PLANNING SYSTEMS FOR SMALL FIRMS

by

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A thesis submitted to the Council for National Academic Awards in partial fulfilment of the requirements for the degree of Master of Philosophy.

SPONSORING ESTABLISHMENT: SHEFFIELD CITY POLYTECHNIC
SCHOOL OF CONSTRUCTION

COLLABORATING ESTABLISHMENT: G. BANKS LTD.

DATE OF SUBMISSION: JUNE 1989

ABSTRACT

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A study was carried out into the planning practices of four small building firms through interviews and questionnaires. The techniques of systems analysis were used to model the information flows through the firms. These revealed the firms to suffer from problems of integration between planning and other functions. The breakdown of the work for one function often did not suit the purposes of others. Project data often had to be regenerated. The firms did not evaluate their performance systematically in a way that would be of benefit to future contracts.

A specification for a new system was developed to eliminate these deficiencies and to take advantage of the power of the microcomputer. The system derived data from the estimate. A work breakdown structure allowed the integration of planning, targeting, progress reporting, reporting of hours, and valuations. The database of estimate operations was maintained through an analysis of timesheets. Information for the scheduling of materials and subcontractors could be derived from the resulting programme.

The small firms problem of integrating the demands imposed by a fluctuating workload on a relatively inflexible labour supply was considered. The use of decision rules to resolve conflicts through the levelling of a multiproject schedule was investigated. A large number of rules were developed using a spreadsheet operating in conjunction with a planning package. These were tested on a number of prototype workloads and assessed by various criteria. After further development a consistently good rule was found.

This rule, and that encoded within the planning software, were applied to the levelling of the workload of one of the collaborating firms at various stages of progress over a three month period. The new rule continued to perform well. The feasibility of deriving planning data direct from the estimate, and of using timesheet data both to update programmes and to evaluate performance was demonstrated.

The firms methods of materials procurement and handling were investigated. It was found that their collection of materials from suppliers was poorly organised.

ACKNOWLEDGEMENTS

I am very much indebted to Mr. Ray Oxley and Mr. Ken Elliott for a degree of support and encouragement which went far beyond that required by their roles as research supervisors.

I must also extend my appreciation to the representatives of the collaborating firms, Mr. Andrew Cammish Mr. Ron Biggins, Mr. Joe Poskitt, Mr. Malcolm Woods, and the late Mr. Ray Lord, for their time and inside knowledge.

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GLOSSARY OF TERMS

activity attribute - a variable upon which a rule can differentiate between activities.

combined duration - (SEE total duration).

contract completion date - date at end of contract period.

contract duration - scheduled duration.

contract float - difference between contract period and contract duration

contract overrun - scheduled overrun of contract completion date.

contract period - duration of contract specified in contract documents.

free float - period of delay sustainable by an activity before a succeeding activity is also delayed.

field - criterion of assessment of outcome of levelling procedure.

levelling - elimination of all instances of overscheduling of a resource beyond a predefined level of availability.

levelling module - a distinct phase in the determination of an activity's priority.

priority - the rating which determines an activity's precedence over other activities in the competition for scarce resources.

'superproject expert' a proprietary planning package.

'supercalc4' - a proprietary spreadsheet package.

total/combined duration - the sum of the contract durations of all the projects in a multi-project schedule.

total float - delay sustainable by an activity before the critical path is extended.

1 INTRODUCTION

1.1 THE BUILDING PROCESS

As an industrial process, building is unique.

Most production systems involve the convergence of resources at a central location, where the bulk of fabrication then takes place. This makes possible the development of fixed facilities and a working environment conducive to the efficient and predictable manufacture of a product capable of being delivered to its final point of use.

This is not so for the building industry, whose product range is markedly less portable. For each contract a new, temporary workplace must be set up, frequently within the fabric of the product itself, to which must be brought the necessary men, materials and equipment. Almost every order is different, and typically is for a single unit or small batch. This limits the application of mass production techniques, which depend on a long production run for a return on a large capital outlay. Thus, except on the larger, more repetitive contracts, the builder cannot appreciably benefit from the efficiencies of the production line. Nonetheless, the client's expectation is increasingly that of the procurement of resources of the right type and quantity, each at the earliest possible opportunity. The expectation is also of a period of tendering and planning far shorter than that allowed for the design process.

The traditional isolation of the design and production responsibilities, another characteristic of the industry, neither promotes the consideration of production issues at the design stage, nor affords the production team the opportunity to make an early appraisal of its task before work is under way. The builder cannot raise or lower production by decree, but is subject to his current contractual obligations, and the fortunes of an unpredictable tendering system.

In these conditions, production planning is an exacting business, and therefore one of critical importance to management.

1.2 THE 'SMALL' BUILDING FIRM

The low capitilization of the industry, the contracting out of work in small packages, and the mobility of the workplace encourage the birth and survival of small building firms serving limited geographical areas. Consequently, in 1987, 97% of building firms were small by Bolton's definition (less than 25 employees), employed 49% of the workforce, and were responsible for 41% of the industry's output (BOLTON,J:71,DOE:88). Over the past fifteen years the shift in demand from new work to refurbishment and repair and maintenance, and the decline in the value of individual contracts put out to tender, has seen these proportions steadily increasing. Only in the past two years has this trend shown any signs of changing.

The expansion of the labour-only component of the industry's workforce in recent years has rendered the classification of building firms solely by their number of employees increasingly meaningless. The systems and procedures of an organisation need to be determined by the nature of the goods and services provided by that organisation. Hence this study relates to any building firm whose workload is typically composed of:

(a) alterations and extensions;

(b) repairs and maintenance;

(c) new work other than large speculative housing developments;

under contracts that are:

(d) of low individual value in relation to total turnover;

(e) typically less than six months duration;

(f) inclusive of both labour and materials;

(g) frequently documented by a set of drawings and a specification (GARDINER,C.:82);

and which are to be executed by a workforce relatively inflexible in size (NORRIS,K.:84,HILLEBRANDT,P.M.:71).

This classification includes the larger contractor forced by economic circumstances to enter the small contract market, but excludes the self-employed individual and the labour-only subcontractor (LABOUR RESEARCH:86). These latter two groups are quite distinct from the traditional small builder in terms of both organisation and function.

1.3 A SMALL BUILDER'S PLANNING INFORMATION SYSTEM

A plan is a communicable store of information about decisions that have been taken and predictions that have been made. As a flow of information the plan has origins and destinations and must therefore be considered a part of an overall planning information system. To varying degrees such a system interfaces with similar systems serving other management functions such as estimating and buying, etc. The advent of the microcomputer holds out the promise of improving both the quality of planning data and the integration of management functions. The requirements of a computer based planning system are dictated by the nature of the work to be planned together with the structure of the organisation that has evolved to undertake such work. It is in this context that the needs of the small firm are investigated in chapters 4,5 and 6.

1.4 THE MULTIPROJECT SCHEDULE

Planning may be described as the pursuit of certain externally prescribed objectives - quantity, quality, duration - under the constraints of cost and available manpower. This is attempted by the manipulation of a number of variables such as construction method, work sequence, and the assignment of labour. Above all else what distinguishes the planning problem of the small firm is the relative inflexibility of its workforce set against the rapidly changing demands placed on it by a workload composed of numerous short contracts. Therefore the assignment of labour amongst its contracts is a matter of crucial importance to the small firm. The development and application of multiproject scheduling as an aid to resolving conflicting demands for a shared labour resource, is explored in chapters 7 to 10.

2 METHODOLOGY

The majority of the data collection and analysis related to the development of the planning system. This in turn created the context for the investigation into decision rules.

2.1 BACKGROUND READING

A review of relevant literature was carried out with the aims of;

(i) overcoming any bias that might otherwise have entered into the research from restricting the field study to only four firms;

(ii) taking advantage of the findings of previous research, whilst ensuring that old ground was not re-covered;

(iii) familiarising the researcher with the range of planning practices employed in both this and other sectors of industry;

(iv) acquainting the researcher with research methods and the basics of computing.

In addition to a search of printed bibliographies and listings of current publications, access was gained to a number of computer-stored national and internatiomnal databases. These were interrogated on the basis of certain keywords, providing listings of titles of which the most promising were selected for ordering. These titles included books, articles, theses, and conference proceedings. The major periodicals continued to be scanned for further articles of interest throughout the period of the research.

2.2 CASE STUDIES OF SMALL FIRMS

The objective of the case studies was to acquire a thorough understanding of the working practices of small firms upon which to base the development of a planning system. To this end the co-operation of four small building firms was secured at the outset of the research. The information required from them fell into three categories;

INFORMATION	METHOD OF COLLECTION
1. Precise, factual details of the organisation	SELF-ADMINISTERED QUESTIONNAIRES + TABLES
2. Operational procedures	DOCUMENTATION + INTERVIEWS
3. Management attitudes to operational procedures	INTERVIEWS

The methods of data collection were dictated by the need to minimise the inconvenience to management. Their involvement in the research was entirely voluntary, and the outcome of the research could only be of limited immediate benefit to them. Thus, information of type 1 which was factual and needed looking-up, was best sought through self-administered questionnaires and tables that could be completed at a time convenient to the respondent (PARKIN,A.:80). The data to be gathered of types 2 and 3, was less well defined. In soliciting this information, the direction that each enquiry was likely to take would be determined to some extent by the answers given to preceding questions. Furthermore each answer could be lengthy and therefore time consuming for the respondent to record in his own handwriting. Interviews, recorded on cassette and transcribed later, were the appropriate means of gathering such information.

2.2.1 Self-administered Questionnaires And Tables [Figs. 1,2 & 3]

As there would be no opportunity for discussion at the time these were filled out, it was imperative that the questionnaires be simple and unambiguous (GORDEN,R.L.:75). Wherever possible a 'closed question' format was used. This restricted the possible answer to a tick-in-a-box, thus minimising the effort of the respondent, whilst simplifying the analysis of the results (SUDMAN,S. & BRADBURN,N.M.:82).

Care was exercised in making the questions as friendly as possible, by phrasing them in plain language, by spacing them well apart on the paper, and by avoiding ego-threatening lines of enquiry (GORDEN,R.L.:75, SUDMAN,S. & BRADBURN,N.M.:82). The table format used to elicit data concerning the composition of each firm's workload, was somewhat uninviting but unavoidable given the nature of the data being sought.

2.2.2 Interviews [Fig. 4]

Although both category 2 and category 3 type information

DETAILS OF ORGANISATION

1. Is your firm a:

- SOLE PROPRIETORSHIP ☐
- PARTNERSHIP .... ☐
- UNLIMLITED COMPANY . ☐
- LIMITED COMPANY .... ☐

2. What approximately was the turnover for the last financial year?

3. Currently how many 'productive' operatives do you employ directly on site?

TRADE	NO. OF MEN

4. At this moment how many men are employed by you as labour-only subcontractors?

TRADE	NO. OF MEN

5. How many 'non-productive' personnel (ie, staff, management) does the firm employ?

- FULL TIME ☐
- PART TIME ☐

6. How far from the head office would you normally be prepared to go to carry out work? Would your limit be within the range:-

< 5 miles ☐ 5-10 miles ☐ 10-15 miles ☐ 15-25 miles ☐ 25-35 miles ☐ >35 miles ☐

7. What are the minimum and maximum values of a contract for which you have ever tendered?

MIN ☐ MAX ☐

8. Does the firm keep a yard for the purposes of:

- STORING PLANT AND EQUIPMENT ☐
- STORING STOCKS OF MATERIALS ☐
- RUNNING A JOINER'S WORKSHOP ☐

9. Briefly describe the firm's history since it was formed, giving details of any notable events, chaanges in ownership, opening of new offices, changes in company strategy, changes in working practices, etc..

Figure 1. 'DETAILS OF ORGANISATION' - SELF-ADMINISTERED QUESTIONNAIRE

COMPUTER USAGE

1. Do you own a computer?

How many?

IF 'NONE' GO TO QUESTION 6.

2. What type and make of computer is it, and what associated items of equipment do you have, such as printers, plotters, digitisers, etc..

3. For what purposes is it now being used? Please list the software that you now run on your machine.

4. Has the computer and its software lived up to expectations? If not, in what way have they performed poorly?

PROBE: Breakdowns And Errors?
Slowness Of Entering Data?
Incompatibility with Firms Other Operations?
Limited Capacity Of Software Or Hardware?
Failure To Cope With Exceptional Circumstances?
Poor Presentation Of Results?
Lack Of Machine Compatible Software?

5. Have you any plans to extend the use of computers in any way?

PROBE: New Computer?
New Software?
New Peripherals?

NOW GO TO QUESTION 8.

6. What has discouraged you from installing a computer?

PROBE: Cost?
Computer Would Not Improve The Business?
Uncertainty About The Subject Of Computers?
Not Found The System To Match The Firm's Needs?
Insufficient Time To Investigate?

7. Have you any plans to purchase a computer in the future?

8. How would you rate the degree of benefit to a small building firm of the following possible results of computerisation? Would you expect the benefit to be 'NONE', 'SLIGHT', 'MODERATE', 'SUBSTANTIAL', or 'VERY GREAT'.

	NONE	SLIGHT	MODE- RATE	SUBST- ANTIAL	VERY GREAT
SAVINGS IN MANAGERIAL OR CLERICAL TIME					
REDUCTION OF HUMAN ERROR ...					
BETTER PRESENTATION OF INFORMATION					
INCREASED SPEED OF PRO- CESSING AND PRESENTING INFFORMATION					
INCREASED VOLUME OF INFO- AVAILABLE TO MANAGEMENT					
GREATER PRECISION OF INFORMATION					

9. How would you order these applications in terms of the degree of benefit to a small building firm that would accrue from them? [Put '1' against the application you feel would be most beneficial, '2' against the next most beneficial, etc..]

	RANK
STOCK CONTROL	
ESTIMATING	
GENERAL ACCOUNTS	
PREPARATION OF VALUATIONS	
WORD PROCESSING	
COSTING	
PLANNING	
PAYROLL CALCULATION	

Figure 2. 'COMPUTER USAGE' - SELF-ADMINISTERED QUESTIONNAIRE

FEEDBACK

FIRM - - - - - - - - - - -

This part of the questionnaire is intended to investigate the records of past activities that are generated by the site. Please give the details of those reports, etc., that are returned from your sites, both from the list below and any that may have been missed off the list which should be added at the bottom.

	FOR WHICH JOBS IS THIS REPORT PRODUCED? [eg 'spec. housing + all other contracts > 20,000 in value']	FREQUENCY [eg 'at end of every week', OR 'at end of each contract', etc.]	CONTENT [eg 'hours and description of work carried out by each operative']	PREPARED BY [eg 'contract manager']	USE(S) OF REPORT [eg 'payroll calculation + job costing']
SITE DIARY					
PROGRESS REPORT					
INVOICES					
TIME SHEETS					
LABOUR RETURN					
PLANT RETURN					
TARGET MEASURE (Gang)					
TARGET MEASURE (individual)					
SUBCONTRACTOR MEASURES					
MEASURE OF WORK COMPLETED					

Figure 3. 'FEEDBACK'

MANAGEMENT FUNCTIONS

1 ESTIMATING

1.1 As an approximate proportion of total turnover in the past 12 months, what share of the workload was priced on each of the following types of information?

DRAWINGS (alone)
DRAWINGS + SPEC (no quantities)
DRAWINGS + SPEC (with quantities), OR A BILL
VERBAL DESCRIPTION
....
....

1.2 What other information can be at your disposal at the time of pricing a job?

1.3 Considering first those contracts for which priceable quantities are included in the tender documents, and then those without quantities, can you describe how you would build up an estimate in each case?

1.4 Roughly what proportion of your turnover in the past 12 months might be described as " Design and Build"?

1.5 Who converts the estimate to a tender and how does he deal with the costs of haulage, prelims, overheads and profit?

2 OBTAINING QUOTES

Subcontractors;

2.1 How often do you subcontract each of the following work packages? (- ALWAYS, NEARLY ALWAYS, USUALLY, SOMETIMES, RARELY, NEVER)

BRICKWORK
EARTHWORKS
PLUMBING (copper)
PLUMBING (leadwork)
ROOFING
PAINTING
ELECTRICAL
JOINERY

1

2.2 How do you go about selecting subcontractors?

Materials and Plant;

2.3 What sort of records do you keep on materials suppliers and plant hirers to which you might refer whilst compiling an estimate?

All Quotes and Prices;

2.4 Do you check all prices and delivery periods taken from price files with the suppliers before including them in the tender, and are the same details checked again (whether taken from the file or received as a quote) for both suppliers and subcontractors before placing an order with them, in the event that the contract is won?

3 PLAN + ORGANISE THE WORK

3.1 What are the first actions to be taken once a contract has been awarded to the firm?

3.2 Is a method statement ever produced for any contracts?

3.3 For each of the following work categories how common is it for a master programme to be produced, who produces it, and in each case on what does the decision to programme (or not) depend?

REPAIR + MAINTENANCE (inc. jobbing)
ALTERATIONS + EXTENSIONS (inc. refurbishment)
NEW WORK

3.4 Have you ever tried any programming techniques other than the barchart?

2

3.5 How often are each of the following sources of information consulted when drawing up a programme?

BILL, OR SPEC. WITH QUANTITIES
TAKE-OFF DOCUMENT
FIIES OF PAST OUTPUTS
PUBLISHED OUTPUTS (e.g. price books)
DRAWINGS
PREVIOUS PROGRAMMES
INCENTIVE TARGETS
METHOD STATEMENT
THE EXPERIENCE OF OTHERS
THE PLANNER'S OWN EXPERIENCE

3.6 Who does the programming?

3.7 Do you programme by the hour, day, half-day, week or half-week?

3.8 Is the critical path always identified?

3.9 What does a "bar" represent?

3.10 Who receives copies of the master programme?

3.11 Do you do any short term programming?

3.12 Is either the master or the short term programme updated on the basis of progress achieved, and if so, is this done on a regular basis or only when there is a significant deviation from the plan?

4 SCHEDULING OF LABOUR

4.1 How and at what point do you predict the number of men you will assign to a particular task at a particular date for a particular period of time?

4.2 How do you know which of the firm's employees will be available to a new contract at a particular time in the firm's future, and when it appears that the demand for labour will exceed it's availability, how do you react?

