, a previous study (122), when faced with this similar problem, used detailed testing on the basis of a limited number of projects and suggested that further validation would be required.

The justification for the use of the three discrete projects as vehicles for the testing of the research is that each is being used for a discrete purpose and as a part of an overall testing strategy. The use of three projects has also been of value to the work in the following ways.

Firstly, any analysis of an existing system and design of a database to support such a system is by its nature an iterative process. To be able to develop a logical model of data that represents that required in a practical solution requires a detailed understanding of the nature of the data that is being used. The process of data analysis is the primary means by which such an understanding is gained but this has been supplemented by an appreciation of the problems of physically implementing the database. In addition such iterations of implementation aid the process of data analysis in itself.

Secondly, the use of earlier implementations has been of assistance to the process of collaboration with building contractors. An indication has been possible of the nature of the work and clarification of the potential benefits of the approach to industrial collaborators. This was fundamental to the work in that the research has necessitated extensive collaboration by a large number of building contractors in order to construct an accurate model of the detailed methodology of tender preparation for the most complex situation.

This section of the thesis consists of a description of the three implementations that have been made together with examples of the retrievals of data that they were able to produce. Full details of the first two implementations have been documented as earlier research reports (115).

6.3.1.1 Stores Project

A fictitious project was used of three stores buildings of brick/block cavity wall construction on concrete strip foundations with concrete floor and roof slabs and asphalt roof finishing. All data has been generated for the project manually including full measurement, specification, costing and programming data.

The approach within this implementation was to demonstrate a sample of the alternative reports that were possible together with a sample of interrogations that were made. These are specified below in a descriptive form and have then been defined in terms of format and content in accordance with the methodology.

The information matrices produced are those that were produced by sample documentation and do not represent the total capacity of this first implementation in terms of coordination of data.

Reports;

Bill of Quantities locational format
Priced Bill of Quantities SMM format
Resource Schedule unformatted
Resource Usages - a definitive method statement
Bulk Operation Cost Analysis
Bulk Resource Cost Analysis
Bill of Quantities work package format
Activities schedule unformatted
Work Packages scheduled in time format
Cost Analysis cost centre format
Cost Analysis work package format
Cost Analysis location format

Interrogations;

Resource cost by operation format
Operation cost by location format
Operation quantities by resource format
Resource cost sorted but unformatted
Operation cost sorted but unformatted
Operation cost by Cost centre format and time format
Operations by time and resource formats
Resource quantities by time format
Operation quantities by time and resource formats
Operation costs by time format

This sample of data retrieved from the database is shown in terms of a data matrix below.

Details of example retrievals from the database are to be found in the appendix. A selection of sample retrievals are shown here.

	BULK OPS.	ELEMENTS.	PARTIES.	QUERIES.	ANSWERS.	OPERATION	PRELIMS.	WORK PACKAGES	SUB-CONTRACTC	BULK RES'.	COST CENTRES.	RESOURCE USAGES.	ACTIVITIES	RESOURCE:	PROJECTS.	LOCATIONS
BULK - OPERATIONS.																
ELEMENTS.																
PARTIES.																
QUERIES.																
ANSWERS.																
OPERATIONS.	R					RI		R			RI	R		I		RI
PRELIMS.																
WORK PACKAGES.													R			
SUB-CONTRACTORS.													R			
BULK RES'.																
COST CENTRES.													I			
RESOURCE USAGES.																
ACTIVITIES.													R			
RESOURCES.	R					I				R		R	I	RI		
PROJECTS.																
LOCATIONS.																

STORES DATABASE.

Example Database Interrogation from Stores project.

Plant Resources used in Excavation Operations

Operation	Resource	Cost
A001	Hydraulic excavator	74.55
A002	Hydraulic excavator	74.55
A003	Hydraulic excavator	40.75
	Total	189.85

Operations in Block C costing over 300 pounds

	Operation	Cost
C001	Concrete in strip foundations	336.99
C114	Reinforced concrete roof slab	489.23
D102	Half-brick skin of hollow wall in facings.	1344.68
D201	100mm skin of hollow wall in lightweight concrete blocks.	1080.45
D311	Half-brick skin of hollow wall in engineering bricks.	557.12
F101	20mm Mastic Asphalt in 2 coats.	652.50
G100	Formwork to reinforced concrete roof slab.	886.38
	Total	5347.35

Cumulative costs centre costs at period 54

Cost Centre	Cum. Cost	Total Cost	% Complete
Sub-structure	4982.20	4982.20	100
Superstructure	15.48	5899.08	0.26
Roof	0.00	5751.06	0
Doors	53.30	456.68	11.67

6.3.1.2 Hawthorne Road Project

The data here was one used in a project developed over a period of time by the construction management staff team at the Polytechnic of the South Bank. Under the supervision of the staff team, and in particular that of David Coles, the specification, measurement, costing and programming of the project has been performed by M.Grice to whom acknowledgement is made (116).

The project consists of a four-storey office block on an inner-city site adjacent to existing buildings. The building is of a reinforced concrete frame structure with brick cladding and aluminium curtain walling. Only the brickwork and asphalt trades have been included in data retrieved from the database.

The following is a similar analysis of the reports and interrogations produced from this second implementation.

Reports;

- Priced Bill of Quantities in work package format
- Priced Bill of Quantities in elemental format
- Priced Bill of Quantities in location format
- Operation cost in increased cost category format
- Resource schedule unformatted
- Resource cost in elemental format
- Resource costs in locational format
- Activities schedule

Interrogations;

- Activities in time format
- Operations in resource and time formats
- Operations in element and location formats
- Operations sorted in location format
- Resources in elemental format.

This sample of data retrieved is shown in terms of a data matrix below. Similarly, full details of example retrievals from this database are to be found in the appendix, whilst a further selection of sample retrievals is reproduced here.

Example Database Interrogations from Hawthorn Road project.

Schedule of Activities carried out between weeks 35 and 44

	Activity	Start	Finish	Duration
025	Roof - brickwork, screed, asphalt	35	38	3
026	Fourth floor - windows, screed, second fix, etc.	38	43	5

Bill Items in External Walls on the Third Floor

Bill Item	Quantity	Unit
Common brickwork in gauged mortar in English Bond.	14	m2
Common brickwork in piers	3	m2
Extra over for facings	56	m2

Resources used in Internal Walls

Resource	Quantity	Cost
Bricklayer	2906	11274.12
Bricklayer's Labourer	1162	3742.54
Lignicite 100mm concrete blocks	348	1320.88
1:2:9 Mortar	2	43.44
Total		16380.98

	BULK OPS.	ELEMENTS.	PARTIES.	QUERIES.	ANSWERS.	OPERATION	PRELIMS.	WORK PACKAGES	SUB-CONTRACTOR	SUB-CONTRACTS	INCREASED COST CATEGORIES	RESOURCE USAGES.	ACTIVITIES	RESOURCES	PROJECTS	LOCATIONS
BULK OPERATIONS.																
ELEMENTS.																
PARTIES.																
QUERIES.																
ANSWERS.																
OPERATIONS.		RI				R		R			R		I	I		RI
PRELIMS.																
WORK PACKAGES.																
SUB-CONTRACTORS.																
SUB-CONTRACTS.																
INCREASED COST CAT.																
RESOURCE USAGES.																
ACTIVITIES.													RI			
RESOURCES.		RI												R		R
PROJECTS.																
LOCATIONS.																

HAWTHORN ROAD DATABASE.

6.3.1.3. Saltbarn Project

The data used here was that from a commercial shed building obtained during the process of construction. The work involved the construction of a new saltbarn for a local authority client and included associated works in demolition of existing facilities and alteration work to a second building. From this point of view, the project embraced a variety of trades and taken together with projects 1 and 2, illustrates the application of the database to a range of construction types and trades.

The project consists of a portal frame construction with steel sheet cladding and roofing together with associated work in mechanical and electrical services. Other trades included were excavation and earthworks, concrete, brickwork and blockwork, woodwork, structural steelwork and painting.

The analysis of reports and interrogations that has been produced for projects 1 and 2 is not repeated here as the Saltbarn project is subjected to detailed analysis in the following section.

6.3.1.4. Summary

These implementations were primarily executed as iterations of the methodology being used within the research. Taken together with the tender and data models, which were based on survey of methods used for all construction projects, they illustrate that the methodology is applicable to a significant range of project types and sizes. The data upon which an implementation is based is unique in its detail for each project as is to be anticipated in extracting from a generalised model.

These iterations are taken as part of the primary testing of the database design being applied to three discrete construction projects. This progression in analysis was necessary for testing to be at the level of detail required and although this inevitably has led to a small sample being used, the supportive experience of these iterations is held to contribute to general conclusions that are being drawn.

6.3.2. Measurement of Performance

The primary measure of coordination, and thereby the most important means by which the hypothesis is being tested, is by evaluation of the flexibility with which data can be retrieved from the model. This is being evaluated through the vehicle of a data interrogation which is specified in terms of;

1 - the format of data - its structure.
2 - the content of data - what has been quantified.

In the course of structured systems analysis certain discrete data entities were established as being used and/or produced by the project tendering system. These entities have been taken as the variables of format and content which it is relevant to examine. As 31 entities were established in structured systems analysis, it follows that there are 31 x 31 = 961 potential combinations in which data can be retrieved.

Testing has measured how many of these 961 combinations are possible under three conditions;

Condition 1 - Saltbarn project data produced manually.
Condition 1A - Stores and Hawthorn Road data produced by the database.
Condition 2 - Saltbarn project data produced by the database.

6.3.2.1. Comparison between conditions 1 and 2

The evaluation of database retrievals has been performed for the two conditions in the following way.

Condition 1

All entities were examined for the availability of data for the project. This led to the construction of a smaller (16 x 16) matrix of 256 combinations of format and content. In effect the conclusion that was arrived at was that only 16 of the total 31 entities of project data were actually present in the data available for this particular project.

All tender documentation, within the limits expressed later, has been made available by the contractor for the project. All documentation was examined for the occurrence of any combination of format and content that was present. Each unique occurrence of a combination was then recorded on the following matrix. A total of 64 such combinations was found in the project documentation.

Condition 2

The smaller matrix was again used and all 256 combinations examined for the nature of the interrogations that were to be attempted. The first result of this process was to classify combinations as being meaningless regardless of the method of data retrieval that may be used. The reason for a combination of format and content for data retrieval being meaningless has been classified in two categories;

	BULK OPS.	ELEMENTS.	PARTIES.	QUERIES.	ANSWERS.	OPERATION	PRELIMS.	WORK PACKAGES	SUB-CONTRACTI	SUB-CONTRACTS	QUOTES.	RESOURCE USAGES.	ACTIVITIES	RESOURCE	PROJECTS	LOCATION
BULK - OPERATIONS.	√														√	√
ELEMENTS.		√													√	
PARTIES.			√												√	
QUERIES.				√		√									√	
ANSWERS.					√	√									√	
OPERATIONS.	√			√	√	√		√						√	√	√
PRELIMS.	√						√							√	√	
WORK PACKAGES.						√		√		√	√				√	
SUB-CONTRACTORS.								√	√		√				√	
SUB-CONTRACTS.								√		√	√				√	
QUOTES.	√					√		√	√	√	√	√		√	√	
RESOURCE USAGES.	√					√	√					√			√	
ACTIVITIES.													√		√	√
RESOURCES.	√					√	√					√		√	√	
PROJECTS.															√	
LOCATIONS.															√	√

SALTBARN DATABASE. CONDITION 1 - MANUAL DOCUMENTATION.