3

Figure 4(a). 'MANAGEMENT FUNCTIONS' - INTERVIEW GUIDE

4.3 How common is it for temporary gaps to appear in the workload of particular gangs or individual tradesmen employed by the company (say between jobs) and how are the men kept occupied when this occurs?

4.4 How often is casual labour taken on, why, and typically for how long?

4.5 How does the supervision of the workforce vary from site to site?

5 MATERIALS SCHEDULING

5.1 Are all materials taken off the drawings again once the contract has been awarded, or is the original take-off used to prepare the orders?

5.2 Is any sort of material schedule prepared ever prepared?

5.3 How do the men on site know whether a particular material is to be delivered to site by the supplier or is to be picked up by themselves?

5.4 Do you find that the slowing or halting of progress on site due to the lack of the correct materials is a significant problem on your sites?

6 OTHER RESOURCES

6.1 Do you ever formally schedule:-

PLANT

SUBCONTRACTORS

DRAWINGS

7 INCENTIVES

7.1 What form(s) of incentive scheme do you operate and who calculates the targets?

4

7.2 Roughly how much of the work is covered by a bonus scheme?

7.3 Are the work descriptions of the bonus targets related to the estimate in any way, and from what source(s) are the targets calculated?

8 VALUATIONS

8.1 Which contracts are paid for by interim valuations and how are these measured and calculated when there is no Bill of Quantities?

9 FEEDBACK

9.1 To what extent are actual and estimated costs compared for your contracts?

9.2 Are outputs for site operations ever calculated?

9.3 To what use is information about outputs put?

9.4 What would discourage you from practising a more detailed system of monitoring performance on site?

10 GENERALLY

10.1 Can you give me a rough indication of the ranges of times taken for each of the following stages?

	RANGE
From the receipt of the enquiry to latest date for tender submission:	
Awaiting notification of success or failure:	
Lead-in time from notification to start on site:	

5

Figure 4(b). 'MANAGEMENT FUNCTIONS' INTERVIEW GUIDE (cont.)

related to the firm's operational procedures, and both were best extracted in the context of an interview, the more precise method of enquiry demanded by systems analysis clashed with the more discursive interrogation appropriate to the reporting of attitudes and opinions. However to have contrived to maintain two separate but parallel lines of questioning throughout the one interview would have resulted in a disjointed, repetitive session, too much of which would have been taken up by the presentation of questions rather than the reporting of the answers. The maximisation of reply time not only represented an optimal use of limited interview time, but also allowed the interviewee to be more expansive, increasing the interest for him and allowing unexpected but important facts and viewpoints to emerge (GORDEN,R.L.:75).

Thus a schedule of introductory, open-ended questions was assembled, peppered by a number of more precisely formulated enquiries intended to ensure that nothing of vital importance was missed. To offset the risk of digression from the intended subject, short prompt lists were inserted after each question to which the interviewee's attention could be drawn if it was felt necessary.

Shortly before the date agreed for the interview, the questionnaires, tables, and interview guide were sent to a senior manager in the firm, with a cover note explaining how each was to be tackled. This offered the respondent a chance to prepare for the interview, and to collate any possible queries about the rest of the survey for airing at the time of the interview.

Once the interview had been transcribed, the preliminary stages of systems analysis were performed, during which discrepancies and omissions in the data inevitably appeared. Such points were cleared with the respondent in a second, shorter, follow up interview, recorded and transcribed in the same manner as the first.

2.2.3 Documentation

Samples of the documents that supported the flow of data through the organisation, and whose existence became apparent after the first interview, were listed and requested at the second interview. An appreciation of the contents of these documents was an integral part of the systems analysis.

2.3 ANALYSIS OF DATA

It was correctly anticipated that the planning function in a small firm would be so enmeshed with other organisational functions that any attempt to examine it in isolation would prove meaningless. This expectation was reflected both in the scope of enquiry at the data collection stage, and in the extent of the analysis deemed necessary to place planning properly in its context.

It was also felt that no single method of presentation could satisfy the requirememnt for both a vivid communicable description of a firm's procedures, and an exact specification from which the detail of a new system could be derived. Hence the system was examined and presented in two different ways.

2.3.1 Structured Systems Analysis

Structured systems analysis is a technique for plotting the movement and transformation of information within an organisation. This it does in terms of data flows, operations on data (processes), and stores of data (files). Its application provided an exhaustive description of each firm's operations, and therefore the source for a detailed specification of a new, improved system.

A top down functional decomposition of each firm's operations was carried out, resulting in a hierarchy of data flow diagrams (DFD's), and an accompanying set of process descriptions. Once all the analyses were completed, the logical model of a new system was developed and refined, according to the principles of systems analysis, to incorporate all the recommendations arrived at during analysis.

2.3.2 Narrative Description

A written description of how the management of each firm executed their organisations' functions offered a more intelligible view of the problem than did the results of systems analysis. Based on both, a statement of the requirements of any proposed system was drawn up as a framework for the development of the new system.

2.4 SOFTWARE REVIEW

A review of commercially available planning packages was carried out with the twin objectives of assessing the likely performance of each as the central core of a planning 'system', and to choose one suitable for testing resource allocation strategies.

From reviews in trade journals, a shortlist of those seemingly able to meet the most basic criteria of performance and price was drawn up. On the basis of publicity material and sample disks subsequently received from the suppliers, and on the evidence of demonstrations at exhibitions and seminars, a package was chosen with which to implement and appraise decision rules.

2.5 THE TESTING OF DECISION RULES

These were encoded as 'macros' - short, simple programs, using a general purpose package in conjunction with the planning package purchased. Initially the rules were tested against artificial data generated using the computer. Assessments were made on the basis of a number of different criteria. Once all but the most successful rules had been eliminated, a simulation was conducted using project data supplied by one of the firms. The procedures used to implement and test the rules is described fully in chapter 7.

2.6 MATERIALS TRANSPORTATION AND HANDLING

A self-administered table covering basic aspects of materials procurement for a range of typical materials was completed by each of the firms' respondents [Fig. 5]. Follow up interviews permitted the discussion of the planning and control of materials delivery, and of the firms' materials handling problems [Fig. 6].

MATERIALS

This part of the questionnaire relates to the procurement of materials. With the exception of one possible response to question 7 *, please indicate your answer by placing a 'tick' in the appropriate location.

FIRM ....

MATERIAL	1. As main contractor would you normally be responsible for procuring this material? (If 'NO', then move onto next material without answering further questions)			2. When would you purchase this material from a builder's merchant? (as against direct from the manufacturer)			3. When a materials schedule is prepared would this material usually be included in it?			4. Would this material normally be collected from the supplier as against being delivered?			5. Would this material normally be ordered in advance, or shortly before it's need on site?		6. Would this material normally be stocked in the firms yard? (as opposed to going delivered direct to site)	
	YES	NO	SOMETIMES	NEVER	ONLY FOR SMALL QUANTITIES * eg. a shortfall	VIRTUALLY ALWAYS	YES	NO	SOMETIMES	YES	NO	ONLY WHEN IMMEDIATELY REQUIRED	IN ADVANCE	SHORTLY BEFORE	YES	NO
CONCRETE BLOCKS																
1½" SCREWS																
9mm PLASTERBOARD																
CARLITE BROWNING																
PRECAST LINTOLS																
BUILDING SAND																
150mm CLAY DRAINAGE PIPES																
CEMENT																
KITCHEN UNITS																
FLUSH DOORS																
HIGH LEVEL FLUSH SUITE																
DPC																
FIBRE GLASS INSULATION																
ROOF TRUSSES																
225mm SW JOISTS																
JOIST HANGERS																
½" COPPER PIPE																
ROOF TILES																

*Please state approximate maximum quantity.

Figure 5. 'MATERIALS' - SELF-ADMINISTERED TABLE

MATERIALS HANDLING AND TRANSPORTATION

INTERVIEW GUIDE

(1) What items of handling plant and vehicles does the firm own?

(2) At what point are the major (+ final) decisions taken as to how materials will be transported to their point of use, and which items of plant will be required?

(3) How are any decisions or assumptions (regarding handling methods) that were made at the time of tender, communicated to yourself once the contract is "live"?

(4) Can you describe the thought sequence you might go through when selecting plant and handling methods for a particular site, and indicate the order in which the aspects of the handling problem are taken into consideration?

PROBE: Which materials are specifically considered and in what order? Why these?
Do you look at unloading, horizontal ground movement, or the lifting of materials first?
Do you ever plan materials movement on a drawing?

(5) Do you ever make specific enquiries to a supplier about the packaging of materials?

(6) Are you as the main contractor usually responsible for the movement of all subcontractors' materials around the site?

(7) Do you ever find it necessary to improve the ground conditions, or bring forward any permanent groundworks so as to ease access, storage and handling problems?

PROBE: For which plant and materials must this be done?

(8) Are any of your handling methods or equipment ever chosen to take advantage of the divisibility of unit loads into sub-units (eg., 70-brick "blades")?

1

(9) Why are some materials picked up and delivered by your own transport, whereas others are delivered by a merchant or manufacturer?

(10) How common is it for suppliers vehicles to be self-unloading, and are you always made aware of this in advance?

(11) To your knowledge, do any merchants or manufacturers ever offer financial incentives or penalties dependant on any of the following:

(a) size of an order?

(b) packaging (eg., unitisation) of the loads?

(c) timing of deliveries?

(d) combining of small orders to make full lorry load?

(e) provision of self-unloading facilities?

(f) turnaround time on site?

(12) In order to maximise the efficient use of company vehicles, do any of the following occur:

(a) the accumulation of an individual sites materials requirements in order to make fuller use of vehicle capacity when materials are to be picked up from a particular source?

(b) the coordination of deliveries to all sites in order to achieve fuller use of vehicle capacity?

(13) Why are some materials stocked in the yard against being delivered direct to the site?

PROBE: Lack of site storage space?
Better security?
Advantages of bulk buying?
Insurance against future materials scarcities?
Faster site delivery time?

2

Figure 6(a). 'MATERIALS HANDLING AND TRANSPORTATION' INTERVIEW GUIDE

(14) Which materials are left to be delivered on the date specified in the order, and which are normally to be called off by site as they are needed? (- how long is the lead-in time between call-off and delivery?)

(15) For what reasons would you decide to split the procurement of a particular material into two or more separate deliveries?

PROBE: Lack of storage space?
Order greater than firm's lorry capacity?
Risk of damage/loss from excessive storage periods?
Other reasons?

(16) When materials are to be picked up from the yard or merchant rather than delivered, who is it who actually collects them, and on whose authority? (Is it the tradesmen who need the materials, site labourers whose duties include the collection of materials, or is there a lorry/van driver responsible?)

(17) On approximately what proportion of your sites are some materials temporarily stored at a location distant from their final point of use, rather than being transported direct from the delivery vehicle to within reach of the fixing point?

PROBE: Which sites and materials? Why these?

(18) What to you are the advantages and disadvantages of unit loads?

PTO

3

(19) What particular aspects of a job would lead you to consider each of the following methods for handling one, some, or all of the materials from the moment of their arrival on site to their placement?

METHODS:-

MANHANDLING (Horiz.)

MAN + BARROW

POWERED BARROW

DUMPER

CONVEYOR

FORKLIFT/TELESCOPIC HANDLER

EXCAVATOR

MAN + LADDER

GIN WHEEL

HOIST/ELEVATOR

AERIAL PLATFORMS

JIB CRANE

ASPECTS OF JOB:-

Material types and packaging?
Unit loads?
Total quantities?
Lifting heights (No. of storeys)?
Horizontal distances?
Offloading time?
Lack of storage space?
Speed of operation?
Economy of labour?
Size of job?
Ground conditions?
Ease of conversion to other unanticipated tasks?
Min. practical period of use of eqpt. on site?
Demands/Expectations of subcontractors?
Interface with preceding + subsequent handling methods?

4

Figure 6(b). 'MATERIALS HANDLING AND TRANSPORTATION' INTERVIEW GUIDE (cont.)

3 BACKGROUND TO THE DEVELOPMENT OF A NEW SYSTEM

3.1 REVIEW OF EXISTING PLANNING PRACTICES

3.1.1 Programming Techniques

Although a number of planning techniques have been well-publicised for a number of years, their adoption by small construction firms has been limited. One study revealed that although 85% of owner-managers of small firms claimed that they planned work one month ahead, and 55% were reported to be using 'formal planning techniques', only 13% used barcharts to programme the work (NORRIS,K.:84). A survey covering the whole industry revealed an overwhelming preference (85% of respondents) for using bar charts to programme less complex jobs, rather than network-originated bar charts (9%), networks alone (4%), and line of balance (2%) (ESHETE,S.+LANGFORD,D:87). This brings into question just what 'formal' planning techniques other than bar charts were being used by the respondents to Norris's survey. According to one survey of small firms, planning, when it does occur is usually carried out at the estimating stage and does not involve the universal application of any one technique to all contracts (BARTON,P:86).

Generally, the three major functions of estimating, planning and control are rarely systematically integrated. This is because each has evolved independently, and efforts to standardise have met with little success (WESTGATE,S.E.:86).

3.1.2 Control

Without formal planning, formal control of ongoing contracts is difficult to exercise (BARTON,P.:86), and is often forfeited in favour of a historical review of performance. The method of performance assessment predominant amongst smaller firms is the reconciliation of actual with estimated costs for the contract as a whole. In Norris's survey just over half the firms questioned claimed to make a cost/value comparison for each contract, every month, and the same proportion reported that an analysis of past costs was subsequently used for estimating (NORRIS,K.:84).

Of a sample of those who do not operate any feedback system, two thirds reported that they would like to but did not know how, the remaining third complaining that such a system would either be too costly or too time consuming to set up and administrate (BRAID,S.:84). It appears that an evaluation of company productivity is most often superseded by an evaluation of company profitability as a measure of the efficiency of its operations.

3.1.3 Planning Software

At the beginning of 1987, one in ten of all builders were quoted as being in possession of a computer (BUILDING:9/1/87). The proportion of firms operating a planning package can be expected to be far less than this. Most computers are originally purchased for the purposes of payroll calculation, accounting, business administration, and on occasion, estimating (ELITE,P.:87). However improvements in the capabilities of microcomputers have led to improvements in the performance and ease of use of the software, while costs have remained the same or have fallen. Thus planning packages which were previously viewed as the exclusive province of the larger company with the resources to install and operate them, appear in their latest versions increasingly practical to the small builder.

Most such packages do not appear to have been developed specifically for the construction market, and none are intended primarily for the small building firm. Typically they are based on either arrow or precedence networks, can handle a maximum number of activities in the range 200 - 2500, and are able to generate reports in the form of networks, bar charts, histograms and cash flow predictions, etc. The more expensive programs allow the user to design his own reports should he so desire. Resources (and their associated costs) may be entered and the computer will total them, highlighting overloading when it occurs. The more powerful systems can level resources automatically. Practically, virtually all the packages require that the planner first draws out a network on paper because of the difficulty of representing the overall picture on a small screen. Many of the cheaper packages do not make provision for lead and lag times on the links between activities.

3.2 PROBLEMS ASSOCIATED WITH CURRENT PLANNING METHODS

Planning Is Dissociated From Estimating And Other Functions.

After the frequent absence of any formal planning (NORRIS:84), the most serious fault is the failure to integrate planning with other management duties. Estimating, planning, buying, costing, bonus calculation, and the production of valuations all begin with a division of the work into parts. Commonly, for each function the breakdown of work is organised according only to the needs of that particular function. Hence the results of one function are often not immediately comparable with those of another, and further processing is required (JACKSON,C.J.:83). There is thus much duplication of effort, and a barrier to using the outcome of one management activity to improve or monitor the performance of another (WESTGATE,S.E.:86). Such undesirable data 'firebreaks' have come into existence because each function has evolved its own procedures in isolation to the others. They continue to exist because of the popular view that the configuration of contract data demanded by each is so unique as to make standardisation impractical.

As a document often of interest to other parties in the construction industry, and one that is chronologically the first to describe the works for the contractor, the estimate has been the natural focus of efforts to bring about a greater degree of data co-ordination (NCC:79, ORMEROD,R.N.:83, PASQUIRE,C.+TYLER,A.:87). However none of the coding systems thus developed have come into general usage on a significant scale, compared, for example, to the Standard Method of Measurement (MELIA,C:86, NINOS,G.E.:83). The similarity between estimating, planning, and the operation of incentive schemes, in that an estimation of labour content is integral to each, makes their failure to share a common databank particularily acute. Impeding such a development is the absence of a format for describing estimate items in terms of the self-contained operations that to the planner, bonus-setter, and the operatives themselves, represent the most natural division of the work (PASQUIRE,C.+TYLER,A.:87, JACKSON,C.J.:83, NINOS,G.E.:83).

Contracts Are Planned In Isolation.

The conventional approach to construction planning systems has been unsatisfactory for the small firm in that it has tended to ignore the resource dependencies that exist between contracts. Resource constraints are introduced as limits set against individual contracts rather than the entire workload. This fails to reflect the working environment of small firms, which are faced with the more difficult task of meeting the rapidly changing labour demands of short contracts from a common workforce (BARTON,P.:86). Multi-project scheduling, when it is available is provided as an 'extra' rather than as the central component of a planning system. In its absence, the practice of holding weekly meetings to co-ordinate the movement of labour between sites is a common and effective means of ensuring continuity of work in the short term (NFBTE:78). However, the long term implications of the decisions taken are rarely evaluated. Without an accurate projection of the aggregate demand for each of the trades, it is not possible to make an informed assessment of the likelihood of meeting prescribed completion dates, either for ongoing contracts, or for those currently out to tender, with current manpower levels.

Estimating And Planning Are Not Based On A Systematic Assessment Of Site Productivity.

If the labour contents of operations are rarely derived from standard outputs, there is little incentive to make the effort to evaluate the outputs achieved on site, as the results could not be of benefit to future contracts (NORRIS,K.:84, DUFF,A.R.:80). Thus a firm's estimating is not derived from an analysis of its own performance (BRAID,S.:84). A review of labour performance in terms of cost, either monthly or on completion of a contract, is an inadequate substitute because it fails to distinguish between the components of cost, such as site productivity, bonus payments, overtime rates and down time (SHEREEF,H.A.:81). The work packages costed typically encompass many operations, and do not therefore relate to individual estimate items, creating the potential for instances of poor performance or inaccurate estimate rates to remain concealed. Furthermore the discovery that a contract is in profit may deflect management from any further investigation that might otherwise reveal areas of inefficiency which if corrected, would enhance contract profitability.

Failure To Present The 'Right' Information At The 'Right' Time.

There has been a failure to adhere to the principle of management by exception, with the result that managers have in the past been flooded with information of which only a small proportion has been of interest to them. A management information system should screen project data so that attention is directed to the most major items, and to the most serious deviations from plan (HORNER,R.M.W.:82, SHEREEF,H.A.:81, HUMPHREYS,G.:77, NINOS,G.E.:83).

The speed of data processing should also help the user to follow another important dictum neglected by current practice; the requirement that management information be current rather than historical (HOLLINGWORTH,J.:85). In order that a deviation from plan be corrected at the earliest opportunity, the collection, processing, analysis and presentation of contract information must take place rapidly and at frequent intervals. This is an application of the 'feedforward' system of control, and is to be preferred to the concept of feedback which underlies the conventional approach to production control. The latter can only demonstrate where a contract has been, whereas the former can more profitably indicate where it is heading (KOONTZ,N. & O'DONNELL,C:86, JACKSON,M.J.:86). The speed and frequency of the reporting of short contracts, comprising short activities, is particularily important for effective control.

Preparation And Entry Of Data Is Time-consuming.

Part of the reason that early proposals for co-ordinated information systems experienced rejection by the industry was the burden of additional paperwork placed on those operating them (BISHOP,D.+ALSOP,K.:69, WESTGATE,S.E.:86). With the advent of electronic data processing this obstacle has been reduced but not eliminated. One of the features of the early CPA programs that met criticism was the extent of data preparation necessary before the machine was even switched on (LESTER,A.:82). This is a problem that has been tackled with only moderate success by the latest commercially available packages, which still rely on the user first drawing out the network, a programming technique little used by small builders, and considered inappropriate for the plotting of uncomplicated contracts by those familiar with its possibilities (ESHETE,S.+LANGFORD,D.:87).

Data entry procedures have been criticised for being time-consuming, unstimulating, and often obtuse in their logic, with awkward correction routines (CICC:87, JACKSON,M.J.:86). However with the refinement and wider adoption of menu systems, this aspect of computer usage has recently been experiencing improvement.

Quality Of Charts Has Been Poor.

The quality of graphical output has also been disappointing to those used to reading high definition bar charts and networks produced with the benefit of a draughtsman's skills. This has been due to the limitations of the printers, which until recently were the only means of obtaining 'hard' copies from a computer at a realistic price. Recent improvements in speed, quality, and price, have made high definition printers and now colour plotters practical accessories to the small organisation with a microcomputer, a development which some of the most recent systems have exploited.

Computer Generated Programmes Inhibit Discussion.

Finally, when planning was first computerised, a number of unwelcome side-effects appeared, that led some critics to reassess the requirements of a planning system (LESTER,A.:82). It was found that a computer generated programme containing errors could be passed out to team members with a reduced chance of being queried than its manually produced equivalent. Less discussion of construction method would take place, and when it did, it was hampered by the often undeserved authority vested in the programme. The result was the concealment of bad planning, a reduction in communication between personnel, reduced familiarity with the project, and a programme that was an impediment to the individual's ability to identify with team and job. A programme is more than a document for the communication of dates.

3.3 OBJECTIVES FOR A NEW PLANNING SYSTEM

AIM : To establish a comprehensive planning system suitable for use by small firms which would integrate with the Data Bank, Estimating, Targetting and Labour Control System developed in the course of earlier research.

The system would cover:-

(i) Programming for multi-Projects;

(ii) Scheduling of labour and other resources;

(iii) Production control on the basis of productivity measurement.

The system would:-

(i) Take account of the varied work pattern of many small firms with projects ranging in duration from one day to six months or more, but predominantly of between six to sixteen weeks duration;

(ii) Substantially integrate the production process, in planning terms, from estimating to production;

(iii) Allow for the production of Interim Valuations and Final Accounts from project files originally created at the estimating stage;

(iv) Be designed specifically for small firms and embrace the problems which are unique to small firms, eg. arranging for continuity of work and integration between contracts;

(v) Incorporate efficient procedures for data entry and amendment;

(vi) Fully exploit the capacity of the hardware to present contract reports and charts graphically, and to a very high standard.

The above would contribute further to the efficiency and overall performance of small firms by:-

(i) Integrating the whole of the production process;

(ii) Encouraging programming of projects would not otherwise be programmed due to ever changing circumstances and the problem of integrating a number of projects into one schedule;

(iii) Enabling immediate adjustments to be made to the programme when changes occur;

(iv) Identifying significant and unexpected deviations from the plan and bringing these to the attention of management;

(v) Providing a direct link between production and finance from the estimating to the final account stage.

4 ANALYSIS OF THE FIRMS' CURRENT SYSTEMS

4.1 THE TECHNIQUE OF STRUCTURED SYSTEMS ANALYSIS

To determine the requirements of a new system , it was necessary to methodically analyse the current systems. The method adopted was that of structured systems analysis.

Systems analysis is the description of an information system in terms of **PROCESSES**, **DATA FLOWS** between the processes, and **DATA STORES**. The conjunction of these three components is depicted graphically on a 'Data Flow Diagram' (DFD). Their definitions, and the conventions used to represent them, appear in Fig. 7. The 'data' represented is itself not physical, but can take the form of a document, a computer file, or even a human memory.

The level of detail of an individual DFD is related to the proportion of the overall system it represents. A top down analysis starts with the global view of the system, and passes through a succession of increasingly detailed diagrams covering progressively smaller divisions of the system. This is achieved by exploding each process in a diagram into a complete lower level diagram. The procedure is repeated until the lowest level processes are found to be 'functionally primitive', that is, their further decomposition would not add to their understanding. A brief mini-specification of each primitive process is then produced (GANE,C.+SARSON,T.:79).

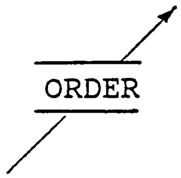
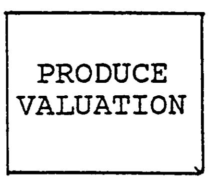
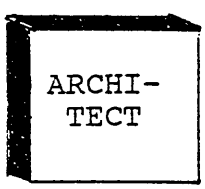
	PROCESS	Transformation of inputs into outputs.
	DATA FLOW	Inputs, Outputs.
	DATA STORE	Data at rest.
	SOURCE or DESTINATION	Process external to DFD but described elsewhere.
	EXTERNAL ENTITY	Source or destination of information outside domain of change.

Figure 7. FLOW DIAGRAM CONVENTIONS

4.2 APPLICATION TO THE SYSTEMS UNDER STUDY

Each firm's analysis was based upon a partially structured interview, questionnaires and tables returned by the firms, complemented by samples of each firms documentation. A second interview was conducted to verify the accuracy of the developing model.

All the firms' systems were initially decomposed into the three functions of Estimating, Production Management, and Financial Management, as depicted in the schematic context diagram in Figure 8. Financial Management, which mainly covered the maintenance of accounts and wages calculation, was excluded from the 'domain of change' as being too far removed from planning. Estimating was decomposed to the next level. The analysis of Production Management was taken one level further. A simple convention for the numbering of processes was followed. Figure 9 illustrates the resulting hierarchy of processes.

Prefaced by a brief description of the firm's organisation and history, the resulting diagrams and mini-specifications for each firm appear in Appendices 1 to 4.

It was beyond the resources of this project to carry out full analyses of the contents of data structures and of the logic of primitive processes for the systems of four different organisations. Instead a narrative summary of the firms' key operational characteristics was prepared.

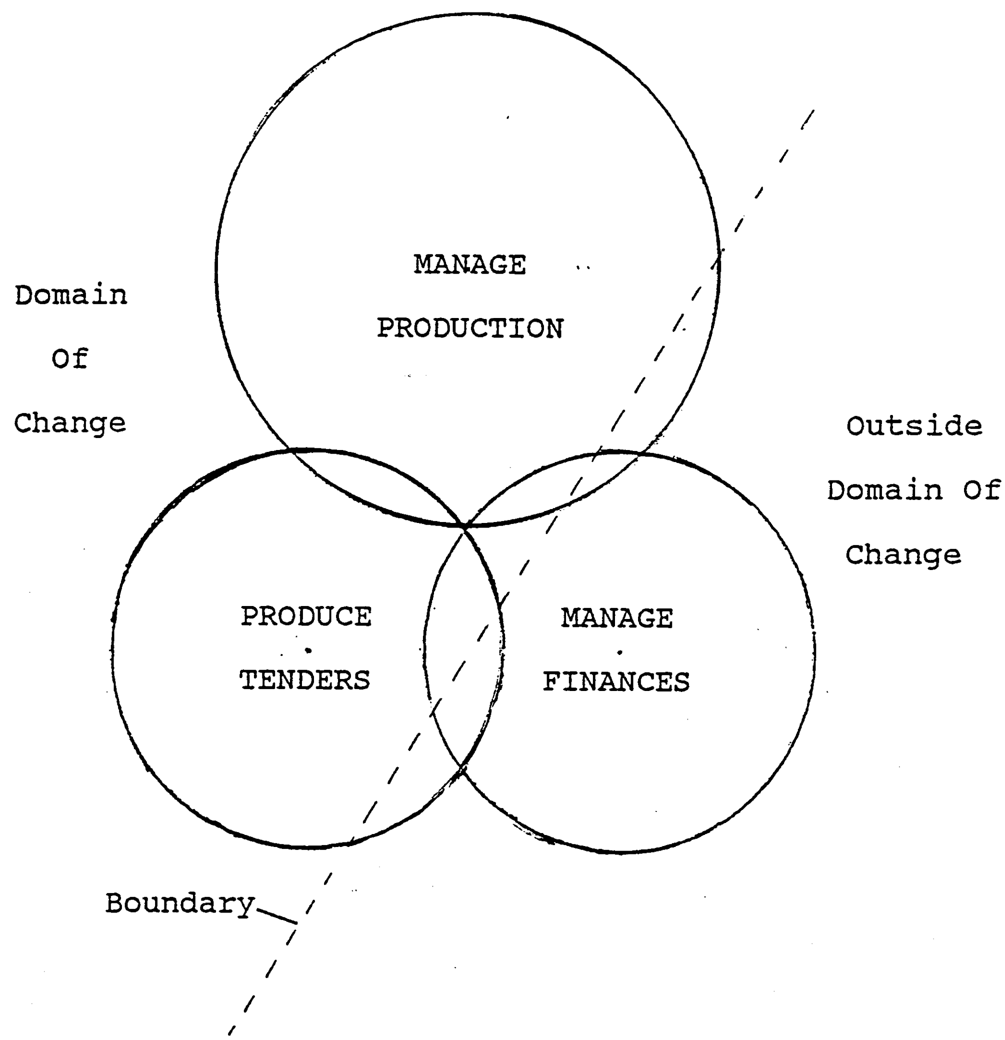


Figure 8. SCHEMATIC CONTEXT DIAGRAM

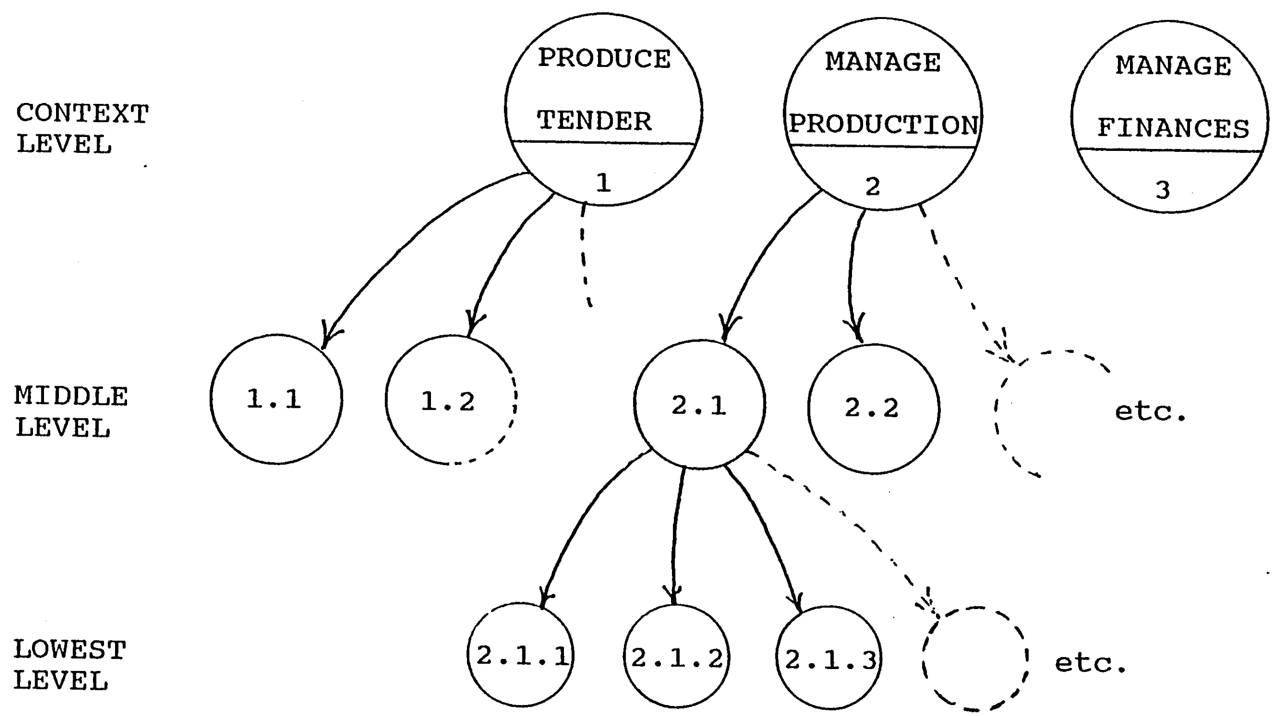


Figure 9. PROCESS HIERARCHY

4.3 SUMMARY OF COLLABORATING FIRMS INFORMATION SYSTEMS

4.3.1 PRODUCING TENDERS

INFORMATION AVAILABLE UPON WHICH TO TENDER

[- never % rarely %% sometimes %%% usually %%%% always]

	FIRM A	FIRM B	FIRM C	FIRM D
% OF TENDERS DOCUMENTED BY ?				
DRAWINGS ALONE	5	10	20	5
DRAWINGS + SPEC. (NO Q'TIES)	50	75	40	55
DRAWINGS + SPEC. + Q'TIES, OR BOQ	25	10	20	40
VERBAL DESCRIPTION	10	5	20	0
(STANDARD PRICE LIST)	10	0	0	0
CONTRACT DATES PRESCRIBED IN TENDER DOCUMENTS ?				
START	%%	%%	%%	%%
FINISH	%%	%%	%	%%
SITE VISIT MADE ?	%%%	%%%	%%%%	%%%%

Tender Documents

For all the firms it was common for there not to be fixed quantities against which to price.

Contract conditions were normally only specified for the contracts covered by a specification or a bill of quantities. They were often specific to the client. All of the firms seemed to have established a mutually beneficial relationship with particular clients or types of clients, such as housing associations, the NCB, Sheffield Forgemasters, and certain breweries.

Contract Dates

Two of the firms (A,B) reported that start and finish dates were often specified by public authorities, but rarely by others. In the case of about half its tenders, firm C asked for the projected start date if it was not already provided, but a finish date was rarely considered at the tender stage. Firm D, whose work was dominated by the breweries, was sometimes given start and finish dates but stated that on winning a contract they could be asked to start the next day, or as much as two months ahead. Generally, when contract periods were specified by the client, they were often considered to be unreasonable.

Site Visit

The sites were almost always visited by all the firms to consider access and to gain a better appreciation of the job, but formal site reports were seldom made out.

BUILD-UP OF THE ESTIMATE

[- never % rarely %% sometimes %%% usually %%%% always]

	A	B	C	D
<u>TAKE-OFF FORMAT</u> ?				
OPERATIONS	%%%	%%	-	%
SMM	-	-	%%%%	-
FOLLOWING THE SPECIFICATION	%	%%	-	%%%
SCHEDULE OF RATES	%	%	-	-
<u>BUILD-UP OF ESTIMATE</u> ?				
LAB, MATS, PLANT PRICED SEPARATELY .	%%%	%%%	-	%%
UNIT RATE BUILT UP FOR EACH ITEM ...	%	%	%%%%	%%
STANDARD UNIT RATES	-	%	-	%
<u>ORIGIN OF PRICING INFORMATION</u> ?				
FIRM'S OWN LIBRARY OF OUTPUTS	%%%	-	-	-
PREVIOUS ESTIMATES	%	%	-	%
FIRM'S OR CLIENT'S SCHEDULE OF RATES	%	%	-	-
PUBLISHED OUTPUTS, RATES	%	-	-	-
ESTIMATOR'S OWN RATES	-	-	-	%
EXPERIENCE	%%%%	%%%%	%%%%	%%%%

MARGIN (FOR OVERHEADS + PROFIT) ?

% OF CONTRACT SUM	%%	%	-	%%
% OF LABOUR COST	%%	-	-	%%
WEEKLY SUM	-	-	%%%%	-
ALLOWED FOR IN LABOUR OR UNIT RATES	-	%%%	-	%%

PRE-TENDER QUOTES - SCHEDULE INFO. ?

SUBCONTRACTOR'S START + FINISH DATES DISCUSSED	%%%	%%%	-	%%%
SUPPLIER DELIVERY CHECKED	%%	%%	%	%

Method Of Measurement

Two of the firms (B,D) could have as many as four members of management engaged in measuring work and building up rates at any one time, each using his own 'method'. The other two firms each had two estimators who conformed to one system in each case. Firm A measured work in an operational format, ie, describing estimate items as they were to be carried out. The system of work measurement used by firm C conformed loosely to the Standard Method Of Measurement.

Firm B's estimators either measured quantities against specification items, or wrote out their own items "as how one builds", even when a bill with quantities had been provided. Firm D measured quantities against items from specifications which were particular to each of its brewery clients. When occasionally these two firms did write out their own descriptions, they did so in an operational format.