- those instances where the entity that formed the format of the retrieval was of a similar nature to that which formed the content. Such a combination would be meaningless if the format entity were to be at a finer level of detail. This would have simply led to data being structured in categories that were sub-categories of the data itself. An example of this form would be bulk operations classified by operations.

- those instances where the two entities that were to be combined as a format and content in a retrieval had no meaningful relationship with each other. The data model would allow their coordination through both entities having a relationship with a common third entity. An example of this form would be parties (giving answers to queries) classified by quotes received from sub-contractors.

  Meaningless combinations of this second form would be meaningless in both instances of the two entities playing the part of the format and content.

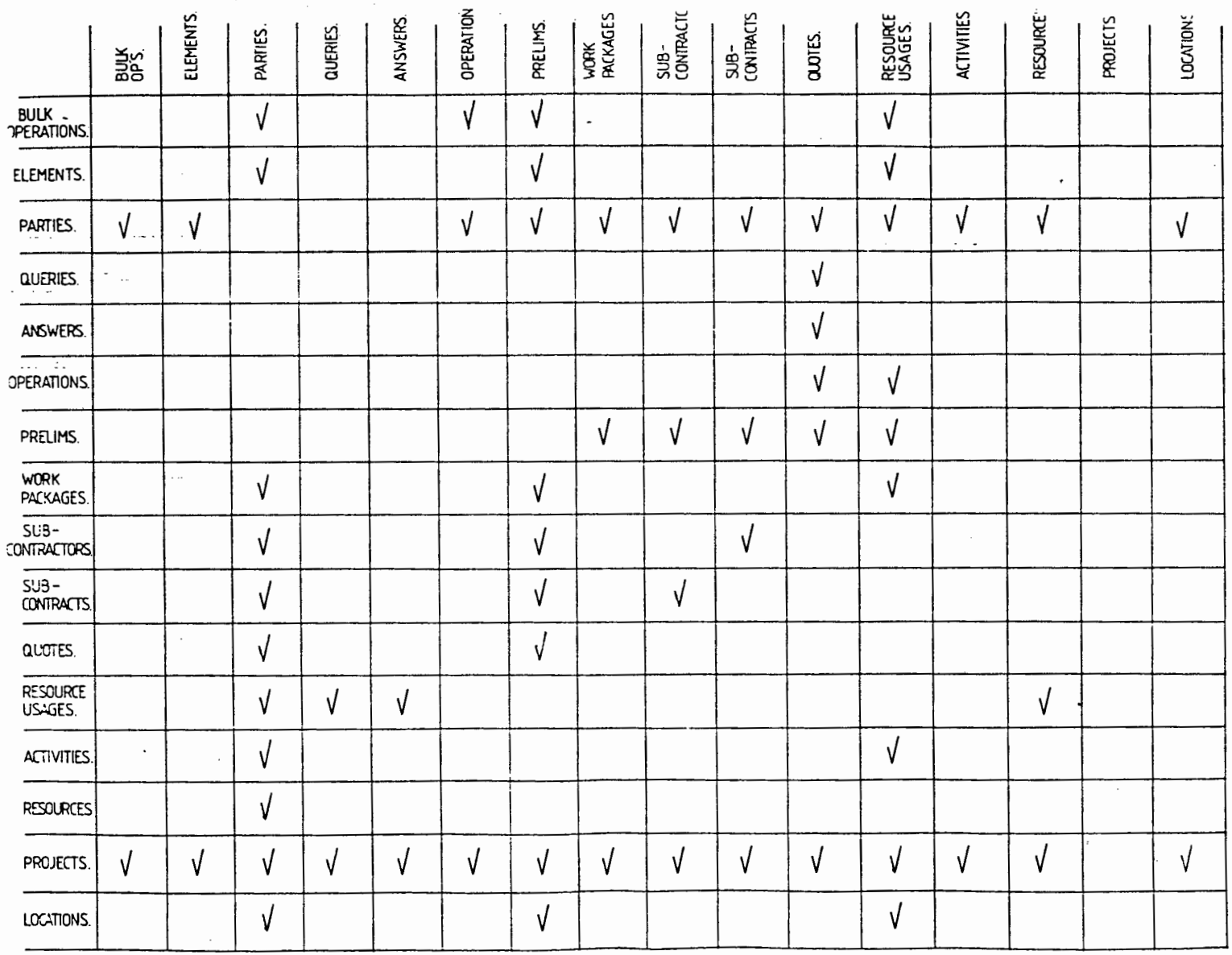
  i.e. parties classified by quotes is meaningless therefore quotes classified by parties is meaningless.

A total of 64 combinations were found to be meaningless by these definitions leaving 192 combinations which would have meaning if a retrieval of that nature could be performed.

The meaningless combinations are shown in the following matrix.

A programming utility within the database management system used, allowed all remaining combinations to be attempted. The success of these attempted retrievals is now examined.

Through the destructive operation of the database in this way certain failures in retrieval were identified. The reason for failure of a retrieval has been further categorised into three classifications;



	BULK OPS.	ELEMENTS.	PARTIES.	QUERIES.	ANSWERS.	OPERATION	PRELIMS.	WORK PACKAGES	SUB-CONTRACTC	SUB-CONTRACTS	QUOTES.	RESOURCE USAGES.	ACTIVITIES	RESOURCE	PROJECTS	LOCATION
BULK - OPERATIONS.			√			√	√	-				√				
ELEMENTS.			√				√					√				
PARTIES.	√	√				√	√	√	√	√	√	√	√	√		√
QUERIES.											√					
ANSWERS.											√					
OPERATIONS.											√	√				
PRELIMS.								√	√	√	√	√				
WORK PACKAGES.			√				√					√				
SUB-CONTRACTORS.			√				√			√						
SUB-CONTRACTS.			√				√		√							
QUOTES.			√				√									
RESOURCE USAGES.			√	√	√									√		
ACTIVITIES.			√									√				
RESOURCES.			√													
PROJECTS.	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√
LOCATIONS.			√				√					√				

SALTBARN DATABASE. CONDITION 2 – MEANINGLESS COMBINATION.

1 - failure due to lack of data meeting the retrieval criteria.

2 - failure due to the nature of the data for the Saltbarn project making the retrieval meaningless.

3 - failure due to incorrect definition of the data model.

Each of these failures can be accounted for in the development of the model and its application more widely to alternative project data.

Failure type 1

This simply refers to the fact that no data was retrieved in the combination of format and content specified. It can be argued that a request for data meeting specific conditions bringing forth the answer that no such data exists is in fact a successful retrieval. An example of such a failure would be a request for preliminaries to be classified by elements showing that no preliminary items had been assigned to an elemental classification of the project.

Failure type 2

This refers to the fact that because of the nature of the data used on the saltbarn project, certain retrievals would be meaningless in this instance although not meaningless with alternative sets of data. An example would be the retrieval of answers to queries being classified by resources. For the Saltbarn project, such a retrieval was possible but because all queries related only to operations, the retrieval had linked queries and resources through a common third entity where no meaningful relationship exists. For other projects it is conceivable that queries would relate specifically to resources regardless of the operation in which they were used. This failure type is in effect a combination of failures 1 and 3.

	BULK OPS.	ELEMENTS.	PARTIES.	QUERIES.	ANSWERS.	OPERATION	PRELIMS.	WORK PACKAGES	SUB-CONTRACTC	SUB-CONTRACTS	QUOTES.	RESOURCE USAGES.	ACTIVITIES	RESOURCES	PROJECTS	LOCATIONS
BULK - OPERATIONS.									3							
ELEMENTS.						2										
PARTIES.				2	2											
QUERIES.							1				2			2		
ANSWERS.							1				2			2		
OPERATIONS.			2				1		3	2						
PRELIMS.	1	1	1	1	1	1							2			1
WORK PACKAGES.				2	2	2							2	2		
SUB-CONTRACTORS.	3			3	3	3					3	2	3	3		3
SUB-CONTRACTS.				2	2	2					3			2		
QUOTES.						2			3	3						
RESOURCE USAGES.																
ACTIVITIES.						2	2	3	3							
RESOURCES.				2	2				3							
PROJECTS.																
LOCATIONS.						2			3							

SALTBARN DATABASE. CONDITION 2 - FAILURE TYPES.

Failure type 3

Failures of this type have retrieved meaningful data that is inaccurate in terms of the criteria of format and content that have been specified. They are all due to the incorrect definition of the data model and refer to the distinction between sub-contractors moving from the stage of quoting for work to that of having been selected to carry out part of the work. A re-design of this part of the data model would be necessary to account for this failure type. Normalisation beyond third normal form may account for such failures otherwise re-examination of entity-relationship modelling would need to be performed.

It is more likely to be the case that these failures are accounted for by the definition of an external schema specific to this project as an extract from the conceptual model (schema) that has been used. This conclusion is supported by published work in database design methodology (123).

Successful retrievals have all been examined to ensure that what has been retrieved meets with the criteria of format and content specified. Examination has also established whether the retrieval has meaning.

A further matrix is shown illustrating successful combinations of format and content that have been retrieved under conditions 1 and 2 of the test. This has been repeated using both a narrow and a broad definition of retrieval success. The broader definition classifies as successful those retrievals that suffered failure type 1.

	BULK OPS.	ELEMENTS.	PARTIES.	QUERIES.	ANSWERS.	OPERATION	PRELIMS.	WORK PACKAGES	SUB-CONTRACTC	SUB-CONTRACTS	QUOTES.	RESOURCE USAGES.	ACTIVITIES	RESOURCE	PROJECTS	LOCATIONS
BULK - OPERATIONS.	X	2		2	2			2	2	2	2		2	2	X	X
ELEMENTS.	2	X		2	2			2	2	2	2		2	2	X	2
PARTIES.			X												X	
QUERIES.	2	2	2	X	2	X		2	2			2	2		X	2
ANSWERS.	2	2	2	2	X	X		2	2			2	2		X	2
OPERATIONS.	X	2		X	X	X		X					2	X	X	X
PRELIMS.	1					1	X					1		X	X	
WORK PACKAGES.	2	2				1		X	2	X	X				X	2
SUB-CONTRACTORS.		2						X	X		1				X	
SUB-CONTRACTS.	2	2						X		X	1	2	2		X	2
QUOTES.	X	2				1		X	1	1	X	X	2	X	X	2
RESOURCE USAGES.	X	2		2	2	X	X	2	2	2	2	X	2		X	2
ACTIVITIES.	2	2		2	2					2	2		X	2	X	X
RESOURCES.	X	2				X	X	2		2	2	X	2	X	X	2
PROJECTS.															X	
LOCATIONS.	2	2		2	2			2		2	2		2	2	X	X

2,1 = Successful under conditions '1' or '2' only.

X = Successful under both conditions

SALTBARN DATABASE. COMPARISON BETWEEN SUCCESSFUL RETRIEVALS UNDER CONDITIONS 1 & 2 (NARROW DEFINITION OF SUCCESS).

	BULK OP'S.	ELEMENTS.	PARTIES.	QUERIES.	ANSWERS.	OPERATION	PRELIMS.	WORK PACKAGES	SUB-CONTRACTC	SUB-CONTRACTS	QUOTES.	RESOURCE USAGES.	ACTIVITIES	RESOURCE:	PROJECTS.	LOCATIONS.
BULK - OPERATIONS.	X	2		2	2			2	2	2	2		2	2	X	X
ELEMENTS.	2	X		2	2			2	2	2	2		2	2	X	2
PARTIES.			X												X	
QUERIES.	2	2	2	X	2	X	2	2	2			2	2		X	2
ANSWERS.	2	2	2	2	X	X	2	2	2			2	2		X	2
OPERATIONS.	X	2		X	X	X	2	X					2	X	X	X
PRELIMS.	X					X	X					1		X	X	2
WORK PACKAGES.	2	2				1		X	2	X	X				X	2
SUB-CONTRACTORS		2						X	X		1				X	
SUB-CONTRACTS.	2	2						X		X	1	2	2		X	2
QUOTES.	X	2				1		X	1	1	X	X	2	X	X	2
RESOURCE USAGES.	X	2		2	2	X	X	2	2	2	2	X	2		X	2
ACTIVITIES.	2	2		2	2					2	2		X	2	X	X
RESOURCES	X	2				X	X	2		2	2	X	2	X	X	2
PROJECTS.															X	
LOCATIONS.	2	2		2	2			2		2	2		2	2	X	X

2,1 = Successful under conditions '1' or '2' only.

X = Successful under both conditions.

SALTBARN DATABASE. COMPARISON BETWEEN SUCCESSFUL RETRIEVALS UNDER CONDITIONS 1 & 2 (BROAD DEFINITION OF SUCCESS).

Deriving a proportional scale of measurement, the level of coordination achieved through the two conditions has been found to be as follows.

Condition 1

$$\text{Factor of Coordination} = \frac{\text{Combinations found in documentation}}{\text{Total Combinations - Meaningless combinations}}$$

$$= 64/(256-64)$$

$$= 0.33$$

Condition 2

$$\text{Factor of Coordination} = \frac{\text{Successful combinations}}{\text{Total combination - Meaningless Combinations}}$$

(by narrow definition) = 140 /192 = 0.73

(by broad definition) = 150 /192 = 0.78

These calculations should be further amended to take account of those combinations of format and content which used the same entity e.g. operations classified by operations.

Such combinations are inherent in the quantification itself and do not represent a level of coordination. Removing such combinations from the calculations gives the following factors of coordination which more accurately reflect a proportional scale. The previous scale could be described as interval.

Condition 1 48/176 = 0.27

Condition 2

narrow definition	124/176	=	0.70
broad definition	134/176	=	0.76

The resultant factors of coordination give measurements of the level of coordination achieved under the two conditions on a proportional scale and can therefore be used to express relative coordination between conditions.

Therefore the improvement in coordination by the use of the database for saltbarn project data is by a factor of;

124/48 = 2.58 (for a narrow definition)

134/48 = 2.79 (for a broad definition)

The results of this analysis are that for a particular set of tendering data, the database was able to produce between two and three times as many retrievals of data as are available through manual documentation.

Closer examination of the matrices will illustrate that there are instances where a retrieval is:

1 - successful under both systems
2 - successful under the manual system only
3 - successful under the database only

Numbers of combinations corresponding to each of these three categories for a broad definition of success are as follows:

1	59
2	7
3	87

A contribution of this research lies in the combinations of format and content in an information retrieval which it has not previously been possible to produce from existing documentation without the need for re-measurement or the regrouping of measured work.

The above results indicate that for this third testing project set of data, a measured improvement in coordination has been achieved.

6.3.2.2 Comparison between conditions 1 and 1A

Re-examination of the results of the first two projects is possible on a similar basis to that above. In this case, testing is on the basis of example use of the two databases rather than full and destructive analysis.

For the stores project, the number of unique retrievals covered by sample interrogation is sixteen. Of these, four were produced in the form of both reports and interrogations, seven were produced in the form of reports only, and five were in the form of interrogations only.

In comparing this sample of retrievals with the manual documentation of the Saltbarn project, three of the sixteen retrievals are found to be inappropriate as they involve different data entities. This supports the conclusion that different projects will draw upon a different sub-set of the general model of data entities.

The remaining thirteen retrievals have been analysed and it has been found that ten were possible with both the stores database and with the saltbarn manual documentation. Three of the sample were found to be only possible by the stores database and one of these was a successful retrieval here that suffered failure type 1 when attempted through the Saltbarn database.

For the Hawthorn Road project, eleven unique retrievals were found in sample interrogations and reports. Four again were in the form of both reports and interrogations, five were solely in the form of reports and two solely in the form of interrogations. A single retrieval was found to contain a data entity that was not common to both projects.

Comparison of the remaining ten retrievals shows that six of these were possible under both conditions but that four retrieval types were only possible with the database.

In summarising this section, when analysing the capability of the database with the manual system under the two specified conditions the following results have been found for a small sample of interrogation specifications.

For stores:

Sample size 13 -	13	possible under condition 1A
	10	possible under condition 1

For Hawthorn Road:

Sample size 10 -	10	possible under condition 1A
	6	possible under condition 1

On the basis of these samples, factors of coordination improvement can be calculated as being 1.3 and 1.67 respectively. Factors of coordination are not calculable on the basis of example interrogation.

6.3.2.3. Relevancy Survey

The second aspect of primary testing is related to an evaluation of the value of the increased data coordination that has been achieved.

The principal aim of the work has been to establish whether data coordination is possible in terms of the flexibility of format and content with which data can be retrieved. It is anticipated that a major area of further work will lie in the assessment of the value of such flexibility. In providing an initiation to such further work and in providing a context for this study the value of coordination has been assessed here. This study consists of a survey of the perceived relevance of combinations of format and content of data retrievals.

The methodology has been to use the database to produce sample interrogations for every interrogation type which it has been found to be possible to produce from the database but which was not available in the manual documentation for the Saltbarn project.

Each of these interrogations can be seen as being additional data that it is possible to produce as a result of applying the data model to the data of the third testing project.

The sample retrievals have then each been subjectively assessed by the estimator responsible for preparing this particular tender. Assessment has been of the relevance of the particular retrieval on a five-point scale ranging from meaningless through to necessary data.

The values and their associated assessments of relevance are as follows;

4	Necessary
3	Very Relevant
2	Quite Relevant
1	Not Very Relevant
0	Meaningless

The interpretation that was assumed by both the estimator and myself was that 'Necessary' retrievals would be those where ad-hoc re-measurement or regrouping of measured work was required. 'Very' or 'Quite Relevant' retrievals were jointly considered as being desirable data for which the restraints of time did not allow re-measurement or regrouping.

The full assessment of all additional retrievals is reproduced in the following matrix.

A summary of these responses is shown here;

Relevancy	Number	%
4	16	15
3	32	30
2	35	33
1	17	16
0	7	6

	BULK OPS.	ELEMENTS.	PARTIES.	QUERIES.	ANSWERS.	OPERATIONS.	PRELIMS.	WORK PACKAGES.	SUB-CONTRACTORS.	SUB-CONTRACTS.	QUOTES.	RESOURCE USAGES.	ACTIVITIES.	RESOURCES.	PROJECTS.	LOCATIONS.
BULK OPERATIONS.		1		1	1			4	0	1	0		3	2		
ELEMENTS.	3			0	1	4		2	1	1	0		3	2		4
PARTIES.				3	4											
QUERIES.	1	1	3		4							3	3	2		3
ANSWERS.	2	0	3	4								1	3	2		2
OPERATIONS.		1							3	3			4	3		
PRELIMS.													4			
WORK PACKAGES.	4	2							2				1	2		3
SUB-CONTRACTORS.	1	1				3						2	4	2		2
SUB-CONTRACTS.	3	2				3						3	4	3		2
QUOTES.		2											3			2
RESOURCE USAGES.		2		3	3			2	2	3			4			2
ACTIVITIES.	2	4		3	3	3	0	0	1	1	4			3		
RESOURCES.	2	2		1	2			3	2	3	2		4			2
PROJECTS.																
LOCATIONS.	2	3	2	3	3			2	2	2	2		4	2		

SALTBARN DATABASE. — RELEVANCY SURVEY - Estimators perceptions of relev

Interpretation of these results shows that 78% of the extra data retrievals that have been possible with the database have been judged to be of relevance to the process of tender preparation by the individual that was responsible for preparing this tender.

Consideration was given to the potential for broadening the relevancy survey on the basis of a wider sample of estimators' opinions. It was concluded that this was not a valid input to the research on the basis that opinions expressed would not be given on the basis of familiarity with the project or its data. A further reservation was held with regard to the drawing of conclusions and the emphasis on evaluation being based on peoples' opinions of what exists.

A valid method of assessing the relevance of data retrievals would be through examination of their use within a fully implemented database of the type advocated. This is beyond the scope of the study but would be a recommendation for further work in the future.

With regard to the evidence gained through the use of this survey, a total of 15% of extra retrievals were judged as being necessary. As such, these required re-measurement or re-grouping of measured work. The remaining 63% of extra retrievals were perceived as being relevant but given the constraints of time, were not subject to re-quantification or re-grouping. These were therefore perceived by the estimator as being inadequacies in the project data with which he was working.

6.3.2.4. Summary

This aspect of testing has therefore shown that for the range of data entities within the Saltbarn project the potential combinations by which the format and content of data retrievals can be specified is measurably increased.

The complete range of combinations of format and content has been analysed in detail and each individual combination of format and content has been classified as being: meaningless, possible by manual methods and/or by the database, or potentially possible by the database only but unsuccessfully retrieved due to one of three failure types.

Factors of coordination have been quantified on this basis for the two defined conditions. On the basis of these measurements, a factor of coordination improvement has been established of between 2.6 and 2.8.

This is supported by the study of example operation of the first two databases. Here, factors of coordination improvement have been measured on the basis of a sample of retrieval types.

These extra retrievals that were found to be only possible by the database have been considered to be the contribution to data coordination that has been made by the work. These retrievals have been presented to the estimator responsible for preparing the tender of one of the testing projects for assessment of their relevance. A range of perceptions were obtained but it has been shown that a large majority of them were perceived to be of some relevance as a data source in the process of compiling a tender.

By analysing the sample interrogations and reports from the first two testing projects it has also been established that some of these were not a combination of format and content that is to be found in the manual documentation of the Saltbarn project. On this basis, factors of coordination improvement have been calculated which relate to the sample itself rather than the summary of analysis which has been used for the comparison between conditions 1 and 2.

6.4. SUPPORTING EVIDENCE

The previous section forms the primary testing of the research and the detail of its analysis has been orientated to reflect this. However, further criteria were identified previously as means by which the coordination of tendering data can be assessed. This section forms the measurement according to these further criteria and the results of the analysis of these measurements are presented as supporting evidence in the drawing of conclusions from the research.

No attempt has been made to combine separate measurements within the testing of the work and the remainder of this section contains details of the discrete measurements and analysis in relation to the criteria of; the currency of data and the resource cost of providing data coordination; and assessment of the range of tendering tasks and the data embraced by primary testing.

6.4.1. Currency of Data

In the context of this research, currency refers to the point at which data has most recently been updated.

The methodology has been to examine those combinations of format and content of a data retrieval where the possibility of a retrieval has been found in both manual documentation and through interrogation of the database. For such retrievals, currency of data has been measured on a relative scale by relating the points of data generation or updating back to the task model. The scale is a relative one due to the task model being an indication of the sequence of inter-dependent tasks rather than indicating time intervals or absolute differences in time.

The combinations of format and content that have been analysed for this purpose are only those where both systems allow data presentation and only where the combinations involve two different entities neither of which has 'projects' as the format.