Two of the firms reported that they would modify a past estimate, but only if there was very little difference between the two contracts.

Build-Up Of Rates

Firm A priced labour, materials, and plant separately. The number of manhours for each operation was calculated from the firm's own schedule of outputs, and this was multiplied by a labour rate to arrive at a labour cost, to which materials and plant costs were added. Unit rates could be calculated from the resultant figures if specifically requested by the client.

Firm B operated in a similar way to firm A, except that there was no schedule of output rates to refer to, each estimator relying on his own intuition and experience. It was reported that this did introduce a noticeable variability into the pricing of labour. Efforts were being made to develop a system of unit rates, but little progress had been made.

Firm C claimed to build up all-in unit rates from labour, materials, and plant costs for every item, for every tender. Again the labour content was at the discretion of the estimator. Some spot items had lump sums set against them.

One of firm D's estimators applied all-in rates direct to quantities, whereas his colleagues estimated in a similar way to firm B, again without any schedule of outputs.

All of the firms priced major items of plant separately, usually in the preliminaries section. Firm D was the only firm to separately estimate for smaller items of plant such as hand tools, breakers, etc..

Margin For Overheads And Profit

Firm A calculated a weekly sum based on the present and planned workload for each division of the company, and an assessment of the likely overheads assignable to the contract. Although firm B's labour rates already included an amount for overheads and profit, a further margin would often be added, depending on the current volume of work, market conditions, etc.. Firm D sometimes included a margin in the rates and sometimes did not, depending on the estimator.

Quotations

During estimating, subcontractors being asked to quote by firms A, B, and D were normally informed of the most likely dates for the start, and sometimes the completion, of the main contract. Firm D also tried to give an approximate date for the start of the subcontractor's section of the work.

The potential for the late arrival of subcontractors or materials was not regarded as being a serious problem at the tender stage for a job they would probably not win. Generally a supplier would only be asked about delivery where there was a likelihood of a problem.

Apart from past invoices and price lists, no records were maintained of a subcontractor's performance or a supplier's delivery history. Estimators were reported to be aware of 'bad' suppliers and subcontractors, and of current typical delivery periods for common materials.

INFORMATION RETURNED TO CLIENT WITH TENDER

[- never % rarely %% sometimes %%% usually %%%% always]

TENDER SUBMISSION ?	A	B	C	D
CONTRACT SUM ALONE	%%%	%%%	%%%	%%%
ITEMISED BREAKDOWN OR DESCRIPTION...	%	%	%	%
ESTIMATE OF CONTRACT DURATION	%	%%%	%%%	%%

If not already specified by the client, an estimate of the contract duration was usually supplied by the firms at his request.

Similarly, a description of the works was only provided when requested by the client, or when the works were not already described in the tender documents as in the case of 'Design And Build', or when the required work had been verbally described to the contractor.

Firm D stated that they were increasingly being asked for a priced specification with the tender, but that along with rival competitors they were taking steps to discourage such expectations.

4.3.2 MANAGING PRODUCTION

PROGRAMMING THE WORK

[- never % rarely %% sometimes %%% usually %%%% always]

	A	B	C	D
MASTER PROGRAMME PREPARED ?				
FOR LARGE CONTRACTS	%%%%	%%%%	%%%%	%%%%
FOR SMALL CONTRACTS	%%	%	-	-
FOR REPAIR AND MAINTENANCE	N/A	-	-	-
ALTERATIONS AND EXTENSIONS	%%%	%%%	%%%%	%%%%
NEW WORK	%%%%	%%%	%%%%	%%%%
PROGRAMMING TECHNIQUE ?				
BAR CHART	%%%	%%%%	%%%%	%%%%
NETWORK	%	-	-	-
LINE OF BALANCE	-	-	-	-
SOURCES OF PROGRAMMING INFORMATION ?				
ESTIMATE DOCUMENT	%%%%	%%%%	%%%	%%%
FILE OF PAST OUTPUTS	-	-	-	-
PUBLISHED OUTPUTS	-	%	-	-
DRAWINGS	%%%%	%%%%	%	%%%%
PREVIOUS PROGRAMMES	%	%	-	-
INCENTIVE TARGETS	%%%%	-	-	-
METHOD STATEMENT	%	%%	-	-
THE EXPERIENCE OF OTHERS	%%	%%	-	%%%%
PROGRAMME TIME UNIT ?				
HALF DAY	%%%	-	%%%	-
DAY	%	%	%	-
HALF WEEK	-	%%%	-	%%%%
WEEK	%	-	-	-
WHO RECEIVES THE MASTER PROGRAMME ?				
CONTRACTS MANAGER	%%%%	%%%%	%%%%	%%%%
ARCHITECT	%%%	%%%%	%%%%	%%%%
CLIENT	%	%%%%	%	%%%%
MAIN SUBCONTRACTORS	-	%%%%	%%%%	%%%%
SITE REPRESENTATIVE (E.G. FOREMAN)	%%	%%	%%%%	%%%%
ESTIMATOR/QS	%%%%	%%%%	%%	%%%%

SHORT TERM PROGRAMME PRODUCED ? ...... % - % %

The Decision To Programme

After the obligation to comply with any contract requirements, the principle consideration as to whether or not to programme the contract was its size. The main reasons for not programming repair and maintenance work was the effort involved in producing and maintaining programmes which were continuously going out of date, and the need to carry out this type of work regardless of programme considerations. Firm C did produce job sheets which were arranged in the order in which they were to be carried out by the contract manager responsible.

Type Of Programme

Firms B,C, and D invariably produced barcharts. Firm A had used the 'line of balance' technique once (for a repetitive refurbishment contract) , and had used CPM twice, in each case subsequently converting the network to a barchart for the purposes of control.

Firms B and C had considered the use of alternative techniques in the past, but had never made use of them. Firms A and B were conversant with CPM but only thought it useful where it was essential for a job to be completed in a short space of time. Firm A also thought it appropriate when a large number of variations could be expected. Firm B did not consider the penalties for overrun severe enough to justify the perceived additional effort of producing a network. Both of these firms regarded a network as a method of determining critical dates and activities and not as a means of communicating a schedule to others.

Firm D's interviewee thought that his clients would not be able to fully comprehend anything other than a barchart. He did however perceive the potential of other techniques for work more repetitive in nature than that normally undertaken by his firm.

Firm C gave poor management training and lack of familiarity with both CPM and line of balance as the reasons for its exclusive use of barcharts.

Information Used For Programming

Method statements were only ever produced during estimating. Firm A only prepared a method statement when considering alternative and complex methods of construction, and thus only for a very small proportion of the contracts tendered for. Firm B often produced a statement in the course of estimating and used it in the production of programmes for the more complex contracts.

Firm A, the only firm to maintain a databank of output rates, was the only one to systematically derive the programme from the estimate data. Incentive targets in terms of manhours were calculated as the sum of individual estimate items. A gang size was assigned to determine duration. The result was either entered directly into the programme, or combined with other targets to form more substantial activities.

Both firms B and C made an effort to extract output rates from the estimate in order to establish the manhours. Having thus arrived at an approximate labour content, a duration could be assessed assuming some nominal gang size.

Firm B often related programme activities to subsections in the estimate document. Firm B occasionally used price books.

Neither of firms B and C were systematic in their determination of durations. This left much, particularily in the case of firm C, to the discretion of the programmer.

Firm D grouped estimate items under activity descriptions, but only looked at the quantities to get some idea of the work involved before making an estimate of the duration.

Hence all four firms were to some extent amalgamating estimate items to produce programmable tasks, but differed greatly in how methodically and precisely they converted quantities into durations.

The programmer's experience was considered to be of great importance by all the firms.

The Programmer

In firms A and B it was usually the estimator who would prepare the programme on winning the contract. Programming was the responsibility of the contracts manager in firm C, and of the quantity surveyor in firm D.

The Detail Of The Programme

Without network analysis, the firms did not attempt to locate and highlight the critical path on the programme, but all those interviewed claimed that they were aware of which tasks were critical.

All the firms were prepared to programme to a greater level of detail than normal, both in terms of activity size and time unit, when a contract was regarded as 'tight'.

Short-term Programming

Firm A rarely did any short-term programming. Firm B considered that as its workload was composed of such short contracts there were no benefits to be gained from programming a period of their work less than the full duration.

Firm C would use short-term programming when a contract had fallen behind, or when it was not clear from the main programme how a difficult phase of the work would proceed. The programme would be detailed to the half-day, and would be based entirely on the contract manager's understanding of the work. Only the foreman on site would receive a copy.

Firm D often produced an exploded version of the last few weeks of the main programme, as the finishing activities began. A shorter unit of time would be used and the main programme's activities would be broken down into smaller operations.

REPORTING PROGRESS

[- never % rarely %% sometimes %%% usually %%%% always]

<u>FREQUENCY OF PROGRESS REPORTS</u> ?	A	B	C	D
WEEKLY	%%%	-	%%	-
MONTHLY	-	%%%	%%%	-
IRREGULARILY	%	%%	%%	-
A FEW WEEKS BEFORE COMPLETION	-	-	-	%%

Although formal written progress reports were not common, contract managers were reported to be aware of the position of the contract relative to the programme, particularily in advance of progress meetings. Actually altering the programme to reflect progress was generally only carried out when such progress was far behind (or occasionally ahead) of programme. Information about progress was extracted from site visits, timesheets and valuations.

THE SCHEDULING OF LABOUR

[- never % rarely %% sometimes %%% usually %%%% always]

<u>SCHEDULING OF LABOUR</u> ?	A	B	C	D
EVALUATION OF CONTRACT LABOUR DEMAND	%%%%	-	%	-
EVALUATION OF COMPANY LABOUR DEMAND.	%%%%	-	-	-

Only firm A, and occasionally in the past, firm C, made a record of the scheduled labour demand, trade by trade, for each contract. This appeared beneath the programme.

Initial programming by firm A included a resource summary. A multiproject schedule was then prepared on which appeared all the activities to be carried out by the firm's workforce, from all the contracts. If necessary the individual programmes were amended where the multiproject schedule indicated conflicting labour demands. This was done as often as once a week when the individual programmes kept changing, or whenever a new contract was won.

Firms C and D claimed to be aware in advance of any impending manpower shortages , without ever having to evaluate demand for labour precisely. These firms were both larger in terms of turnover and staffing levels than the other two. Consequently their workloads were divided between several contract managers on the basis of work type. This introduced the need for a system for integrating and resolving the conflicting demands for common resources, of which labour was generally held to be the most important. Firm C attempted to solve the problem by allowing the contract managers in effect to maintain their own workforces, permitting only limited movement of labour between them. This afforded each manager a measure of independence with regard to the scheduling of labour.

However, central to the planning function for both firm C and D, was the weekly progress meeting, where each manager informed the others of the progress of his contracts. Agreement was reached amongst them as to the deployment of individual men over the following week, and an assessment of the approximate future labour requirements would be made.

For firm B decisions regarding the number of men to assign to an activity, the integration of the demands of different contracts, and ultimately the direction of individual operatives, were all considered on a day to day basis, shortly before an activity was due to start. The principle expressed here was that of keeping all the men occupied, although it was also reported that as a result, contracts were often not completed on time.

For firm A, although some of its targets were effectively marked out for particular gangs, as they were prepared at the outset of a contract, the final assignment of men was only made a week in advance.

Actions Taken In The Event Of A Labour Shortfall

On becoming aware that the firm's commitments to all its contracts (as expressed in their programmes) could not be met at the firm's current labour levels, the first reaction of all the firms was to accept activity delay. At one time firm A would actually revise it's programmes through its system of multiproject scheduling but this had proved to be too time consuming.

Firm C appeared to be the most ready to call in and lay off labour-only subcontractors to match the ebb and flow of demand. A large proportion of the workforces of firms A and D were also self employed, but they expressed a reluctance to expand and contract this element as a means of absorbing short-term fluctuations in demand.

Firm B never employed labour only subcontractors on principle. As a result, when the workload increased it was accepted that jobs would take longer. Whenever this was considered unsatisfactory, they would ask the men to work on Saturdays.

None of the other firms mentioned additional overtime as a strategy for coping with additional work.

Actions Taken In The Event Of A Shortfall Of Work

When the level of work scheduled for a particular trade fell below that necessary to ensure full employment, none of the firms had 'hospital jobs' to which they could reassign their men.

Firms B and D had regular clients whom they could call upon for additional work if faced with a serious shortage of work. All agreed that in the short term their men would carry out work not normally associated with their trade when no other work was available to them.

The following reasons were offered by firms B,C, and D for not scheduling labour in a more systematic way;

(i) contracts were too numerous and too short to make it feasible;

(ii) it would be too time consuming to produce and maintain a schedule that would be sophisticated enough to be of any use;

(iii) in the absence of a bonus scheme the productivity of the men is both unknown and too variable, making schedules unreliable;

(iv) the facility to find and dismiss additional labour at short notice, and the ability to extend and contract project durations obviate the need to smooth out fluctuations in labour requirements by the preparation of a schedule.

THE PROCUREMENT OF MATERIALS

[- never % rarely %% sometimes %%% usually %%%% always]

[Y YES N NO]

	A	B	C	D
<u>MATERIALS</u> <u>SCHEDULING</u> ?				
ONLY FOR LARGER CONTRACTS	N	N	N/A	Y
ONLY FOR MAJOR ORDERS	N	N	N/A	Y
ONLY MATERIALS ON LONG DELIVERY	Y	Y	N/A	Y

<u>COMMUNICATION</u> <u>OF</u> <u>REQUIRED</u> <u>DELIVERY</u> <u>DATE</u> ?				
ON ORDER	%%%%	%%%	%%	%%
BY TELEPHONE (CALL-OFF)	%%	%%%	%%%	%%%

Materials Schedules

Firm C never produced a written schedule of materials. Firms A and B produced schedules showing details only of those materials which had long delivery periods. Firm D only produced schedules for its larger contracts, but included in them the details of a broader range of materials. Delivery dates appearing on the schedule were either taken from the programme or from the order if it had been already sent out.

Placing Orders

Shortly after winning a contract all the firms sent out a first batch of orders for those materials on long deliveries or identified as being immediately required. Only firm C then continued to place the remaining orders well in advance of their need on site, the other firms electing to leave the orders for the non-specialised and minor items until the contract manager was planning their fixing on site.

Communication Of Required Delivery Dates

Firm A included dates for delivery on all of its orders and rarely saw the need to call them off nearer the time. Firm B indicated 'target' dates on their orders, but subsequently called off the materials shortly before they were needed on site. Firms C and D noted delivery dates on orders for some specialist materials but normally stated on the order that they were to be called off by the site.

Call-offs were made as far in advance of the site's need as the contract manager deemed necessary.

None of the firms considered the late organisation of the delivery/collection of materials as having a significant effect on progress, although firms B,C, and D did acknowledge it as a problem. Generally it was regarded as no more than an inconvenience. For two of the firms the failure of architects to allow for delivery periods when stating contract periods or the late introduction of changes to the specification were greater problems.

SCHEDULING OF OTHER RESOURCES

No separate schedules for subcontractors or drawings were prepared by any of the firms.

Decisions regarding major items of plant, such as craneage, would be made at the tender stage and communicated to the contract manager at a meeting once the contract was won. Otherwise plant requirement were not considered more than a week in advance. Owning little plant themselves, full advantage was being taken by firms A, B, and D of the availability of hired plant (during a period of slack demand) to substantially reduce the need for forward planning.

Firm C, which did possess a number of items of plant, maintained a record of the location of each item to keep the contract managers informed. However no advance scheduling was carried out.

Firm C also reported that it was occasionally obliged to furnish the architect with a list of information requirements (with dates). No other firm reported ever preparing such a schedule.

INCENTIVES

[- never % rarely %% sometimes %%% usually %%%% always]

<u>INCENTIVE</u> <u>SCHEMES</u> ?	A	B	C	D
% OF WORK COVERED BY A SCHEME	75	0	15	0
TARGET MANHOURS, BASED ON ESTIMATE .	%%%	N/A	%%%%	N/A
PRICES	%	N/A	-	N/A

The targets of manhours set by firm A were the direct result of the amalgamation of estimate items themselves derived from a database of outputs. The targets included for the collection of materials, travelling time, and clearing up.

For firm C bonus work was carried out under a system of target manhours for those directly employed by the firm, and pricework for the labour-only subcontractors. Targets, set at the discretion of the individual contract managers, were generally based on estimate rates for each item, but were amended as considered necessary.

All of the firms could see benefits in an incentive scheme. Firm B's respondent thought that with a bonus scheme, productivity would improve, the men would make more money, they would be more inclined to stay with the firm, and the firm would be able to schedule contracts with more conviction. For firm C it was reported that when previously a scheme had been in operation, the men had been more interested, more ready to innovate, and had made sure that materials were requisitioned. Firm D had once set prices for the fitting of windows, and it had 'worked very well'.

PRODUCING INTERIM VALUATIONS

[- never % rarely %% sometimes %%% usually %%%% always]

<u>BASIS OF INTERIM VALUATIONS ?</u>	A	B	C	D
ESTIMATE OF OVERALL VALUE	%%	%	%%	%
BASED ON % COMPLETION OF SECTIONS ..	%%	%%%	%%	%%
SITE MEASUREMENT OF WORK	-	%	-	%%

For all the firms, valuations varied from a simple rough estimate of the value of the work completed to date to the actual measurement of bill items. Most commonly, a site visit would be used to make a broad assessment of the completion of sections of the work upon which to base the valuation. Occasionally some items would be measured, but complete measured valuations were normally only carried out at the insistence of the client as the firms viewed them as unnecessary time consuming operations. Only firm A derived the value of estimate items completed direct from a report of the progress of programmed activities.

The interim valuations were regarded by all as a means of generating cash flow, and not as a precise measure of the value of work completed.

All the firms tried to see that variations were handled as they occurred, but often found that many were left to be included in the final account. All interim valuations were prepared on a monthly basis, and hence for all the firms many contracts were too short to warrant interim payments.