This will exclude the two cases of simple retrievals whose repetition is unsuitable for this analysis. These two types of simple retrieval are as follows;

1 - where the same entity forms the content and format of a retrieval

2 - where 'projects' forms the format entity of a retrieval.

There are 33 retrievals that are not of a simple form where both systems allow retrieval of Saltbarn project data. The full analysis of the relative measure of currency for the two systems for these 33 retrievals is documented as a schedule within the appendix.

A summary of this analysis is given below.

Total number of retrievals analysed = 33
Number where currency is equal in both systems = 23
Number where database system is more current
than manual system = 10

These results were to some extent to be anticipated in that more recent data has been coordinated in the database where the manual system has updated data in an isolated form.

Further to this, it is suggested that the manual system itself acts as a disincentive to updating of data because of the coordination problems it presents. The use of the database would make updating and coordination easier and therefore more likely to be carried out.

The dynamic nature of tendering data is considered fundamental to its coordination and to the requirements of information users. This is supported by evidence gained from the contextual study of functional analysis.

The use of a dynamic database, in contrast to manual documentation which is produced at single points in time, would represent a vehicle whereby the most up-to-date occurrences of data would be coordinated.

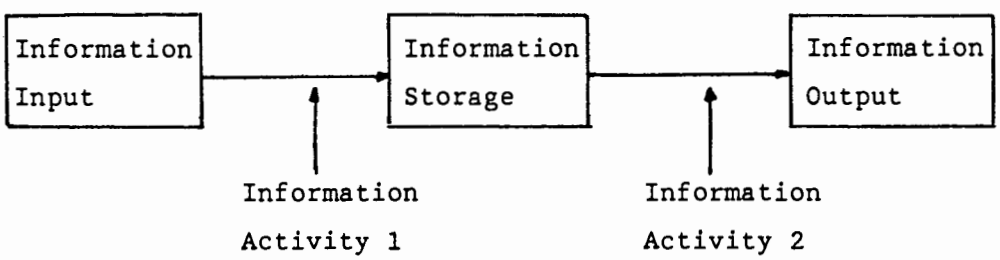
The analysis presented here is not intended as a rigourous examination of the currency of construction project data. It is intended as supportive testing of the principle of data coordination but also would suggest that much more remains to be done in this area in the future.

6.4.2. The Cost of Data Coordination

This research demonstrates a significant contribution to data coordination to which further studies of the benefits and value would follow. Similarly, in enabling a considered decision regarding the implementation or acceptance of the approach of this work, the value of coordination would need to be compared with its cost.

The term 'cost' is used here in its economic sense as being the resources that are used in production of an output and its measure being the output that would be possible with their allocation in an alternative use (124).

The cost of coordination is therefore being measured in terms of the resources used in the production of flexible information as is represented by the combinations of format and content previously described. The productive process of providing information can be described in the following way:



In the case of the use of the database produced in this work, input was from a single source at a single point in time which suggests that Information Activity 1 is a once and for all set of procedures. These have not been described or measured here but would represent the resources necessary in implementing project data into the database model.

Of greater relevance to the research is the resource needed in retrieving data as output from the database, Information Activity 2.

As the database is portrayed as an interrogative, flexible source of data, the extent of resource will vary for the form of output required. In this case, a separate information activity would be required for each combination of format and content that retrievals take.

Information activity has been measured for each combination of format and content found to be possible and to be of meaning for data of the Saltbarn project. Activity has been measured by enumeration of processes of relational algebra (125) that are necessitated.

Relational algebra includes the processes of using, sorting, indexing, selecting, updating, joining and reporting from files within a database.

All retrievals have been found to be of one of five types which require the following variable algebraic processes. All retrievals would also require a single reporting process and a single deletion process.

Activity Type	Indexes or Sorts	Files Used	Joins or Files Created	File Selections
1	1	1	0	1
2	2	2	1	3
3	3	3	2	5
4	4	4	3	7
5	5	5	4	9

Cost, or resource input, has been expressed in this way because algebraic processes represent requirements of processing within a system. The time taken by each process and therefore by each retrieval will ultimately be a function of the characteristics of various hardware and software configurations, together with the quantity of data contained.

Full details, in the form of a schedule, are available in the appendix regarding the algebraic processes required for individual retrievals. The following is a summary of the proportional breakdown of information activity types for the 192 meaningful retrievals performed.

Information Activity Type	% of total retrievals
1	16 (31)
2	5 (10)
3	21 (40)
4	43 (83)
5	15 (28)

6.4.3. Coverage of Tendering

A further criteria by which coordination is being measured is through analysis of the extent to which the database covers all data used and/or produced within the tendering phase of projects.

This has been done in two ways. Firstly, by analysing the data entities and attributes that are contained within each of the following documentation sets;

Documentation set 1 - the database model produced as a result of data analysis.

Documentation set 2 - the manual documentation of Saltbarn project data.

Documentation set 3 - the database for Saltbarn project data.

This analysis is shown in summary form here with a chart indicating whether entities of documentation set 1 are to be found in documentation sets 2 and 3 and if so whether all attributes of an entity are present. Full details of the entity and attribute sets are found in the appendix material.

Entity	DS2	All Attributes	DS3	All Attributes
Bulk Operations	t	f	t	t
Contractors	f	f	f	f
Contracts	f	f	f	f
Tenders	f	f	f	f
Elements	t	f	t	f
Parties	t	f	t	f
Bulk Resources	f	f	f	f
Queries	t	t	t	t
Answers	t	t	t	t
Increased Cost Categories	f	f	f	f
Operations	t	f	t	t
Preliminaries	t	f	t	f
Work Packages	t	t	t	t
Sub-Contractors	t	t	t	t
Sub-Contracts	t	t	t	t
Quotes	t	t	t	t
Quoting Organisation (Preliminaries)	f	f	f	f
Quoting Organisation (Plant)	f	f	f	f
Quoting Suppliers	f	f	f	f
Corporate Resources	f	f	f	f
Resource Usages	t	f	t	t
Activities	t	f	t	f
Resources	t	f	t	f
Projects	t	f	t	f
Locations	t	t	t	t
Cost Centres	f	f	f	f
Bulk Resource Usages	f	f	f	f
Resource Sets	f	f	f	f
28	16	7	16	10

t = indicates the presence of an entity or of attributes

f = indicates absence

The second approach to evaluating the coverage of tendering has been to use the database to produce a data retrieval for each task of the tendering model established through functional analysis. The specification of the form of such retrievals was taken from that to be found in structured systems analysis.

The full extent of these retrievals have not been reproduced because of the volume of material that has been generated. However, a schedule of the nature of retrievals together with randomly selected samples has been included in the appendix.

The following is a summary of the results of performing such retrievals.

Total number of tasks within tender model = 72

Number of tasks for which retrievals
were successfully performed = 36

of which: 6 were data used by tasks
27 were data produced by tasks
3 were data both used and produced by tasks

Number of tasks which were not performed
on the Saltbarn project = 27

Number of tasks for which data was not
made available by the contractor = 8

Number of tasks for which data used was
inappropriate to the data model = 1

Analysis of these results would show that;

- data was not made available for 18 % of the total number of tasks performed.
- the Saltbarn project involved the execution of 63 % of tasks of the tender model.
- for 3 % of those tasks performed, the database model was inappropriate for the data used on the project.

The specific instance of this last case of inappropriateness was for the task of forecasting the likely increases in cost during the duration of the project. The data model suggests that this would be based on categories of work and current and future indices whereas the project calculations were more broadly based with a single figure allowance.

In summary, both parts of this analysis show that the data used and the tasks performed for the Saltbarn project differ considerably from those which would be suggested by the data and task models.

This was anticipated in the execution of the work and indeed it is envisaged that the overwhelming majority of construction projects would use and produce data, and involve the execution of tasks, both of which would be unique sub-sets of those contained within the data and tender models.

This has been the experience gained by each of the implementations of the database and that found when alternative projects were being explored for the primary testing phase.

The potential for covering all tasks and all data entities by primary testing being based on a number of different projects was briefly contemplated. However, the depth of analysis and testing that is required in measuring coordination precluded this approach.

The use of a series of three projects is justified in being a representative sub-set of both the data used and tasks executed for construction projects each of which would make unique adjustments to the data and task models. This single sub-set is considered adequate for the evaluation of the principle of coordination.

Previous work by Walker (126) involved the application of systems theory to the design of construction project management structures. Walker's testing was similarly based on three sets of project data and his conclusions on this matter are of a similar nature.

> " .... such is the nature of the building industry that each project tends to be unique, with its own particular set of problems. Additional testing of the model on other projects will, therefore, provide further insight." (127)

Walker's work substantiates the results that have been found with regard to projects using a sub-set of the activities of generalised models.

> " Each project comprised a number of Sub-Systems of Activity within the Project Realisation System of Activity. Project No.1 had four, No.2 had six and No.3 also had six and although there were similarities in the sub-system of the projects, in no case were they identical." (128)

This conclusion is supported further by Date, Howe and others (129). In describing the fundamental philosophy of database applications and database design methodology, three levels of architecture are recognised.

A conceptual model (or schema) is described as a representation of the data potentially of interest to an enterprise. An external schema refers to a local view of the database required by an individual application. An internal schema describes how data is to be implemented.

In this case a conceptual schema has been defined and individual applications can be thought of as construction projects. It is not merely to be expected that the database view (external schema) required by a project would be a sub-set of the generalised model (

conceptual schema) but it is actually the rationale for the database being designed in this way. This conclusion is further supported by Longstaff (130).

6.4.3.1. Query Types

In attempting retrievals of data for individual tasks, different logical types of query have been defined. These are described here although no analysis has been performed of the number of each query type.

These discrete types of query have been differentiated on the basis of entities and attributes and are followed by an example from the database. The classification that is used follows that of Gane and Sarson (131).

Query Type	Description	Example
1.	For a particular entity occurrence, what is the value of a particular attribute occurrence ?	For the activity "site set-up", what is the duration of the activity ?
2.	For a given value of an attribute, which entity occurrences are specified ?	Which operations are subjected to detailed resource planning ?
3.	For a given entity type and a given attribute value, which entity occurrences match that value ?	Which activities are programmed to start in week 37 ?

4.	For a particular entity occurrence, what are the values of all of its attributes ?	List the details of the sub-structure element ?
5.	For all entity occurrences, give all values of a particular attribute.	List the prices of all resources.
6.	For all entity occurrences, give all the details for occurrences with a certain value.	List all details of operations costing 100 pounds.

Further complexity to queries is introduced through multiple values and the ordering of queries. Multiple values refer to more than one query type being combined e.g. list the prices of all resources that are items of plant that are being used in excavation work.

Queries may also be based on non-exact values e.g. list all details of operations costing more than 100 pounds.

This section shows a further level of complexity within retrievals on the basis of the type of query being performed.

6.4.4. Summary

This part of the testing of data coordination is presented as supporting evidence to the conclusions that are drawn from primary testing. This evidence is classified under three areas of the currency of data, the resource cost of the data coordination achieved and the extent to which primary testing has covered all data used and tasks executed in the tendering process. Each of these areas of evidence are now summarised independently.

Evidence of the currency of data within the respective systems has identified small differences between that which is contained within the database system and that within the manual system. However, it is suggested that the measured improvement that has been achieved is insignificant compared with that which would be achievable by the actual adoption of a database system in practice.

As was indicated in the introduction to this thesis, certain anomalies and inefficiencies of current methods of working have been 'designed in' to the research because of it's being based on systems examination rather than systems design. The level of updating of data would be considerably enhanced given the use of a database system but would necessitate significant re-appraisal of current methods.

In relation to the resource cost of the data coordination that has been achieved, this small section of evidence indicates the resource inputs that would be required for individual retrievals of data. These are far from being the complete resource implications of the use of the database but, accepting its implementation, would be accurate predictions of the marginal costs of retrieval by additional combinations of format and content for a given configuration of hardware and software.

With regard to the extent to which the projects of primary testing embrace the tasks and data of the generalised models of tendering, this aspect of testing has shown that the projects have formed a definable sub-set of the generalised models of tendering tasks, data elements and conceptual model relations.

An argument has been presented postulating that this would be the case for any project that had been selected and that the approach to data coordination should be one of extracting parts from generalised models to suit individual project characteristics.

6.5. EXTRAPOLATION OF RESULTS

The previous section has involved the collection of supportive evidence that enables the conclusions of primary testing to placed in context. The final section of this evidence concerned the extent to which the projects used in testing embraced the full tendering process with regard to tasks executed and data used. The conclusion that was reached was that all projects would involve the use of a sub-set of total data and also a sub-set of tasks executed. This conclusion was taken as a justification for the use of only three projects in the testing of the work and also for the detail to which analysis has been taken on a single project.

To be able to apply testing in detail to all tasks and data entities on the basis of project data would involve the use of an unpredictably high number of sets of testing data.

This section of the thesis represents an extrapolation of the results of primary testing to projects generally on the basis of the experience gained and on the basis that the survey work of this research has established tasks executed and data used on construction projects generally.

It is recognised that such extrapolation is not statistically valid and that general conclusions are limited on this basis. However, this section is intended to indicate what the likely level of coordination would be for projects generally if the results of testing were to be more widely applicable. The testing of this extrapolation clearly remains to be validated as further work arising from the research.

This approach to testing and extrapolation follows that which was used by Walker who stated that:

" The number of projects used limit the conclusions regarding the validity of the model but nevertheless provide a good indication of its validity and provide a basis for further development, testing and application." (134)

This recognises the limitations of such extrapolations but it is held to be valid to give an indication of the effect of the specific conclusions being applied more generally. This is again supported by the conclusions drawn by Walker.

" Although the model was tested against only three industrial/commercial projects for private clients, it is possible at this stage to put forward some implications for the management of building projects in general." (135)

For this research, extrapolation has been made with regard to the potential format and content of data retrievals. A similar analysis has been used as in primary testing. This is based on the use of matrices and the derivation of factors of coordination and a factor of coordination improvement.

The second area of extrapolation has been with regard to data retrievals where more than two entities are involved in the specification of format and content. These have been termed multi-dimensional retrievals.

6.5.1. Data Coordination

In this case, the conditions that are being compared are between existing manual systems and the database but applied to the full range of tendering data.

Condition 3 - existing manual systems applied generally to ideal project data. Measurements gained by literature survey together with examination of manual system documentation.

Condition 4 - database system applied generally to project data with supplements made to missing data. Measurements produced by extrapolation of results of primary testing.

A similar methodology has been used to evaluate the relative coordination between conditions 3 and 4 as was used within primary testing. The original matrix of 31 entities as potential formats and contents has been used and the combinations of condition 1 have been repeated. Further combinations of format and content have been examined in relation to two other sources of possible combinations that have been produced by the research;

Source 1 - those that are evident from structured systems analysis.
Source 2 - those that have been used in attempts to classify data by previous research e.g. sectionalised trade bills, operational bills, etc.

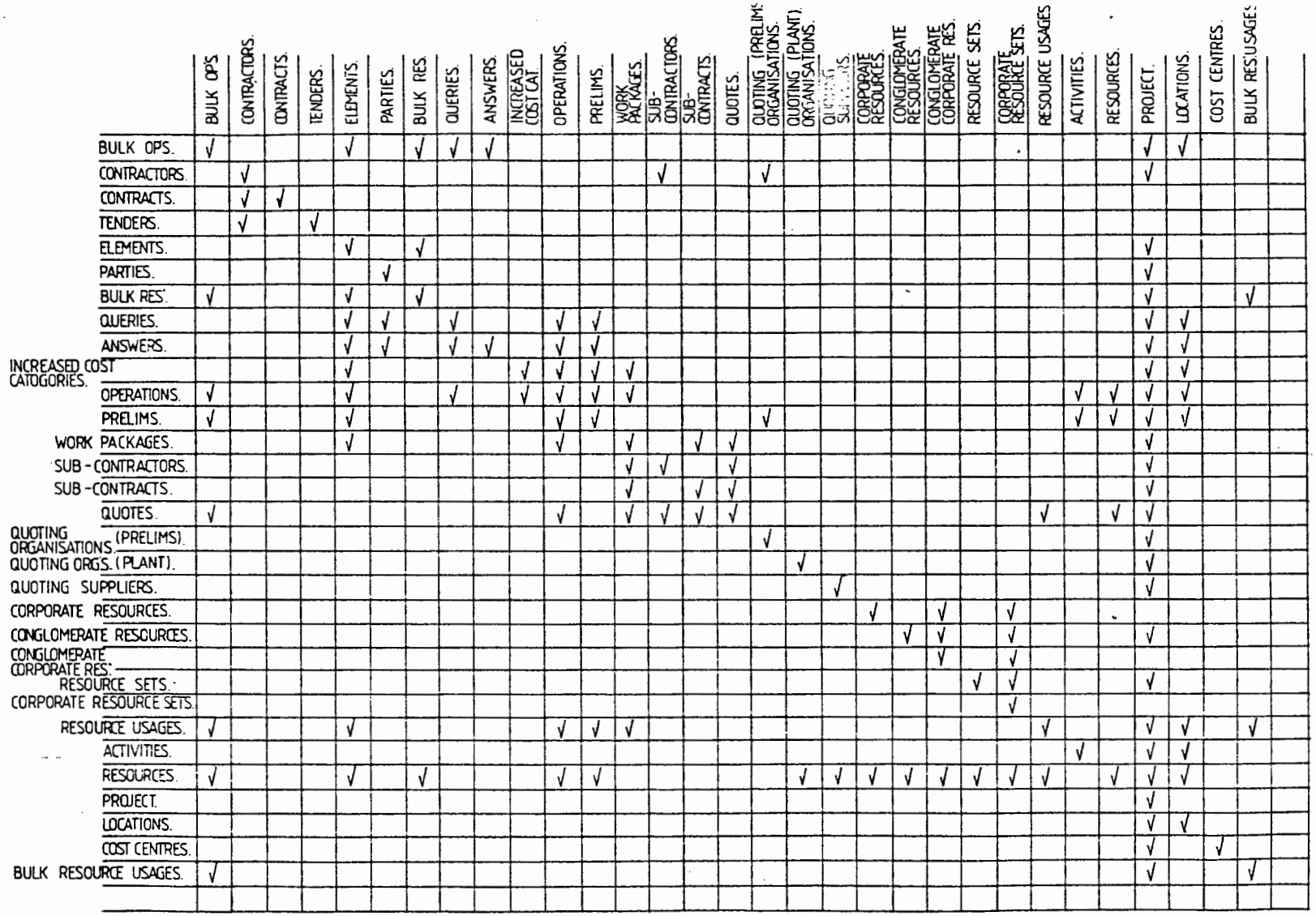
This gives the total possible combinations of format and content for condition 3 which are shown in a matrix. A similar matrix of meaningless combinations is also shown.

For condition 4, extrapolation of the experience of retrieval for the Saltbarn project data has been made assuming that the same failures will occur for failures type 2 and 3 but that failures of type 1 would be removed. The successful and failed combinations are shown in a matrix.

The corresponding factors of coordination and coordination improvement for comparison between conditions 3 and 4 are as follows;

Condition	Factor of Coordination
3	0.22
4	0.85

Factor of coordination improvement = 3.88



ALL ENTITIES. CONDITION 3 - Possible combinations.

	BULK OPS	CONTRACTORS.	CONTRACTS.	TENDERS.	ELEMENTS.	PARTIES.	BULK RES.	QUERIES.	ANSWERS.	INCREASED COST CAT.	OPERATIONS.	PRELIMS.	WORK PACKAGES.	SUB-CONTRACTORS.	SUB-CONTRACTS.	QUOTES.	QUOTING (PRELIMS) ORGANISATIONS.	QUOTING (PLANT) ORGANISATIONS.	QUOTING SUPPLIERS.	CORPORATE RESOURCES.	CONGLOMERATE RESOURCES.	CONGLOMERATE CORPORATE RES.	RESOURCE SETS.	CORPORATE RESOURCE SETS.	RESOURCE USAGES	ACTIVITIES.	RESOURCES.	PROJECT.	LOCATIONS.	COST CENTRES.	BULK RES USAGES
BULK OPS.		√	√	√		√					√	√													√						√
CONTRACTORS.	√				√	√	√	√	√	√	√	√							√	√	√	√	√	√	√	√	√		√	√	√
CONTRACTS.	√			√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
TENDERS.	√		√		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
ELEMENTS.		√	√	√		√						√																			
PARTIES.	√	√	√	√	√		√			√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√
BULK RES.		√	√	√		√														√	√	√	√	√	√		√				
QUERIES.		√	√	√						√						√	√	√	√	√		√		√							
ANSWERS.		√	√	√						√						√	√	√	√	√		√		√							
INCREASED COST CATOGORIES.		√	√	√		√														√		√		√	√						
OPERATIONS.		√	√	√		√						√				√									√						
PRELIMS.		√	√	√							√		√	√	√	√			√	√	√	√	√	√	√						
WORK PACKAGES.		√	√	√		√						√					√	√	√		√	√	√	√	√						
SUB-CONTRACTORS.			√	√		√						√			√			√	√		√	√	√	√							
SUB-CONTRACTS.			√	√		√						√		√							√	√	√	√							
QUOTES		√	√	√		√		√	√			√																			√
QUOTING ORGANISATIONS. (PRELIMS).			√	√		√		√	√				√					√	√		√	√	√	√	√						√
QUOTING ORGS. (PLANT).			√	√		√		√	√				√	√			√		√		√	√	√	√	√						√
QUOTING SUPPLIERS.			√	√		√		√	√				√	√			√	√			√	√	√	√	√						√
CORPORATE RESOURCES.		√	√	√		√		√	√	√	√	√	√	√	√	√		√	√							√		√	√	√	√
CONGLOMEPATE RESOURCES.		√	√	√		√												√	√												
CONGLOMERATE CORPORATE RES.		√	√	√		√		√	√	√	√	√	√	√	√	√		√	√						√	√		√	√	√	√
RESOURCE SETS.		√	√	√		√												√	√												
CORPORATE RESOURCE SETS.		√	√	√		√		√	√	√	√	√	√	√	√	√		√	√						√	√		√	√	√	√
RESOURCE USAGES.		√	√	√		√																					√				
ACTIVITIES.		√	√	√		√																			√						√
RESOURCES.		√	√	√		√																									
PROJECT.	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√
LOCATIONS.		√	√	√		√						√					√	√	√	√		√		√	√						√
COST CENTRES.		√	√	√		√														√		√		√	√						√
BULK RESOURCE USAGES.		√	√	√		√														√		√		√							

ALL ENTITIES. CONDITIONS 3 & 4 - Meaningless combinations.