FEEDBACK

[- never % rarely %% sometimes %%% usually %%%% always]

	A	B	C	D
<u>COMPARISON OF ACTUAL AND EST. HOURS</u> ?	%%%%	-	-	-
<u>COST/VALUE RECONCILIATION</u> ?				
AT TIME OF VALUATION	-	-	%%%%	%%%
AT END OF CONTRACT	%%%%	%%%%	%%%%	%%%%

DETAIL OF RECONCILIATION ?

TOTAL CONTRACT COST/VALUE	%%%%	%%%%	%%%%	%%%%
LAB, MATS, & PLANT SEPARATELY	%%%%	-	-	%
FURTHER BREAKDOWN	-	-	-	-

Monitoring Productivity

Only firm A systematically compared the actual hours taken against the estimated hours. Through the operation of its incentive scheme significant differences between the actual and standard outputs were revealed and if appropriate the latter were amended.

Costing

Although both firm C and D collected costs under resource headings of labour, materials, subcontractors, etc., neither firm was able to extract the corresponding values from the valuation. Hence no breakdown of profit or loss by resource category was possible. For firm C the costing generally came too late to be of use in controlling costs on an ongoing contract. However firm D's contract managers would investigate further, and would supervise individual contracts more closely if the costing indicated a loss-making situation.

Firm B used a system of cost sheets whereby the hours expended and the materials used were extracted from timesheets and requisition books and noted against descriptions of sections of the work also taken from the men's timesheets. These were subsequently costed using labour rates and invoices, and a cost/value comparison at the end of the job gave an indication of overall profitability. The descriptions of the work supplied by the men rarely related to the estimate items in any way, so that it was not often possible to make a check on the accuracy of estimate rates.

For firms B,C, and D there was no tangible system for relating the results of costing back to estimating.

Like firm B, firm A only made an evaluation of overall profitability on completion of the contract.

5 REVIEW OF THE FIRMS' CURRENT SYSTEMS

5.1 GENERAL SYSTEM CHARACTERISTICS

The analysis revealed the firms to possess certain distinctive characteristics when viewed as information systems:-

1. The differences between the information systems serving each of the firms may be attributed to differences in management structure, in the attitudes of key individuals, and in the type of work carried out. They were not sufficient to prevent the development of one system capable of meeting the planning needs of all of the firms.

2. The processing a contract underwent was conditional on the nature of the contract, most importantly its size. The processes described on the data flow diagrams were therefore not uniformly applied in all circumstances. The logic governing the application of many processes was not well defined.

3. With regard to an individual contract, many of the firms' functions were executed intermittently over a long timescale. There were also interludes between consecutive functions during which no processing of data took place. There were thus frequent pauses in the flow of information during the life of a contract during which there was a need to store data.

4. Elements of data were common to many different functions, although often configured differently by each.

5. There was a general failure to store the results of one function in a format accessible to others. Thus information often had to be regenerated. Efforts were being made to derive the data for one function from the results of another but standardised systems and procedures for doing so were rarely in place to support such developments.

6. In the absence of a systematic scheme of data storage and retrieval, the memory, knowledge and experience of the individual were of great importance in the generation and handling of short term routine information (eg., short term planning). This was particularily the case where consecutive functions were executed by the same individual, as was a common occurrence within these small organisations. Such inputs cannot be well represented on data flow diagrams which are oriented towards the representation of non-human information flow and storage.

7. Meetings and conversations played a major part in disseminating information throughout the organisations. Formal documentation was correspondingly less significant. The motivation and assessment of individuals was a very important secondary function of verbal communication.

5.2 DEFICIENCIES IN THE FIRMS' INFORMATION SYSTEMS

Estimate Was Not In A Format Accessible To Production Functions.

For three of the firms the work descriptions used by the estimators were not suitable for planning, targetting and control. Estimate items were commonly defined in terms of material quantities rather than as the operations by which the other functions were better served. By effectively impeding their access to the estimate data in this way, the performance of the subsequent functions was seriously impaired as they were being deprived of the most accurate measurement of the work available.

Estimate Items Were Not Well Standardised.

Two of the firms did not use standard work descriptions for estimating, and a third firm only loosely followed the Standard Method Of Measurement. This prohibited the use of a standard library of estimate rates, and thus prevented the analysis of the performance on one contract from directly benefitting the estimating for another.

Inadequate Effort To Use Estimate Information For Planning.

Three of the firms did not systematically derive the labour content of activities from the estimate, thereby ignoring a valuable potential source of programming information. Instead there was a heavy reliance on the planner's experience.

Labour Schedules Were Not Produced.

It was rare for a record to be made on the programme of the number of men assumed in the calculation of each activity's duration. Hence no one other than the programmer could be aware of planned gang sizes from an inspection of the programme.

Integration Of Contracts' Labour Demands Was Poor.

Inadequate consideration was taken of the firm's total labour requirements when scheduling a new contract, and when alterations occurred to programmes. At the tender stage, without a multiproject schedule it was not possible to predict when new work could be undertaken. Without a 'master' schedule to contain them, many smaller projects were not programmed at all. Priority was given to resolving labour problems arising in the next one or two weeks without sufficiently evaluating the long term prospects. There was an implied risk that the late discovery of problems would limit the options available to management. It was assumed that it would always be possible to delay the completion of a contract, or recruit labour-only subcontractors at short notice. In a period of booming demand the latter might not be a practical alternative.

Programmes Were Not Updated.

Once produced, the programme was rarely updated for progress and variations because of the effort of redrawing involved. The inevitable divergence of actual from planned eroded the programme's usefulness as a control document. This encouraged managers to refer instead to a 'mental' plan of the work, which, although more flexible, was prone to error and was by definition not immediately accessible to other interested parties.

Reporting Of Progress Was Not Co-ordinated.

The production of interim valuations, costing, the calculation of bonus, the updating of programmes, and the holding of in-house and monthly contract progress meetings all rely to some extent on a report of progress. None of the firms were operating a central system of reporting progress to support all of these functions. Instead independent assessments were being made for each, in differing formats, and rarely to a high level of detail or accuracy. Often there was no formal documentation. This constituted both a duplication of effort, and a failure to provide accurate project information.

Failure To Evaluate Productivity.

For three of the firms there was no effort to make a comparison of actual and estimated output. They were therefore without an assessment of productivity or of the accuracy of the estimate rates used.

Costing Information Was Inadequate For Control Purposes.

The cost reconciliations carried out by the firms did not constitute a means of control. The information provided was not sufficiently specific to indicate the sources of a contract's profit or loss. Also the delay associated with the collection of costs and the production of valuations prevented reconciliations being used to monitor the performance of any but the longest contracts. The collection of all costs did not imply recognition of the relative importance of labour-related factors in the variance of total cost.

Operative's Hours Not Recorded Against Meaningful Work Descriptions In The Absence Of Incentives.

Without comprehensive incentive schemes there was little motivation for the operatives of three of the firms to accurately report the hours they expend against specific work sections on their timesheets. This is a prerequisite for the evaluation of productivity for organisations for whom work study techniques are not practical. Operatives were not aware of the output expected of them and have less incentive to bring production problems to the attention of management.

5.3 REQUIREMENTS OF THE NEW SYSTEM

There were a number of central objectives for the new system:-

1. The estimate would describe the work in terms of operations corresponding to the production processes the work would involve.

2. Where possible an estimate operation, its output and resource costs, would be derived from a database of standard operations.

3. All information regarding labour content required by the functions of planning, targeting and control of the work, would originate from the estimate. There would be a precise relationship between the estimate's operations and the division of work for the other functions. This would be expressed in a work breakdown structure [SEE 6.4.2 'A Work

Breakdown Structure'].

4. A programme based on a precedence network, but displayed as a bar chart.

5. The main focus of control would be on labour productivity, rather than costs.

6. The comparison of actual and estimated manhours would be a routine function for the firm [SEE 6.4.5 'A Control Report'].

7. The weekly return of timesheets would provide detailed progress information, and a report of the breakdown of the individual's hours. The single entry of this information would be the main source for the calculation of wages, the reporting of progress, updating of the programme, production of valuations, and the review of performance [SEE 6.4.4 'The Reporting Of Hours And Progress'].

8. The capacity for a comprehensive incentive scheme, but no obligation to operate one.

9. The assignment of labour to activities on a trade basis, but also as individuals [SEE 6.4.3 'Labour Assignments'].

10. Scheduling of labour through a multiproject schedule, to include all contracts regardless of size.

11. Pricing of variations, and their incorporation into the programme.

6 THE DEVELOPMENT OF A NEW SYSTEM

6.1 PRODUCING A SPECIFICATION

As there were four logical models of four current systems, and in view of the radical nature of the changes to be introduced, it was not possible to simply refine the analysis of an existing system to produce a new model. Hence a complete top down design was carried out using the same techniques as those used to conduct the top down analysis of the firms. The same conventions as those described in chapter 4 were used in the preparation of the new system's data flow diagrams. The functions of materials purchasing, and costing, were excluded as not being an integral part of a planning system.

A data dictionary was compiled, defining the data structures of which the data flows were composed. In doing so a formal notation was adopted. This is illustrated by the fictitious entry shown in Figure 10.

The DFDs for the new system appear in Figures 11 to 19, interspersed with the relevant process descriptions. The supporting data dictionary appears in Appendix 5.

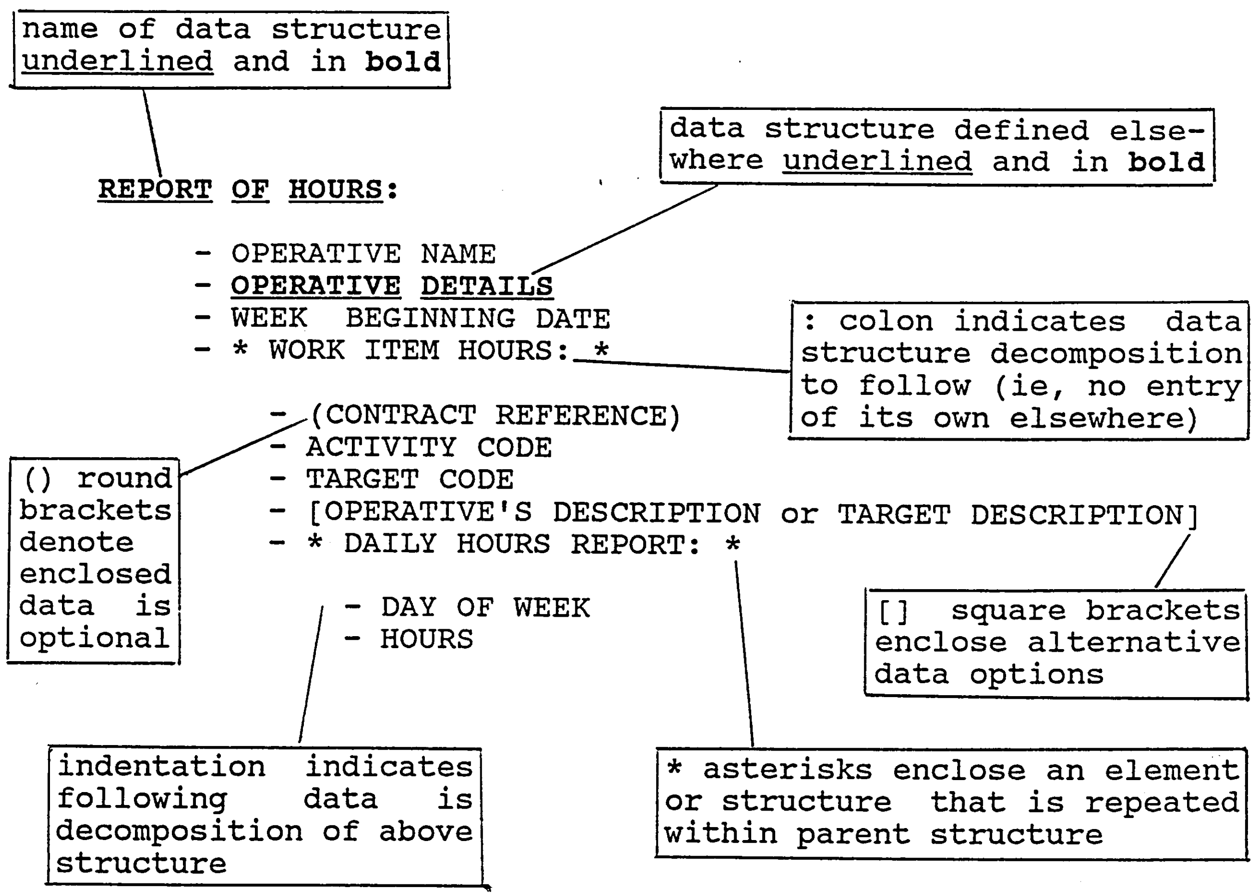
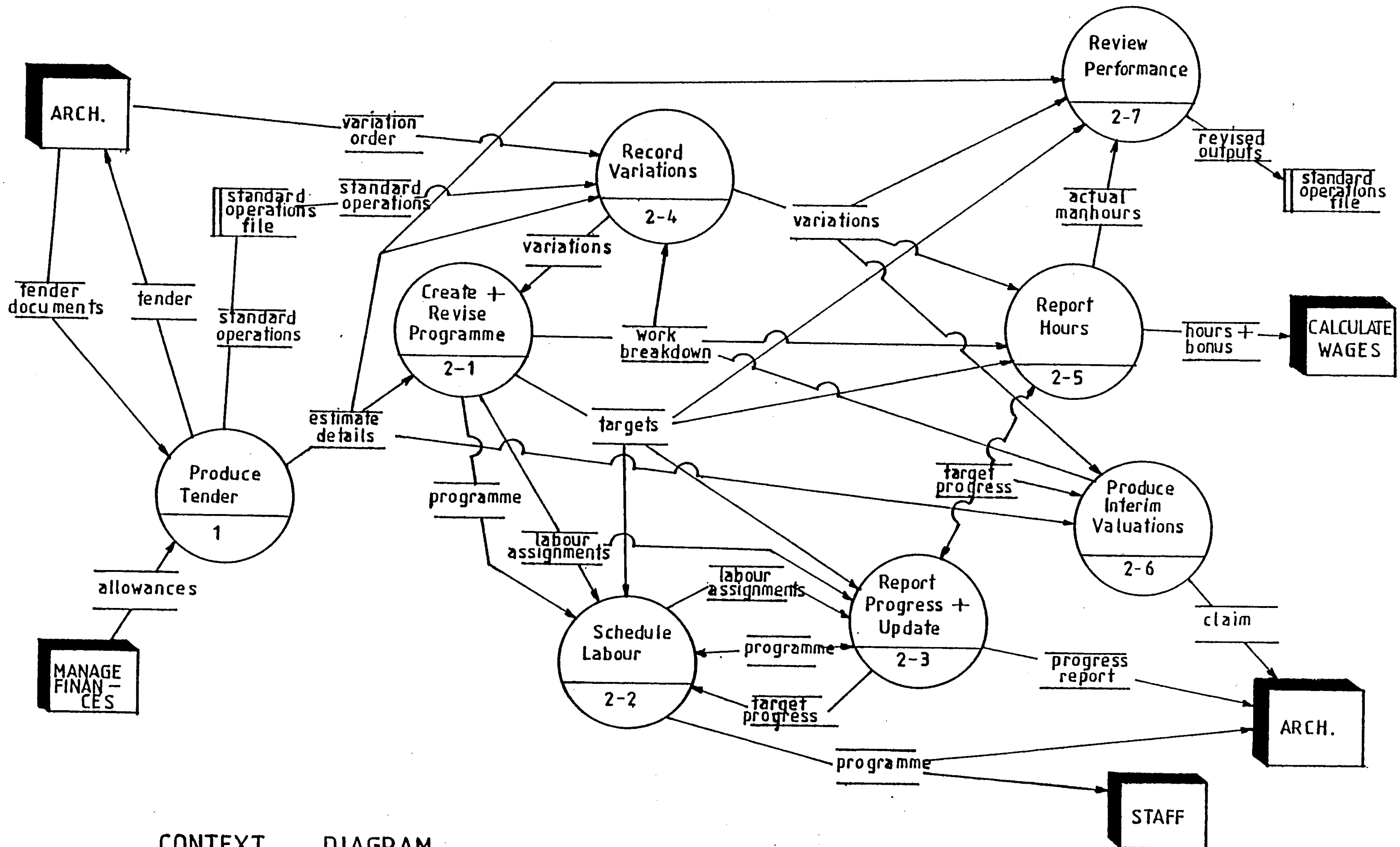
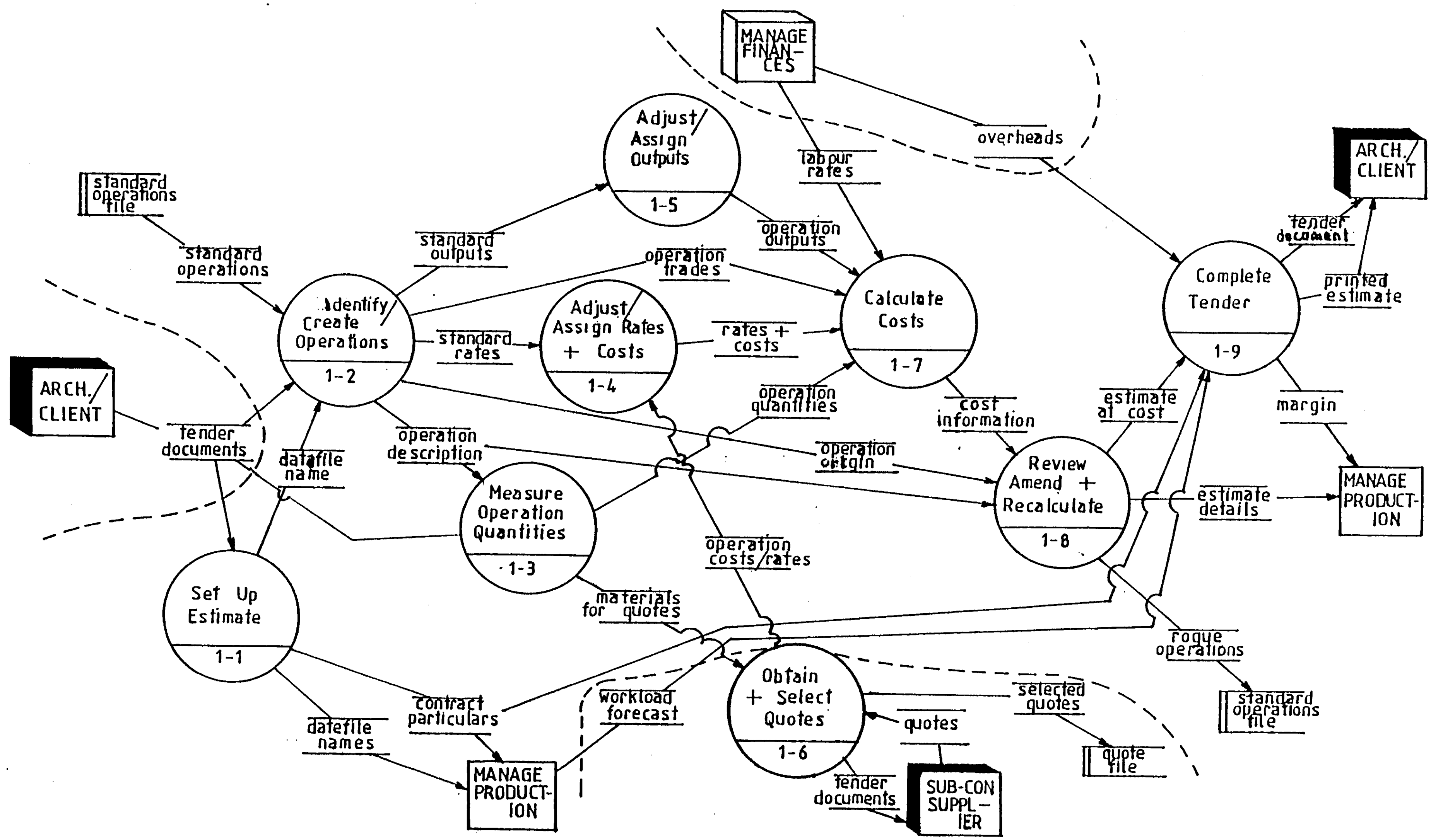


Figure 10. EXAMPLE OF DATA STRUCTURE DEFINITION



CONTEXT DIAGRAM.

Figure 11.



1 PRODUCE TENDER.

Figure 12.

6.2 PROCESS DESCRIPTIONS FOR THE NEW SYSTEM

1 PRODUCE TENDER

1.1 SET UP ESTIMATE

DESCRIPTION: Enter contract name, commencement date, completion date (or contract period), retention, client, etc., if known. Enter contract reference and initialise datafiles specific to contract.

INPUTS: tender documents

OUTPUTS: contract particulars, datafile names

1.2 IDENTIFY/CREATE OPERATION

DESCRIPTION: Select appropriate operation to describe work from standard database. If no suitable operation found, create new description.

INPUTS: tender documents, datafile name, standard operations

OUTPUTS: operation description, operation origin, standard rates, standard output, operation trade

1.3 MEASURE OPERATION QUANTITIES

DESCRIPTION: Measure or derive quantities described by operation from tender documents.

INPUTS: operation description, tender documents

OUTPUTS: operation quantity, materials for quotes

1.4 ADJUST/ASSIGN RATES AND COSTS

DESCRIPTION: Review and amend standard rates and costs for materials, plant and subcontractors, on basis of quotes and experience.

INPUTS: standard rates, operation costs/rates (quoted)

OUTPUTS: rates and costs

1.5 ADJUST/ASSIGN OUTPUTS

DESCRIPTION: Review and amend standard output as considered appropriate.

INPUTS: standard outputs

OUTPUTS: operation outputs

1.6 OBTAIN AND SELECT QUOTES

DESCRIPTION: Identify materials, plant and subcontractors requiring quotes. Send details to suppliers and subcontractors. Receive and select quotes.

INPUTS: materials for quotes, quotes

OUTPUTS: tender documents, selected quotes, operation costs/rates

1.7 CALCULATE COSTS

DESCRIPTION: Apply all rates and costs to quantities. Subtotal costs by resource.

INPUTS: operation quantities, operation trades, operation outputs, rates and costs, labour rates

OUTPUTS: cost information

1.8 REVIEW, AMEND AND RECALCULATE

DESCRIPTION: Review resource subtotals. Call up details of individual operations, examine and amend as appropriate. When estimate acceptable, file rogue operations to standard database. Total operation costs.

INPUTS: cost information, operation description, operation origin

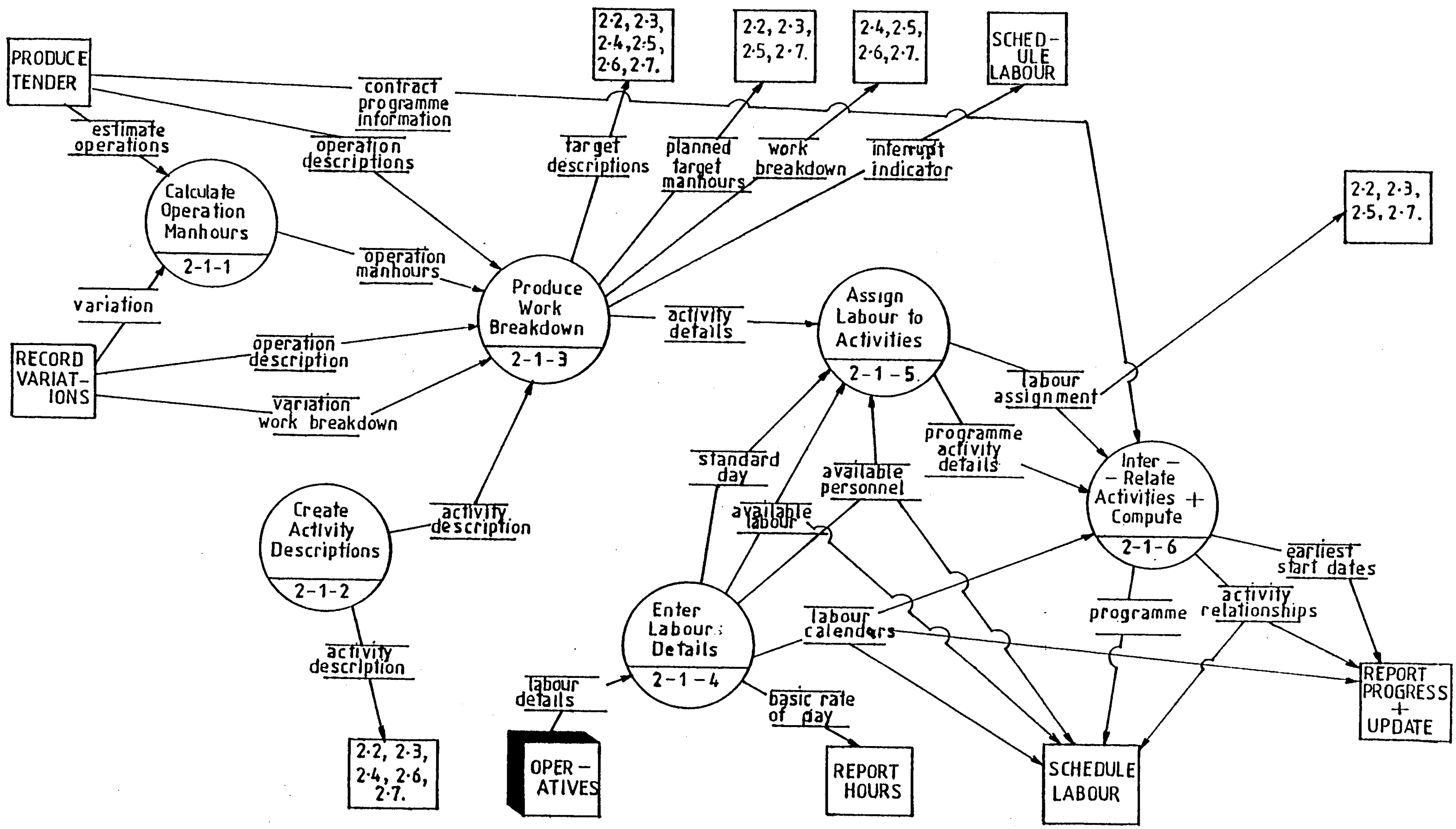
OUTPUTS: estimate at cost, estimate details, rogue operations

1.9 COMPLETE TENDER

DESCRIPTION: Review company overheads costs, workload forecast, and contract period. Enter margin as percentage. Calculate total estimate value. Prepare formal tender submission. Print breakdown of estimate (by operation) if required.

INPUTS: estimate at cost, workload forecast, contract particulars, overheads

OUTPUTS: tender document, printed estimate, margin



2-1 CREATE & REVISE PROGRAMME.

Figure 13.

2 MANAGE PRODUCTION

2.1 CREATE AND REVISE PROGRAMME

2.1.1 CALCULATE OPERATION MANHOURS

DESCRIPTION: Calculate operation manhours from estimate output and quantity. Calculate variation operation manhours in same manner [SEE '2.4 RECORD VARIATIONS'].

INPUTS: estimate operation, variation

OUTPUTS: operation manhours

2.1.2 CREATE ACTIVITY DESCRIPTIONS

DESCRIPTION: Enter a description of programme activity.

INPUTS: NONE

OUTPUTS: activity description

2.1.3 PRODUCE WORK BREAKDOWN

DESCRIPTION: Assign each operation to an activity from listing. Subdivide activity into targets, create target descriptions, and assign operations. If target division not yet decided, accept temporary activity-wide default. Indicate whether activity may be interrupted during multiproject scheduling by reassignment of labour to higher priority activity. Derive target manhours from operations. Derive activity manhours from targets. Amend target hours if result unacceptable. Specify activity duration where manhours inappropriate. Recalculate manhours on entry of variations.

INPUTS: activity descriptions, operation descriptions, operation manhours, variation work breakdown

OUTPUTS: work breakdown, target description, planned target manhours, activity details, interrupt indicator

2.1.4 ENTER LABOUR DETAILS

DESCRIPTION: Enter name and trade of operative. Enter basic rate of pay for each trade. Enter hours available for work for each trade, for each day of week. Enter details of holidays. Create and assign new calendar to individual if different from trade. Enter standard daily hours for calendar, or accept average of daily hours entered as default. Calculate number of members of each trade.

INPUTS: labour details

OUTPUTS: basic rate of pay, available personnel, available labour, labour calendars, standard day

2.1.5 ASSIGN LABOUR TO ACTIVITIES

DESCRIPTION: Assign trade and number of operatives to each activity (no individual assignment to be greater than the total number of that trade's members). Assign operatives by name if known. Calculate activity durations in days based on appropriate calendar's standard day.

INPUTS: activity details, available labour, available personnel, standard day

OUTPUTS: programme activity details, labour assignment

2.1.6 INTERRELATE ACTIVITIES AND COMPUTE

DESCRIPTION: Amend contract dates if changed from tender stage. Link activities through screen bar chart using cursor control. Calculate developing network, allowing for calendar holidays and daily working hours in the evaluation of activity start and finish dates.

INPUTS: programme activity details, labour assignment, contract programme information, labour calendars

OUTPUTS: programme, earliest start dates, activity relationships

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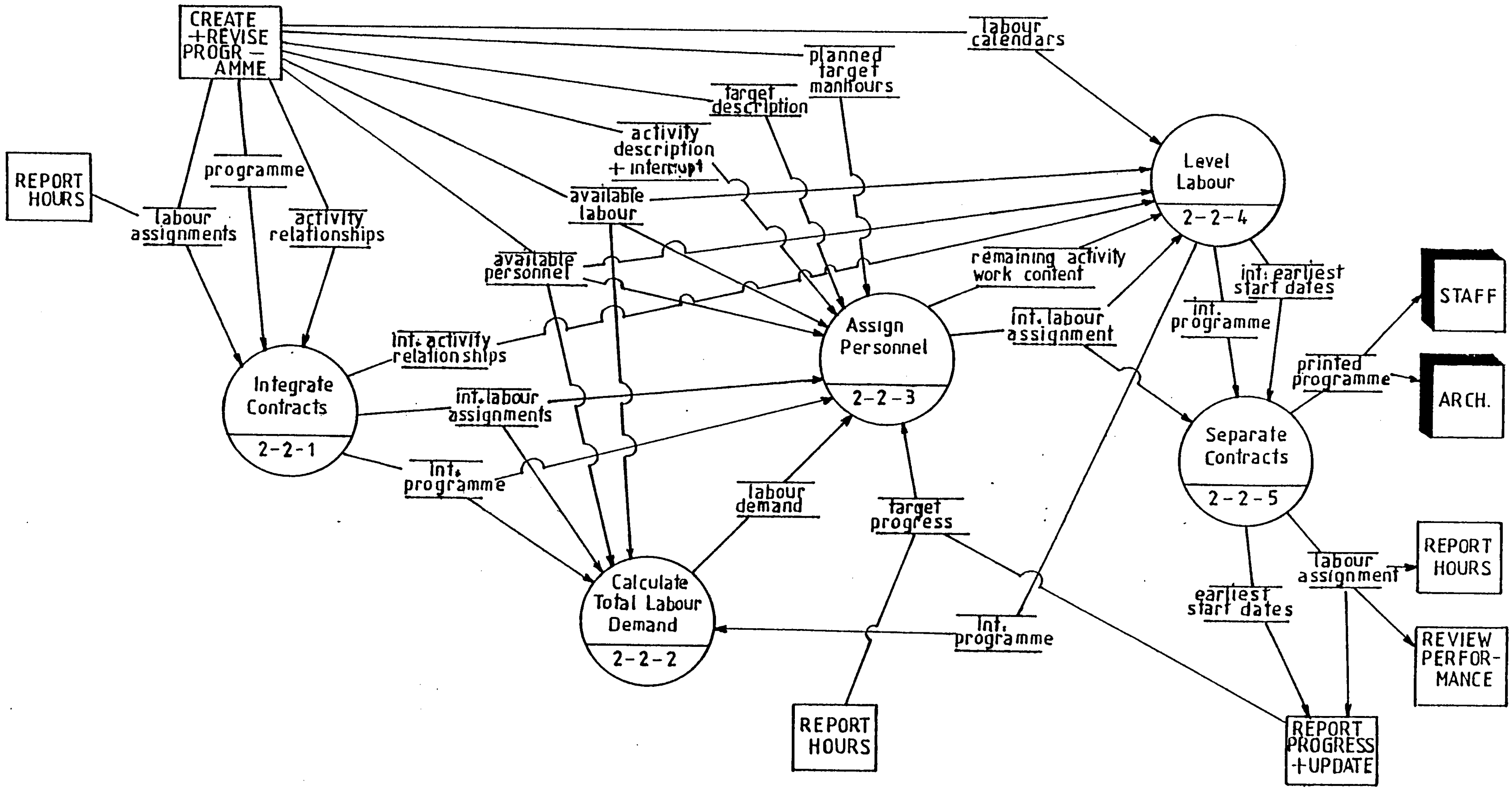

2-2. SCHEDULE LABOUR.

Figure 14.

2.2 SCHEDULE LABOUR

2.2.1 INTEGRATE CONTRACTS

DESCRIPTION: Merge individual programmes into 'multiproject schedule'.

INPUTS: programmes, labour assignments, activity relationships

OUTPUTS: integrated programmes, integrated labour assignments, integrated activity relationships

2.2.2 CALCULATE TOTAL LABOUR DEMAND

DESCRIPTION: Calculate total demand for each trade in terms of manhours per day. On request, calculate demand for individual operatives. Present information in histogram format. Show available labour limit.

INPUTS: integrated programmes, integrated labour assignments, available labour, available personnel

OUTPUTS: labour demand

2.2.3 ASSIGN PERSONNEL

DESCRIPTION: On request, list targets belonging to specific activity. Assign individual operatives and gangs to activities and update histogram to show. Calculate remaining activity manhours from progress reports for constituent targets. Amend interrupt indicators.

INPUTS: integrated programmes, activity description and interrupt, integrated labour assignment, labour demand, available labour, available personnel, target desription, target manhours, target progress

OUTPUTS: integrated labour assignments, remaining activity work content

2.2.4 LEVEL LABOUR

DESCRIPTION: Eliminate overscheduling of trades and individuals by delaying or interrupting activities according to decision rule and status of interrupt indicator. (Return to processes 2.2.2, 2.2.3 to reassign personnel if not satisfied with result).

INPUTS: remaining activity work content, integrated labour assignments, integrated activity relationships, available labour, available personnel, labour calendars

OUTPUTS: integrated programme, integrated earliest start dates

2.2.5 SEPARATE CONTRACTS

DESCRIPTION: Extract levelled individual programmes and print bar charts for distribution.