	BULK OPS.	CONTRACTORS.	CONTRACTS.	TENDERS.	ELEMENTS.	PARTIES.	BULK RES.	QUERIES.	ANSWERS.	INCREASED COST CAT.	OPERATIONS.	PRELIMS.	WORK PACKAGES.	SUB-CONTRACTORS.	SUB-CONTRACTS.	QUOTES.	QUOTING (PRELIMS) ORGANISATIONS.	QUOTING (PLANT) ORGANISATIONS.	QUOTING SUPPLIERS.	CORPORATE RESOURCES.	CONGLOMERATE RESOURCES.	CONGLOMERATE CORPORATE RES.	RESOURCE SETS.	CORPORATE RESOURCE SETS.	RESOURCE USAGES	ACTIVITIES.	RESOURCES.	PROJECT.	LOCATIONS.	COST CENTRES.	BULK RES. USAGES
BULK OPS.	S				S		S	S	S	S			S	F	S	S	S	S	S	S	S	S	S	S		S	S	S	S	S	
CONTRACTORS.		S	S	S									S	S	S	S	S	S	S									S			
CONTRACTS.		S	S																												
TENDERS.		S		S																											
ELEMENTS.	S				S		S	S	S	S	F		S	S	S	S	S	S	S	S	S	S	S	S		S	S	S	S	S	S
PARTIES.						S		F	F																			S			
BULK RES.	S				S		S	S	S	S	S	S	S	S	S	S	S	S	S							S		S	S	S	S
QUERIES.	S				S	S	S	S	S		S	F	S	S	F						S		S		S	S		F	S	S	S
ANSWERS.	S				S	S	S	S	S		S	F	S	S	F						S		S		S	S		F	S	S	S
INCREASED COST CATOGORIES.	S				S		S	S	S	S	S	S	S	S	S	S	S	S	S		S	S	S			S	S	S	S	S	S
OPERATIONS.	S				S		S	S	S	S	S		S	F	F		F	F	F	S	S	S	S	S		S	S	S	S	S	S
PRELIMS.	F				F	F	F	F	F	F		S					S	S								F	S	S	F	F	S
WORK PACKAGES.	S				S		S	F	F	S	F		S	S	S	S				S						F	F	S	S	S	S
SUB-CONTRACTORS.	F	S			S		S	F	F	S	F		S	S		F	S			S					F	F	F	S	F	F	S
SUB-CONTRACTS.	S	S			S		S	F	F	S	F		S		S	F	S	S	S	S					S	S	F	S	S	S	S
QUOTES.	S				S		S			S	F		S	F	F	S	F	F	F	S	S	S	S	S	S	S	S	S	S	S	S
QUOTING ORGANISATIONS (PRELIMS).	F	S			S		S			S	F	S		S	S	F	S			S						F	S	S	F	S	
QUOTING ORGS. (PLANT).	F	S			S		S			S	F	S			S	F		S		S						F	S	S	F	S	
QUOTING SUPPLIERS.	F	S			S		S			S	F	S			S	F			S	S						F	S	S	F	S	
CORPORATE RESOURCES.	S				S		S										S			S	S	S	S	S	S		S				
CONGLOMERATE RESOURCES.	S				S		S	S	S	S	S	S	S	S	S	S	S			S	S										
CONGLOMERATE CORPORATE RES.	S				S		S										S			S	S	S	S	S			S				
RESOURCE SETS.	S				S		S	S	S	S	S	S	S	S	S	S	S			S	S	S	S	S	S	S	S	S	S	S	S
CORPORATE RESOURCE SETS	S				S		S										S			S	S	S	S	S			S				
RESOURCE USAGES.	S				S		S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
ACTIVITIES.	S				S		S	S	S	S	F	F	F	F	S	S	F	F	F	S	S	S	S	S		S	S	S	S	S	
RESOURCES.	S				S		S	F	F	S	S	S	S	F	S	S	F	S	S	S	S	S	S	S	S	S	S	S	S	S	S
PROJECT.		S																										S			
LOCATIONS.	S				S		S	S	S	S	F		S	F	S	S					S		S			S	S	S	S	S	
COST CENTRES.	S				S		S	S	S	S	S	S	S	S	S	S	S	S	S		S		S			S	S	S	S	S	
BULK RESOURCE USAGES.	S				S		S	S	S	S	S	S	S	S	S	S	S	S	S		S		S		S	S	S	S	S	S	S

ALL ENTITIES. - CONDITION 4 SUCCESSFUL AND FAILED INTERROGATION.

This is showing a higher level of coordination improvement for the situation where more data entities are available. It should be pointed out that this measurement represents the proportion of extra formats and contents of data retrieval that are possible with no measure having been given of the relative value of such retrievals.

This section has therefore shown that for the wider range of data entities within the generalised model, the potential combinations by which the format and content of data retrievals can be specified may be considerably increased.

The complete range of combinations for the above two entity sets has been analysed in detail and each individual combination of format and content has been classified as being: meaningless, possible by manual methods and by the database, only possible by the database or potentially possible by the database only but unsuccessfully retrieved due to one of three failure types.

Factors of coordination have been quantified on this basis for the two defined conditions. On the basis of these measurements, a factor of coordination improvement has been established.

6.5.2. Multi-Dimensional Information Retrieval

To this point, all data retrieval has been described as being flexible by the variety of pairs of entities which form the content and the format of an interrogation of the database.

Retrieval of this form has been necessary to provide testing and analysis of the level of flexibility that the coordination enables.

In effect, retrievals of this form are only the first stage of flexibility which the database affords. A retrieval may only have a single content, but the format by which it is structured may be based on more than one entity.

A simple example of this would be the sectionalised trade bill referred to in the analysis of previous work which has trades and elements as a hierarchy of entities which form the format of the document.

An example from the database would be to have operations as a content for a retrieval and for elements, work packages, cost centres, activities, and locations to be five entities contributing to the format. Each alternative hierarchy would represent an alternative data retrieval and from this example it can be shown that there are 5! (factorial) potential data retrievals that use all five entities as part of the hierarchy. Similarly there are 5!/1! retrievals that have four entities only as part of the hierarchy and 5!/2! retrievals that have three entities as part of the hierarchy. The numbers of retrievals that equate with these expressions are as follows:

Number of Entities	Number of Retrievals
5	120
4	120
3	60
2	20

	320

With only one entity forming the format of a retrieval this would not be a multi-dimensional type but is a simple retrieval as found in the two-dimensional matrices above.

The expression can be stated more generally that for a given entity as a content for a retrieval that can be formatted in a retrieval by n other entities in isolation, the number of potential multi-dimensional retrievals will be:

$$\frac{n!}{0!} + \frac{n!}{1!} + \frac{n!}{2!} + \ldots\ldots$$

This combinatorial expression can be more generally expressed as:

$$\sum_{i=2}^{n} \frac{n!}{(n-1)!}$$

where i is the minimum number of entities that must be included in the retrieval as formats. The expression given is therefore true for multi-dimensional retrievals but to include simple retrievals (those of a format of a single entity) the expression would be;

$$\sum_{i=1}^{n} \frac{n!}{(n-1)!}$$

This therefore represents the total number of different retrievals of information that are potentially possible from a database for a given content of retrieval with alternatives in format.

In attempting through calculus to derive an equation for this expression, a standard equation of the following form can be used as a starting point;

$$(x+y)^n = x^n + \binom{n}{1}x^{n-1}y + \binom{n}{2}x^{n-2}y^2 + \ldots\ldots\binom{n}{n}y^n$$

repeatedly differentiating with respect to y would then give;

$$n(x+y)^{n-1} = 1!\binom{n}{1}x^{n-1} + 2\binom{n}{2}x^{n-2}y + \ldots\ldots n\binom{n}{n}y^{n-1}$$

$$n(n-1)(x+y)^{n-2} = \ldots\ldots\ldots\ldots 2!\binom{n}{2}x^{n-2} + 3(3-1)\binom{n}{3}x^{n-3}y \ldots\ldots$$

$$n(n-1)(n-2)(x+y)^{n-3} = \ldots\ldots\ldots\ldots\ldots\ldots 3!\binom{n}{3}x^{n-3} \ldots\ldots$$

The expressions shown in bold are the parts of the series which give the number of retrievals. However, in adding together these equations or by removing the common element of y, the result is;

$$n(n-1)(n-2)(n-3).....(n-n) = n!$$

which is already known.

Therefore the combinatorial expression cannot be improved upon by calculus.

However using values of n within the expression gives;

2 - 2!
3 - 3! x 2
4 - 4! x 2.5
5 - 5! x 2.66

It can be shown that for large values of n, this tends to the general expression that the number of retrievals for a given value n of potential formats will be;

$$n!e$$

This is a sufficiently accurate approximation of the number of retrievals that are possible for high values of n.

Applying this series to all entities within the Saltbarn project data matrix would give the following results allowing for the removal of all failed retrievals of type 1,2 and 3.

Content	Value of n	Number of potential Multi-Dimensional retrievals
Bulk Operations	10	9,863,078
Elements	11	100,849,000
Parties	1	1
Queries	11	100,849,000
Answers	11	100,849,000
Operations	9	986,308
Preliminaries	2	4
Work Packages	7	13,699
Sub-Contractors	3	15
Sub-Contracts	7	13,699
Quotes	8	109,601
Resource Usages	13	16,926,795,000
Activities	9	986,308
Resources	12	1,302,061,300
Projects	0	0
Locations	10	9,863,078

The approximation has been used for values of n greater than 5.

A small sample of these potential multi-dimensional retrievals have been included in the appendix and other examples have been produced for earlier database implementations.

No attempt has been made to fully analyse multi-dimensional retrievals because of the number involved. However, it is considered that the likelihood of failure or of retrievals being meaningless would be significantly higher than for two-dimensional retrievals. In addition, the relevance of multi-dimensional retrievals has not been considered.

This illustrates the fundamentally different approach of this research in that previous and current work has largely aimed at establishing an ideal hierarchy of a single multi-dimensional retrieval whereas this

analysis has shown that there are potentially more than 18,000 million such hierarchies for the data which is being used during the tendering process of the Saltbarn project.

It is suggested that the displayed flexibility of the database approach represents a fundamental solution to the data coordination problem and that further work should be carried out to establish the success and flexibility with which multi-dimensional retrievals may be performed and the value that they have for users of data.

6.5.3. Summary

This section has therefore illustrated what the likely outcome would be if the results of primary testing were to be extrapolated to projects generally. It has shown that for greater complexity within a set of data the factor of coordination of improvement that is likely to be possible is increased.

The second part of this section then extends the scope of the work through analysis of multi-dimensional retrievals. This extension to the central methodology into the area of complex data retrievals fully illustrates the complexity of the problem. Much previous and current work is attempting to establish an ideal classification hierarchy when the limited data available for a simple shed project shows a potential number of such hierarchies in excess of 18,000 million. For a retrieval that may be formatted by a selection from 31 entities as contained within the generalised data model, the number of potential hierarchies would be 31!e.

The derivation of these numbers clearly illustrates the scale of the problem which had previously been addressed and that a fundamental change in approach was required.

The work here has also made the contribution of defining the expression that determines the number of alternative formats and contents of retrievals of data that are potentially possible from a database that contains a given number of entities. This is applicable to retrieval of data from databases generally regardless of their area of application.

This part of the work has in particular done more than was expected in exposing areas for future work rather than providing answers to previously defined problems. The area of multi-dimensional information retrieval is one that requires considerable examination for its relevance to the coordination of construction project data.