INPUTS: integrated labour assignments, integrated earliest start dates, integrated programme

OUTPUTS: labour assignments, earliest start dates, printed programme

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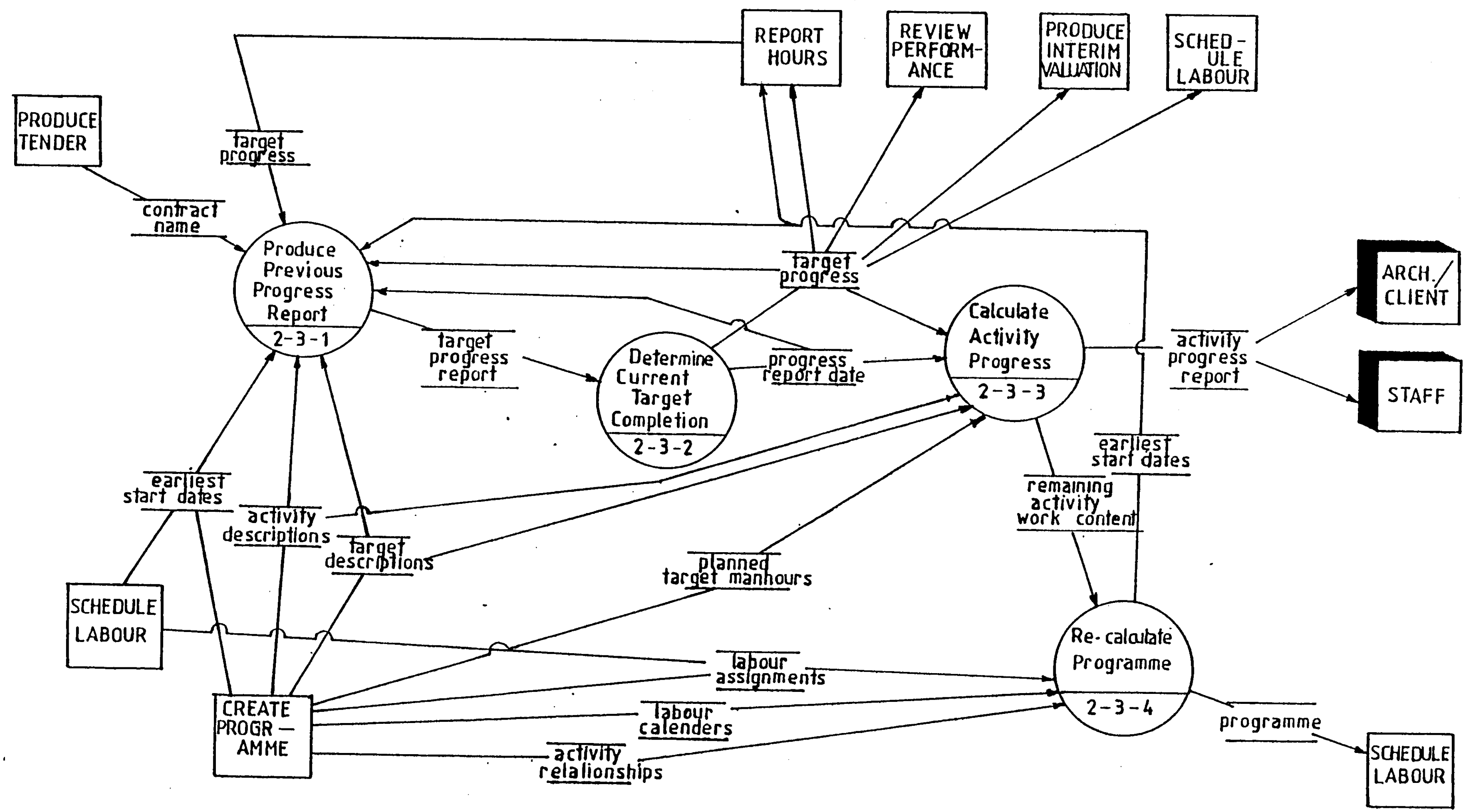


2-3. REPORT PROGRESS & UPDATE. (PROGRAMME)

Figure 15.

2.3 REPORT PROGRESS AND UPDATE

2.3.1 PRODUCE PREVIOUS PROGRESS REPORT

DESCRIPTION: Enter current date. Produce progress report listing targets under activity headings, and indicating last reported progress as a percentage. Include targets whose activities could have started according to their earliest start dates. Report date of last progress report. Print report on request.

INPUTS: contract name, activity description, target description, target progress, earliest start dates, progress report date

OUTPUTS: target progress report

2.3.2 DETERMINE CURRENT TARGET COMPLETION

DESCRIPTION: Review report and enter assessment of current target progress.

INPUTS: target progress report

OUTPUTS: target progress, progress report date

2.3.3 CALCULATE ACTIVITY PROGRESS

DESCRIPTION: Calculate progress of activities from progress of constituent targets. Estimate progress of non-target activities (eg., subcontractors). Calculate remaining activity manhours. Produce activity progress report with breakdown into targets if required.

INPUTS: target progress, progress report date, planned target manhours, target descriptions, activity descriptions

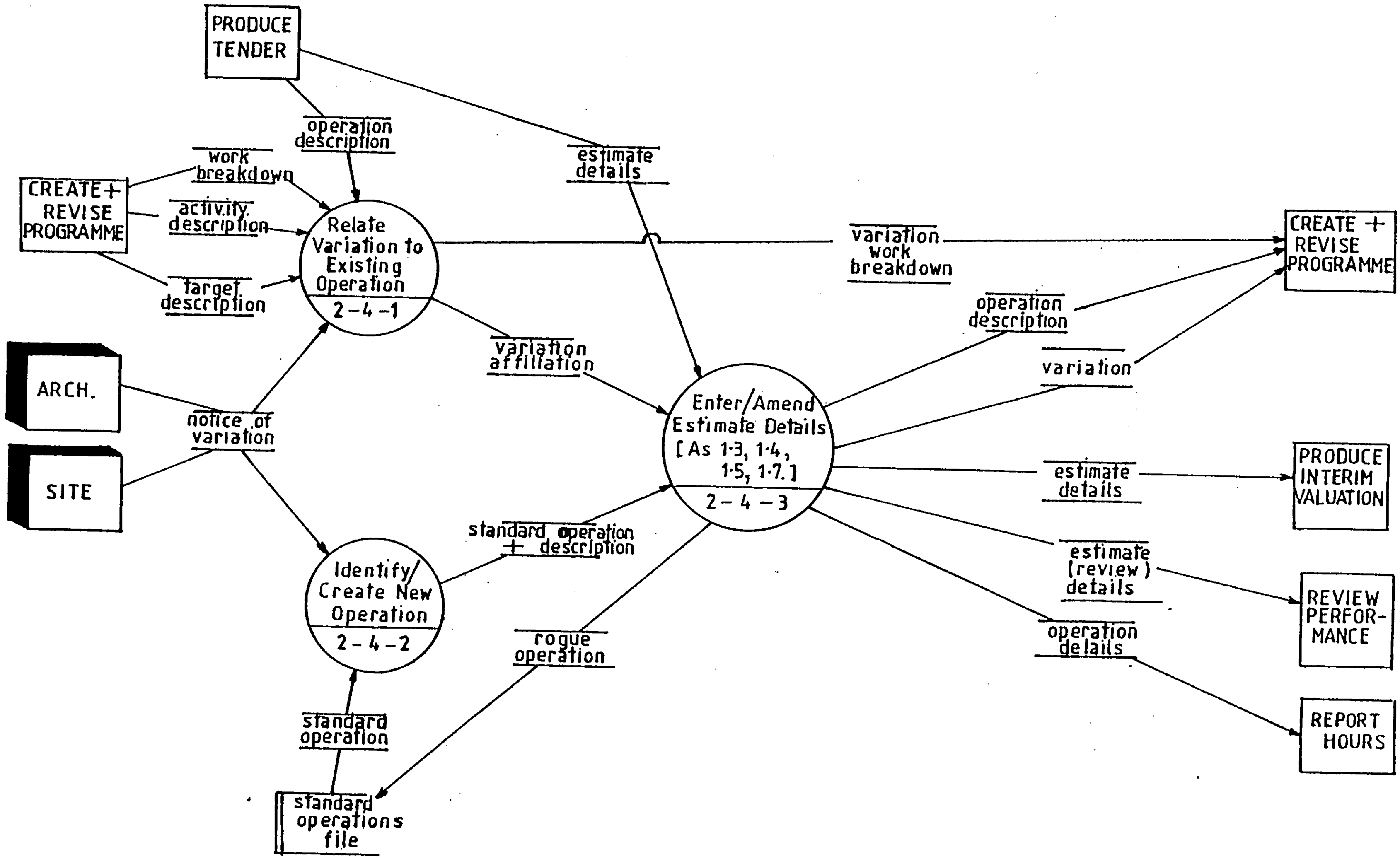
OUTPUTS: remaining activity work content, activity progress report

2.3.4 RECALCULATE PROGRAMME

DESCRIPTION: Recalculate the programme to account for progress before reentry to multiproject schedule.

INPUTS: labour assignments, remaining activity work content, labour calendars, activity relationships

OUTPUTS: programme, earliest start dates



2-4. RECORD VARIATIONS.

Figure 16.

2.4 RECORD VARIATIONS

2.4.1 RELATE VARIATION TO EXISTING OPERATION

DESCRIPTION: Review breakdown of activity to which the variation relates. If variation represents extension of scheduled operation then identify operation and assign variation the same work breakdown code.

INPUTS: notice of variation, work breakdown, activity description, target description, operation description

OUTPUTS: variation affiliation, variation work breakdown

2.4.2 IDENTIFY/CREATE NEW OPERATION

DESCRIPTION: If variation does not relate to a scheduled operation, identify appropriate standard operation from file, or create new operation.

INPUTS: notice of variation, standard operation

OUTPUTS: operation and description

2.4.3 ENTER/AMEND ESTIMATE DETAILS

DESCRIPTION: ['MEASURE OPERATION QUANTITIES', 'ADJUST/ASSIGN RATES AND COSTS', 'ADJUST/ASSIGN OUTPUTS', 'CALCULATE COSTS' (- SEE 'PRODUCE TENDER')]

INPUTS: estimate details, variation affiliation, operation and description

OUTPUTS: rogue operation, variation (operation), operation description, estimate details, estimate (review) details, operation details

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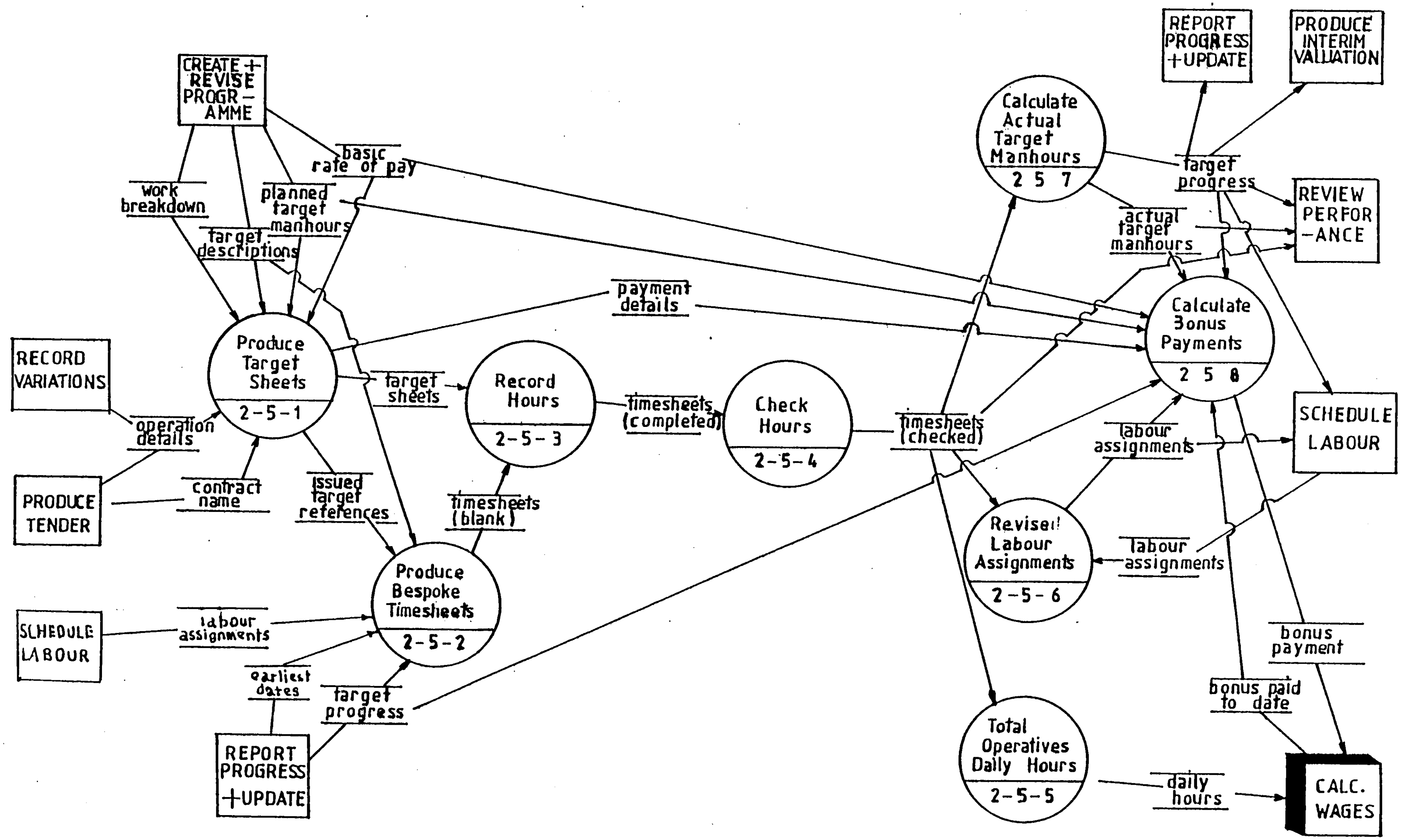


2-5. REPORT HOURS.

Figure 17.

2.5 REPORT HOURS

2.5.1 PRODUCE TARGET SHEETS

DESCRIPTION: If a pricework target, convert target manhours to a price or rate. If target is of payback type, decide and apply target factor to planned target manhours and decide payback rate. Produce extended description of target if considered necessary. Produce report listing target's constituent operations and indicating basis of payment of bonus, including price, rate or target manhours. Record issue of target.

INPUTS: contract name, work breakdown, target descriptions, planned target manhours, operation details, basic rate of pay

OUTPUTS: target sheets, payment details, issued target references

2.5.2 PRODUCE BESPOKE TIMESHEETS

DESCRIPTION: If target has been issued, or target is reported to be in progress, or earliest start date of target's activity is within a specified period from current date, then enter target description onto timesheets to be distributed to members of trade assigned to execute target.

INPUTS: issued target references, target progress, early start dates, labour assignments, target descriptions

OUTPUTS: timesheets (blank)

2.5.3 RECORD HOURS (- operatives)

DESCRIPTION: Enter hours against target descriptions for each day of the week. Note estimate of percentage completion of target at end of week. Note hours worked on any other activities, targets or unscheduled work.

INPUTS: target sheets, timesheets (blank)

OUTPUTS: timesheets (completed)

2.5.4 CHECK HOURS (- management)

DESCRIPTION: Verify hours recorded and adjust if necessary. Add estimate of target completion, if not included or if inaccurate.

INPUTS: timesheets (completed)

OUTPUTS: timesheets (checked)

2.5.5 TOTAL OPERATIVES DAILY HOURS

DESCRIPTION: Total hours to be paid by hourly rate.

INPUTS: timesheets

OUTPUTS: daily hours

2.5.6 REVISE LABOUR ASSIGNMENTS

DESCRIPTION: As hours are entered revise record of labour assignments where activity has been progressed by different operatives from those originally assigned.

INPUTS: timesheets, labour assignments

OUTPUTS: labour assignments

2.5.7 CALCULATE ACTUAL TARGET MANHOURS

DESCRIPTION: Once hours are entered (against target references) total manhours from timesheets of all those who worked on the target. Enter target progress.

INPUTS: timesheets

OUTPUTS: actual target manhours, target progress

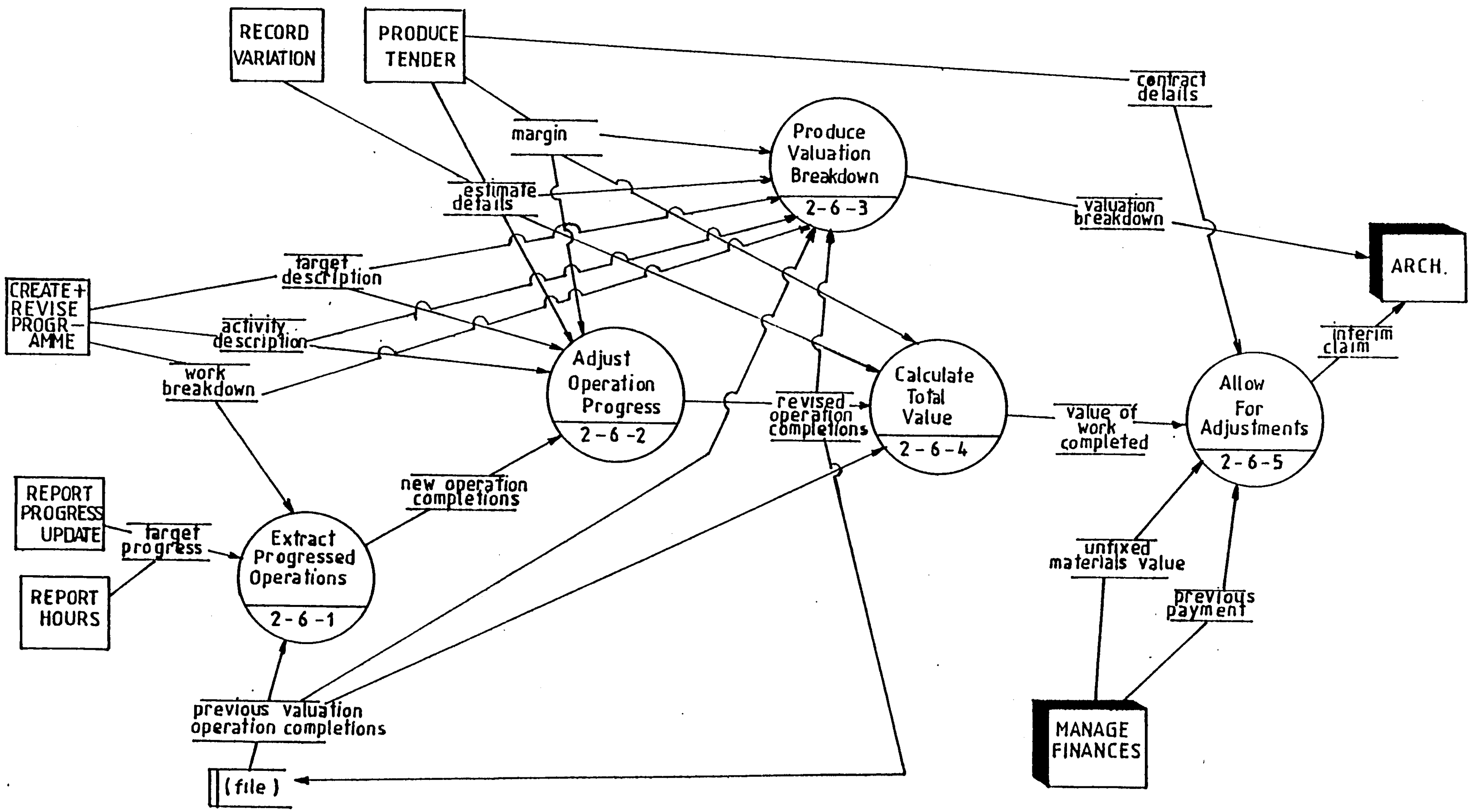
2.5.8 CALCULATE BONUS PAYMENT

DESCRIPTION: If bonus of payback type, and if target completed, multiply manhours saved by payback rate by basic rate of pay to evaluate bonus payment. Divide between members of gang who worked on target.