7. CONCLUSIONS

This chapter contains the statements relating to the contribution that has been made by the work and is classified into two sections. The first contains the primary conclusions that are drawn. The second section contains further concluding statements that have been drawn relating to the results and methodology of the research.

7.1. PRIMARY CONCLUSIONS

Conclusions are possible on the basis of the stated hypothesis and objectives but the study also allows more fundamental conclusions to be drawn regarding the efficiency of current tendering practice, the coordination of construction project data and the detailed methodology by which tenders are prepared.

7.1.1. The Efficiency of Current Practice

The work has clearly identified the scope for considerable improvement in the effectiveness with which tenders may be prepared. The use of a coordinated database would increase the flexibility of data available to those responsible for the preparation of tenders. A coordinated database would remove inadequacies identified within current systems which are typically performed under restrictions of time.

The identified areas of inadequacy of project data are firstly the need for re-measurement and secondly, the need for re-grouping of existing quantification. The retrieval system proposed by the research has been shown to remove such inadequacies when applied to the data of the projects used in testing. For these areas of inadequacy of data provision identified by the work, it has been shown that in some cases adjustment in the form of re-measurement or re-grouping is not performed. This extends knowledge of the problem which had been previously described by Ferry and Holes (132).

The study has been focussed upon the problems of data transfer during the tendering stage. However, the work has also shown the relevance of the database to other stages including the design, procurement and construction of buildings. The main benefits to be obtained in applying the philosophy of the work, lie in the increased flexibility with which project data can be used and the coordination that is possible between separate tasks and forms of documentation. It is concluded that data requirements for the aesthetic, financial, technical, legal and constructional functions of projects would be best provided from one single coordinated database.

The complexity of the database that would be required in coordinating all aspects of construction project data makes it imperative that a fundamental re-appraisal is made of current methods and procedures and of traditional professional roles and demarcations. A specific conclusion that refers to these requirements is that in future there will be a need for a new professional role to be provided in the form of a database administrator to manage data transfer. The activity of the database administration role would include the application of the methodology in a similar way to that used in this research.

The work has placed into context the subject of information retrieval within the design and construction process and represents an innovative framework for the future development of information systems to serve construction.

The application of information technology in the construction industry has historically been of an imitative nature. Applications have typically aimed to use the technology by repeating the processes in a similar form to that by which the activity is performed manually. It is concluded that this has led to the full potential of such technology not being achieved. New technologies require a re-examination of processes and this research has shown that in the case of data coordination and transfer, the use of theories and techniques of information science is appropriate. The pattern of future development should therefore be based on a complete re-examination of the appropriateness of conventional processes to the technology available to serve them.

7.1.2. The Coordination of Construction Project Data

The implementation of the data model for three sets of project data has enabled measured improvements in the level of coordination that is possible. This leads to the inescapable conclusion that the use of such a model, and its implementation in the form of a database, allows an increased level of coordination of tendering data.

It has concluded from the study that single format documentation will inevitably be inappropriate as a vehicle for the transfer and retrieval of project data for tendering. Examples of conventional single format documents would include Bills of Quantities, Buying Schedules, Method Statements, Plant Schedules and Tender Programmes. The work has identified the need for all individual documents to be inter-related within a single store and for retrieval from the store to be possible on a flexible basis. The database produced by the research enables all tendering data to be inter-related and for a fundamental improvement in the flexibility with which data can be retrieved.

The requirements in the classification of construction project data are such that a framework of conventions is required. The database produced represents such a framework and it has been demonstrated to be efficient in its ability to coordinate data. The database has been shown to be of considerable benefit as a means of data retrieval and has been shown to be effective, appropriate and practical. It also utilises the most recent advances in computing technology notably fourth generation software. For the future, the retrieval system will be enhanced with the current developments in technology particularly in the field of Artificial Intelligence and more specifically Expert Systems as a means of the database interacting with the users of data. The application of the database would also be enhanced through advances in the capacity and cost of mass data storage and other developments in the form of networking and data communications. The database also provides the foundation upon which individual computing applications in tendering may be based.

The work leads to the conclusion that the greatest benefit from data is to be obtained through allowing flexibility in its use rather than imposing limiting standardisation. This clearly shows that the search for fundamental or natural groupings of work as a means of data classification is misguided. Such classifications have been produced by Ormerod and others (133). Fundamental or natural groupings of construction work are a subjective concept and different uses of data will have different perceptions of what is important. This research is based upon providing a framework whereby unique classifications may be derived for individual uses of data and coordinated with other classifications to maximise the flexibility of data retrieval and minimise the restrictions of standardisation.

A conclusion of the work is that flexibility in a retrieval is defined by the data that forms its content, the format by which it is structured and the level of detail in which it is expressed. As such, full documentation of tendering processes is inappropriate to retrieval. The need has been identified for data retrieval to be of an interrogative form. An interrogation is defined as a user defining the format, content and level of detail required and only that data relevant to the interrogation being retrieved.

In relation to the origin of interrogations, the study has clearly shown that it is the task that is executed which defines data interrogation requirements. This supports the findings of Skinner (136) and others (137). A premise upon which most previous work has been based is that data requirements in this field are defined by and vary with the job title of the person making the request. Recognition of the fact that tasks are the means by which requirements are defined is important in enabling the retrieval system to be appropriate to tenders prepared under different organisational structures and procurement methods.

The research makes obvious the fact that for the extensive use that is made of data in the tendering phase of construction projects, the goal of a single classification system is neither practical nor desirable. Considerable research effort and current development (138) continues on the premise that a single all-embracing classification system is both desirable and attainable for the structuring of construction project data. This is another attempt at standardisation where every alternative classification proposed by others has been shown by this work to be inappropriate. It is further concluded that all attempts at producing an all-embracing classification will not lead to an appropriate solution. The work has demonstrated the scale of potential hierarchical classifications that are possible and that individual tasks require variations within this range. The need for flexibility is thereby demonstrated.

The implementation of the database in testing has shown that it is possible to construct a coordinated data model which embraces all the data of the tendering process. This adresses a particular objective of the study. As the construction of the data model is based on relationships between items of data rather than any reference to tasks being executed, it is further concluded that a data model can be constructed to embrace data used and produced by other stages of project design and construction.

The operation of a database of this type requires knowledge of the interrogation rules required in obtaining a specified retrieval. Interrogation rules and query types have been defined by the research and from this it is concluded that a practical implementation of the database would be possible with the user being unaware of the specific nature of the database structure or of the procedural implications of its use. A black-box principle can be achieved with a user specifying the form of interrogation required and the system being able to specify the interrogation rules and query types independently.

7.1.3. Tasks executed and data used and produced in tendering

This study has produced a generalised model of tendering tasks together with an understanding of the revisions that are necessary to apply the model to a particular firm, size of project and method of procurement. In relation to this point, it is concluded that the detailed procedure by which tenders are prepared, differs between contracting firms and procurement methods used. These differences have been established through the survey work of the research.

It is further concluded from functional analysis that detailed methods of tendering operated by smaller building contractors tend to be a simplification of those operated by larger firms. Similar tasks are executed to a less detailed level whilst other tasks are not performed at all. There was no evidence of smaller firms performing tasks of an entirely different nature to those executed by large contractors.

The uniqueness of individual projects is often quoted as a characteristic and a problem within construction. From this fact and the evidence of this research, it is concluded that standardisation in the presentation of project data will be inherently inappropriate to the requirements of an individual project. It is suggested that in place of standardisation, a means is required for coordinating data used an produced by individual projects.

The theory of database design recognises three perceptions of a data model: the conceptual model which embraces all data potentially of use by all applications; the external schema which is the part of a conceptual model required by an individual application; and an internal schema which is the translation into a physical store of an external schema (139).

Construction practice is predominantly occupied with internal schemas. This study has produced a conceptual model both of tasks executed as part of the tendering process and a second of the data used in the process. By definition, a conceptual schema can only be validated by observation of all of its constituent external schemas. This is beyond the scope of this work but for the tasks of the tendering process, the conceptual model is validated by observation of eleven external schemas. These external schemas are represented by the methods of tendering adopted by eleven national building contractors.

The conceptual model of data has been validated by implementation of three internal and external schemas in the form of three sets of construction project data. Whilst recognising that such validation does not allow definitive statements regarding the industry as a whole, it is possible to conclude that conceptual models have been defined and tested within these limitations.

The work has produced models of the way in which tenders are currently being prepared and of the data used and produced in the process. Existing models are available in a normative form but these fail to recognise differences in practice between organisations and for different projects in terms of procurement methods, project size and complexity and time available. It is concluded that existing models do not attempt to provide such flexibility and are therefore attempts at standardisation. The models produced by this research go beyond the recommendation of what practice should be but are generalised descriptions of current practice which are able to be extracted from to suit the particular environment and requirements of individual projects.

As a result of the work in structured systems analysis it has been possible to produce an exhaustive definition of the entities and attributes of data that are used and produced by the tendering process. Such data elements can be linked to individual tendering tasks. The definition is in the form of a generalised schedule of data which can be modified for alternative project conditions. In addition attributes of a data entity which are unique identifiers of an entity occurrence can be defined for all data used in tendering and all the attributes of tendering data entities can be defined. This represents the only detailed specification of data entities and attributes used in the tendering process.

It has been shown that construction project tenders will draw upon subsets of the same generalised models of tasks to be executed and data elements to be used in the construction of a database pertaining to an individual project. It follows from this that the principle of a computerised database is appropriate to a range of projects in terms of size, functional use and procurement method. Each project would draw from the generalised models of tasks and data and therefore the database model is able to be amended in line with the requirements of a particular project. This is in line with the general principles and overall concept of a database which is able to serve a number of alternative applications and in doing so is able to present alternative local views of the database structure.

This summarises the primary conclusions that are drawn from this work. The following section contains further concluding statements relating to the results and methodology of the study.

7.2. FURTHER CONCLUDING STATEMENTS

The following are the further direct conclusions that have been drawn from the preceding programme of work. They have been presented here in the chronological order in which they were derived in the study. No sense of priority is therefore implied.

The implications of the results found for the three testing projects being generally applicable have been commented upon. This has shown that the use of a computerised database would lead to a considerable increase in the factor of coordination of data for projects generally. It has also been shown that this coordination would represent a considerable improvement in the flexibility of data available during the tendering process. It is further concluded that such flexibility would improve the efficiency and the effectiveness of tendering and would enable an enhanced level of utility to be gained from the data available.

Data that is specific to a particular project differs from non project-specific data in terms of its points of initial generation and updating. It is concluded that for this reason, means for its provision and presentation should be accordingly differentiated. Current trends in non project-specific data illustrate the considerable advances that are being made as is shown by Shoolbred (140). It is not suggested that the differentiation between the two types of data should be permanent. Indeed the database produced by the research would be capable of coordinating non project-specific data of relevance to a project. The importance of the difference between the two forms is recognised and is necessary in the focussing of a study of this nature.

A conclusion that is drawn from functional analysis and further justification for the nature of the methodology relates to the ability of a sample of practitioners to define and provide solutions to the problem of data coordination. Current estimators, buyers and tender planners are unable to identify the inadequacies in current information

systems, to criticise such ystems, to specify fundamental improvements in data retrieval, or able to comment upon the value to be gained from such improvements. For this reason the methodology as it is defined was necessary as a means of progressing the research. It is concluded from this that any re-appraisal of methods and roles in construction should not be left entirely in the hands of current practitioners but should recognise the contribution to be made by those able to take an objective and un-biased view of the problems.

The work done as a prelude to data modelling in the examination of alternative database types has shown that a relational database provides a means by which a coordinated store of tendering data can be retrieved from with full flexibility in the format and content of a retrieval. The hierarchical and network forms place restrictions upon such flexibility which implicitly assume some form of primary classification. This makes these forms of database fundamentally inappropriate to data retrieval for tendering.

The work of data modelling itself has shown that a combination of the techniques of entity-relationship modelling and relational normalisation are appropriate in the modelling of tendering data entities and attributes. These two techniques of data modelling are typically portrayed as alternatives. The complexities of the data used in the tendering process are such that either of the two techniques in isolation would be inappropriate. It has been shown in the study that both can be successfully combined in constructing a hybrid methodology that is suitable for such a complex data modelling problem.

In attempting to evaluate the conceptual model, cohesion analysis has been found to be inappropriate to the evaluation of a conceptual data model where no significant systems design activity has taken place. No satisfactory method has been identified whereby a conceptual data model produced on the basis of systems examination can be validated for its appropriateness to the system that has been examined. This is an important weakness in the database design theory that has been used.

A conclusion is also possible in relation to the implementation of the conceptual model. The current state of technology with regard to hardware and software has been shown to be adequate for the implementation in principle of a coordinated database for tendering data.

With regard to the method of evaluation used in the study, it has been shown that the coordination of data can be measured by the flexibility with which data can be retrieved from a store. This flexibility has been shown to be dependent upon the format and content of a data retrieval. It is therefore concluded that these two aspects of flexibility represent the level of coordination inherent in a single store of data.

The results of testing applied to the data for three construction projects has shown that certain combinations of format and content for the retrieval of data will always be meaningless whilst others will be meaningless depending upon the specifics of the data being used. Meaning is defined as the data entities that are combined as the format and content of a retrieval, having no direct relationship with each other but with a common third entity. This condition may apply to retrievals generally or only for the characteristics of a particular set of data.

The significance of meaningless retrievals is that total coordination of project data in a single store is neither achievable nor desirable. No database application would be able to provide full flexibility in data retrieval without certain retrievals being meaningless in terms of the arbitrary relationships between unconnected items of data.

In addition, the failure of a database to produce a retrieval of a given format and content can be classified as failure due to;

- the specifics of the data making the retrieval meaningless.
- no data existing which meets the parameters of the specified retrieval.
- inadequacies and errors in the data model leading to inaccurate or inappropriate data being retrieved.

Where a specified data retrieval results in no data meeting the parameters of the interrogation, this may be classified as either a failure of retrieval or as a meaningful result depending upon the specific nature of the interrogation. It has also been found that such failures are likely to be removed when alternative sets of data are used. The existence of these failures indicates that the stage to which data modelling has been taken in this study is insufficient for a full application of the database in practice. This particularly refers to the process of relational normalisation. Modelling has only been taken to third normal to illustrate the principle of coordination. Higher normal forms would be necessary before implementation of the database was possible without the identified failures of the prototype model.

Further analysis of the potential use of the database has shown that retrievals can be classified as multi-dimensional in nature if more than one entity is used within a hierarchy of formats by which the retrieval is structured. The number of potential multi-dimensional retrievals of data for a single construction project has been calculated as being in excess of 18,000 million. This represents a quantification of the complexity of the database system. From this it can be concluded that the use of the database in practice would require a fundamental re-examination of the concept of flexibility in data retrieval and transfer. It is also possible to conclude from this quantification of complexity that any further attempt to derive an ideal single hierarchy for project data classification would represent a failure to appreciate the potential for flexibility and the benefit to be derived from it. The need for unique interrogations of a database as required by individual tasks enables the flexibility of data retrieval to be exploited.

The number of potential multi-dimensional retrievals of data for any given database can be established by use of a combinatorial expression that has been directly derived through the research. Approximations are possible when a large number is involved through the use of a refinement to this expression. This would allow the complete flexibility of any individual database implementation to be calculated at an early stage. It would also enable the classification of multi-dimensional retrievals that were possible for any implementation of the data base for an individual project.

A further outcome of the testing of the work has shown that the use of a computerised database provides the potential for an enhanced level of updating of project data over that which is practically possible with manual documentation. The work has identified the fact that maintenance of an up-to-date store of project data is of importance to the execution of tendering tasks. The work has also demonstrated a means by which such an up-to-date store can be provided and maintained.

Other analysis within testing has shown that the resource requirements of retrieving data from a database can be stated generally as the stages of relational algebra that are necessary as part of an interrogation. The specific nature of these stages of relational algebra form the interrogation rules for tendering and it is possible to relate these to individual tendering tasks. It is therefore possible to quantify the marginal cost of database retrievals in the form of processing power required. Processing power is a function firstly of these stages of relational algebra and secondly of the hardware and software configuration together with the quantities of data. These second determinants of processing power will therefore be determined by the form of an individual practical implementation.

8. RECOMMENDATIONS FOR FURTHER WORK

The following is an outline of parts of the study which remain to be examined in detail together with other areas of further work where the testing of the hypothesis has indicated the need for a further contribution. A recommendation is also made for the work required in enabling the database proposed by this research to be implemented into the current practice of building contractors' tendering.

8.1. FURTHER RESEARCH

The research has been tightly focussed upon the tendering stage of projects and the procedures of the building contractor. This was necessary for examination in sufficient detail and because of the position that tendering has in the generation and manipulation of data for construction projects. The problem at which the work has been addressed and the methodology of its application would be equally valid to other aspects of the building contractors function.

Extension of the methodology to embrace project monitoring and control would enhance the conclusion which it has been possible to draw here. Similarly, application of the methodology to the building contractors corporate planning procedures and in particular the data requirements of multi-project estimating, monitoring and control would add an extra dimension to the coordination of data achieved here.

In placing the research within its context in the introduction to this thesis, the problems of professional restraints were identified. This necessitated the application of the work within the domain of a single professional role.

These restraints would apply to any further studies of this nature in a similar way. The use of functional analysis has been found to be appropriate for the development of generalised models of tasks in tendering and this approach should be applied to a further study aimed at producing a generalised model of tasks of design quantification and documentation. This is not a recommendation for a standardisation in procedures but a standardisation in the manner in which such procedures are described.

The application of the same data analysis and modelling techniques would then allow the possibility of coordination of data for these disparate stages of a projects life cycle. There is potential here for a significant contribution to be made to the problems of the separation of the design and construction functions. The development of a central unifying database, to which all functions contribute their data output and from which all functions retrieve their data input, would provide an impetus by which closer cooperation between separate functions and professional roles may be achieved.

This theme can then be continued to relate the contribution of architectural and engineering design to the same central database and a major area of further work is likely to be the linking of a quantitative database to those of three-dimensional solid modelling computer aided design systems.

The research has been specifically orientated towards project data whilst recognising that other aspects of information and data of a more general nature require different interpretation and analysis. A significant further study would be the examination of these other aspects of information used and produced by construction projects and any relationship that may be established between an information system covering their provision and that system which has been defined here.

The above recommendations regarding multi-project data and data from

other functions would partly cover this work. Research into the development of product information systems is a further area of interest within this recommendation that has not been referred to.

The conclusion that has been drawn regarding the comparative methods of tendering carried out by large and small organisations is one that requires to be supported by further examination and observation.

A major limitation that has been exposed by the research relating to methods of database design concerns the evaluation of a conceptual model. Cohesion analysis was the only technique that could be found but its limitations for a study of this kind have already been highlighted. Further work is therefore required in the evaluation of conceptual data models. The evaluation of this research is not restricted by this problem as full testing has been based on the implementation of the conceptual model with three sets of construction project data.

This work has resulted in the first attempt to provide a measure of the coordination of a source of data. This has been based on the flexibility of data output which was acceptable for the purposes of testing here. However, the concept of coordination has consequences beyond data output and a further study aimed at defining and measuring data coordination more generally would be of merit to further developments in information systems.

Because of the depth to which the work has been taken, the subject of multi-dimensional retrievals, their nature, number, relevancy and means of production have only been touched upon. This is potentially a major area of development in information retrieval for construction and would form the natural development of the work to a higher level of complexity. A study aimed at taking the conceptual model as it stands and exploring the area of multi-dimensional retrievals is therefore seen as imperative to the continuing development of the theme of this work.

The generalised model of tendering that has been produced has been

shown to be representative of the firms involved in the study. It is in the form of tasks from which a sub-set would be drawn for particular projects. Further studies are possible in defining exact modifications that are necessary to the model for alternative projects. This would be possible by using a series of case studies of tendering procedures for different projects and establishing whether any relationship exists between factors such as procurement method, project size, etc and the set of tasks that are carried out.

The most significant area of further work that is required in advance of any implementation of the database principle is an extension of the limited work that has been presented here in the relevancy of data retrievals. The primary aim of the research has been to ascertain the extent to which flexibility in data coordination can be achieved. The benefit to be derived from this coordination is a large subject in itself and proved to be beyond the scope of the study. Much further work is required in the area of the quality, necessity, value and fitness for purpose of information. This would be a large research project that would considerably enhance the application of the work in a practical context.

The suggested method for such a validation study is to fully implement the database design within a commercial tendering environment. Examination of relevance would then be possible on the basis of observation of retrievals used. This is held to be preferable to the approach of seeking opinions of the relevance of retrievals.

8.2. IMPLEMENTATION PLAN

This thesis is presented as an academic investigation into the subject of data coordination in tendering for construction projects. The contribution that has been made by the work is described within the conclusions of the study.

However, the work has addressed a recognised practical problem of construction management and, as is to be expected in research in an applied science, is able to make a contribution to the efficiency of the processes at which it is aimed.

This section is a recognition of this fact and forms specific proposals to enable the work to be translated into practice.

Significant contributions have been made to the study by a number of building contractors and although post-research work is continuing between the author and some of these organisations, the results of this work are open to be exploited by all to whom benefit may accrue.

In the first instance, it is suggested that implementation of the database should be orientated towards a retrieval system for single project tenders.

This may be achieved by making extractions from the conceptual models to suit the particular characteristics of individual organisations, procurement methods and projects.

The first stage in development would therefore be to examine the model of tasks of tendering such that an accurate depiction of specific methods is obtained. This resultant model would then need re-examination of data flows such that an accurate specification can be gained of the data entities and attributes of relevance to a particular situation.

Further work in data modelling would be required to take account of the new specification obtained above. It would also be necessary to extend the application of modelling techniques. Specifically, development of the data model to Fifth Normal Form would be required.

The data model could then be implemented with the use of a relational database management system and appropriate hardware. For the purposes of the research, micro-computing equipment has been utilised. For any development that would foreseeably extend beyond the pilot study stage, the requirements of data storage and processing power would require the use of more powerful facilities. A mini-computer installation is suggested.

Considerable programming activity would be required within the database management system in the design of input screens, report format and retrieval routines. This would enable the disguise of the complexities of the database structure from users of the system and would allow increased confidence and flexibility in its use.

There is a considerable staffing requirement here in the form of systems and data analysts and software engineers. The number of staff required would be dependent upon the scale of the implementation and the period of the pilot study.

There would also be a requirement for a permanent database administration function to maintain the database, ensure security and database integrity.

Beyond the pilot study stage, the database could be implemented for multi-project estimating and for post-contract financial and production management. This would require a more significant development project along similar lines.

The methodology used in the research, together with its results, provides the fundamental framework and the established basis from which such development is possible. The benefit of implementation has been demonstrated by this study.

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