If bonus of pricework type, multiply percentage by price, or quantity by rate to derive bonus. Subtract previous bonus payment if appropriate.

INPUTS: planned target manhours, actual target manhours, payment details, target progress, basic rate of pay, labour assignments

OUTPUTS: bonus payment



2-6. PRODUCE INTERIM VALUATION.

Figure 18.

2.6 PRODUCE INTERIM VALUATION

2.6.1 EXTRACT PROGRESSED OPERATIONS

DESCRIPTION: Identify all operations reported to be in progress at the last valuation. Identify all those operations whose targets have been reported to be in progress.

INPUTS: previous valuation operation completion, target progress, work breakdown

OUTPUTS: new operation completions

2.6.2 ADJUST OPERATION PROGRESS

DESCRIPTION: Transfer and apply latest target completions to estimate values of comstituent operations. Accept or adjust new operation completions and values. Enter details of progress of any operation not otherwise reported.

INPUTS: new operation completions, activity description, target description, estimate details, margin

OUTPUTS: revised operation completions

2.6.3 PRODUCE VALUATION BREAKDOWN

DESCRIPTION: Dictate detail of valuation presentation. On request, calculate and list activity completions and value of work done from constituent operation details. On request, also present details of operation completions and values beneath activity heading.

INPUTS: work breakdown, activity description, target description, estimate details, margin, previous valuation operation completions, revised operation completions

OUTPUTS: valuation breakdown

2.6.4 CALCULATE TOTAL VALUE

DESCRIPTION: Total all operation values to derive value of work completed to date.

INPUTS: previous valuation operation completions, revised operation completions, estimate details, margin

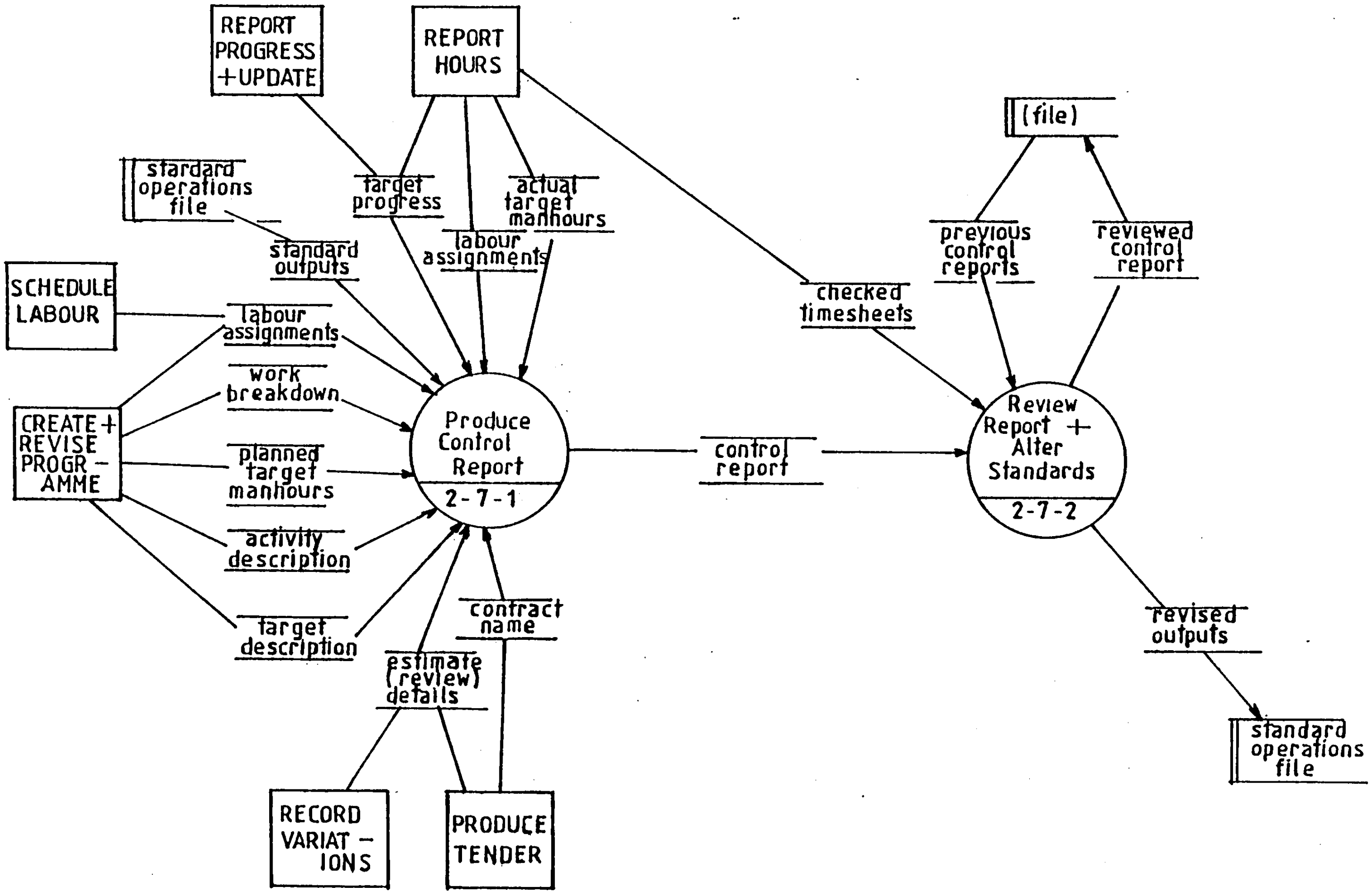
OUTPUTS: value of work completed

2.6.5 ALLOW FOR ADJUSTMENTS

DESCRIPTION: Adjust total for unfixed materials value, previous payments, retention, VAT, etc. Enter date of valuation and certificate number. Produce interim claim document and issue with accompanying breakdown.

INPUTS: value of work completed, unfixed materials value, previous payment, contract details

OUTPUTS: interim claim



2–7. REVIEW PERFORMANCE.

Figure 19.

2.7 REVIEW PERFORMANCE

2.7.1 PRODUCE CONTROL REPORT

DESCRIPTION: Calculate and present four assessments of target manhours, based on (1) standard operation outputs, (2) estimate operation outputs, (3) planned target manhours, (4) actual manhours reported. List operations for each target, including both standard and estimate outputs and manhours.

INPUTS: contract name, estimate (review) details, work breakdown, activity description, target description, planned target manhours, actual target manhours, target progress, labour assignments, standard outputs

OUTPUTS: control report

2.7.2 REVIEW REPORT AND ALTER STANDARDS

DESCRIPTION: Analyse report and agree any changes to standard rates with key management personnel. Revise standard outputs accordingly.

INPUTS: control report, previous control reports, checked timesheets

OUTPUTS: reviewed control report, revised outputs

6.3 NORMALISATION

The system was described as if it was continuous. Therefore no files appear on the diagrams unless integral to the observer's understanding of the system. In reality all the data passing between processes within the system boundary had to be stored or derived from stored data. The most efficient structure of the database that would serve the system was established after an analysis of the data structures that the processes operated on. This process is called normalisation, and involves the evolving data structures passing through three stages of simplification. A fully normalised data structure has to satisfy three conditions:

1. NO REPEATING GROUPS:- Each data element occurs only once in each record.

2. ALL NONKEY ELEMENTS ARE FULLY DEPENDENT ON THE KEY:- In the situation where a key is concatenated from two or more elements, the nonkey elements in the record must depend on the complete key, and not just on part of it.

3. NO FUNCTIONAL DEPENDENCIES BETWEEN NONKEY ELEMENTS:- There must be complete independence between the nonkey elements, such that one element does not determine another.

(For a full description of normalisation, see GANE,C.+SARSON,T.:79.)

The result of normalisation was a ten-file database structure;

STANDARD OPERATIONS FILE:

TRADE {Key}
NUMBER {Key}
STANDARD DESCRIPTION
UNIT
STANDARD OUTPUT
(STANDARD MATERIALS RATE)
(STANDARD PLANT RATE)
(STANDARD SUBCONTRACTOR COST)

ESTIMATE DETAILS FILE:

ESTIMATE REFERENCE CODE {Key}
TARGET CODE
ACTIVITY CODE
TRADE
NUMBER
DESCRIPTION
QUANTITY
OUTPUT
LABOUR RATE
[MATERIALS RATE or MATERIALS SUM]
[PLANT RATE or PLANT SUM]
[SUBCONTRACTOR RATE or SUBCONTRACTOR SUM]
COMPLETION

TARGET DETAILS:

ACTIVITY CODE {Key}
TARGET CODE {Key}
TARGET DESCRIPTION
EXTENDED TARGET DESCRIPTION
TYPE
FACTOR
PAYBACK RATE
PLANNED TARGET MANHOURS
(PRICE)
ISSUE STATUS
ACTUAL TARGET MANHOURS
PROGRESS

ACTIVITY DETAILS:

```
 ACTIVITY CODE {Key}
 ACTIVITY DESCRIPTION
 INTERRUPT INDICATOR
 START - scheduled/actual.
 FINISH - scheduled/actual.
(INTERRUPT START)
(INTERRUPT FINISH)
 EARLIEST START
[REMAINING DURATION or REMAINING WORK CONTENT]
```

ASSIGNMENT DETAILS:

```
 ACTIVITY CODE     {Key}
 TRADE             {Key}
[NAME or DEFAULT] {Key} - default indicates no. of men
 ASSIGNMENT TYPE - output contributes to completion of
                   activity manhours OR assignment is
                   for activity duration.
```

ACTIVITY RELATIONSHIPS:

```
 ACTIVITY CODE {Key}     extension of key to include
 ACTIVITY CODE {Key} -   link type allows more than one
 LINK TYPE     {Key}     link between two activities.
[LEAD or LAG]
```

LABOUR DETAILS:

```
 NAME {Key} - operative or gang, may be abbreviated
 TRADE
(CALENDAR NAME)
 BASIC RATE
```

STANDARD CALENDAR WEEK:

```
[CALENDAR NAME or TRADE] {Key} - created for every trade
 STANDARD HOURS PER DAY - mean of daily hrs if not spec.
 MONDAY HOURS AVAILABLE
 TUESDAY HOURS AVAILABLE
 WED'DAY HOURS AVAILABLE
 THURSDAY HOURS AVAILABLE
 FRIDAY HOURS AVAILABLE
 SAT'DAY HOURS AVAILABLE
 SUNDAY HOURS AVAILABLE
```

CALENDAR HOLIDAYS:

[CALENDAR NAME or TRADE] {Key}
NON-WORKING DATE {Key}

CONTRACT DETAILS:

CONTRACT REFERENCE {Key}
CONTRACT NAME
MARGIN
RETENTION
(VAT)
(CONTRACT COMMENCEMENT)
[CONTRACT COMPLETION DATE or CONTRACT PERIOD]
LATEST PROGRESS DATE
LATEST VALUATION DATE
LATEST CERTIFICATE NUMBER
LATEST PAYMENT VALUE

6.4 FEATURES OF THE NEW SYSTEM

A thorough definition of process logic, menu systems and report and screen formats was not attempted. In their absence a number of key features are described to complement a partial system specification.

6.4.1 Integration With An Existing Estimating System

The database structure that supported an estimating system developed on an earlier project was found to be an acceptable starting point for the new system (WESTGATE,S.E.86). Thus the 'STANDARD OPERATIONS' and 'ESTIMATE DETAILS' files represent an expansion of this earlier work, and data generated by the estimating system would be in a format directly compatible with the production requirements of the new system.

6.4.2 A Work Breakdown Structure

A simple three-tier breakdown structure was considered adequate for expressing the decomposition of a small firm's contracts.

ACTIVITY
↓
TARGET
↓
OPERATION

ACTIVITY: An assignment of labour to a series of targets. Linked in a network to other activities. May be interrupted (between targets) whilst the operatives are assigned to another activity of higher priority. May also be specified as a fixed duration.

TARGET: A division of the work suitable for setting as an incentive target. To be carried out by the operatives assigned to the activity of which it forms a part. It cannot be scheduled to be interrupted.

OPERATION: An estimate item, forming a part of a target.

The assembly of targets from operations is an obvious organisation of the work. The further amalgamation of targets into activities is intended to eliminate unnecessary complexity in the schedule. In repetitive construction, the same or similar target may be set for each each block, house or room, to be carried out by the same gang. As it would be tedious to individually schedule such items, they are to be collectivised.

At the outset of the contract when the division of the work into targets is not decided, this intermediary level can be ignored and the labour content of activities may be derived directly from their constituent operations. It may occasionally be the case that an activity is composed of a single operation.

The derivation of a work item's content from its origins may always be overridden by the user. Although the default is for the estimate operation to use a standard output, and for the target manhours to be calculated from the estimate, the option is always available to specify a different value from that generated.

A system of concatenated contract, activity, target and operation codes is used to express the work breakdown structure in a way that uniquely identifies each work item.

6.4.3 Labour Assignments

Labour may initially be assigned as anonymous units of a trade, e.g. 1 No. bricklayer. It may further be assigned in terms of specific individuals, e.g. 'J. Bloggs', or specific gangs e.g. 'Tom/Dick/Harry'. If the assignment is of this specific nature, the levelling procedure associated with the multiproject schedule will recognise both the individual and his trade as resources, and will schedule the assignment to suit the availability of both. The same applies to gangs if the assignment is so specified. This allows the recognition of discrete abilities within broad categories of labour. It also permits a more detailed scheduling of labour for the immediate future without having recourse to a separate short term programme. The limited size of the small firm's workforce should make the scheduling of individual operatives a practical possibility.

To permit greater flexibility in the levelling of a schedule, activities may be interrupted between targets to allow the temporary transfer of operatives to another assignment perceived to be of greater priority.

6.4.4 The Reporting Of Hours And Progress

The success of the system depends on the quality of the production information returned from site. It was particularily vital that the descriptions on the timesheets relate precisely to those in the estimate and the programme.

Where an incentive scheme is in operation, target sheets detailing the operations to be carried out are prepared and issued as the date of the target's commencement approaches. A record is made of the issue of each target. Early in the week a customised blank timesheet is produced for each trade listing all those targets which have been issued, or are reported to be in progress, or are capable of being started during the week as indicated by their earliest start dates. The latter criterion allows for the possibility of activities starting earlier than scheduled. Copies of the sheets are distributed to each member of a trade.

Against the target descriptions listed on the sheet, the operatives note the hours spent for each day of the week. Any targets not worked on are left blank. Space would be provided for details of unspecified work to be noted. At the end of the week a rough figure for the proportion of a target completed is added. These figures are then checked and amended as necessary by the foreman and/or contract manager before entry by clerical staff into the computer.

The co-operation of the workforce would be better secured if the targets were part of an incentive scheme. However the effort required of them is little more than that demanded by existing practice amongst some of the firms investigated.

Although desirable, the reporting of hours against operations was considered to be too time-consuming and inaccurate in view of their expected large number and small typical size.

A further enhancement of the system might be to personalise the timesheet. By recording the issue of a target against the individual, only these targets, and those not yet issued but to which an operative has been personally assigned, would appear on his timesheet. This would reduce the volume of irrelevant information presented on the timesheets, but at the cost of the obligation to specify individual assignments. There would be the further complexity of conveying, and if misplaced, replacing timesheets unique to an individual. The enhancement has not therefore been included, but might be considered as an option in any finalised system.

6.4.5 A Control Report

Control reports would be compiled at regular intervals, or as dictated by management. For each contract the targets completed in the preceding period are listed together with their constituent operations. Against these appear six measures of productivity:

1. STANDARD OUTPUT:- The operation output stored in the database.

2. ESTIMATED OUTPUT:- The operation output actually used in the estimate.

3. ESTIMATED HOURS:- The estimated manhours, derived from the estimated outputs and quantities, for each operation and for the whole target.

4. STANDARD MANHOURS:- As for 'estimated hours', except based on standard output rates.

5. PLANNED MANHOURS:- The target manhours used as the basis of the programme and the incentive scheme.

6. ACTUAL MANHOURS:- The actual manhours expended on a target (from timesheets).

It is anticipated that such reports would be reviewed as an item at meetings at which both chief estimator and contract manager would be in attendance. Any agreed changes to standard outputs would be noted on a copy of the report for amendment of the database by clerical staff.

6.4.6 Leads And Lags

Most leads and lags between linked activities express a physical dependency between them. A distinct proportion of the work, such as that delineated by one room, must be completed by one trade before another can start to overlay it with its own contribution. This is a lead. A proportion of a second activity cannot be undertaken until after the completion of the first. This is a lag.

The representation of a lead or lag as a fixed duration is inadequate in a context where the time taken to complete the volume of work it is supposed to represent can vary with the number of operatives assigned to that activity. In the case of a schedule which is continually being updated, it is inevitable that labour assignments will be changed with circumstances. Therefore the system has been provided with the facility to express leads and lags in terms of a percentage of overall duration, from which a time period is calculated during each recalculation of the schedule.

7 RESOURCE LEVELLING BY DECISION RULES

7.1 INTRODUCTION

The results of the few studies in decision rules which have relevance to construction, suggest that float, or some variant of float, is the most reliable indicator of an activity's precedence for resources (NUTTALL,J.F.:65, ALLAM,S.I.G.:88). The result has been a predominance of levelling facilities amongst planning software, which operate by a simple examination of float, usually total float. The few more sophisticated algorithms that have found an entry into the market are rarely published for commercial reasons. Only limited consideration has been given to the effect of the number of assigned resource units on the outcome of a decision, and of any objective of levelling other than the minimisation of total delay (GOMEZ-CHADWICK,P. & WOOTTON,A.H.:78, KURTULUS,I.:85).

Resource levelling by activity delay is one of a number of options available to the planner to solve labour overscheduling problems. Although its choice does not preclude the trial of other measures, it does imply a suspension, if only temporary, of other potential solutions, and therefore the acceptance of certain programming constraints. These are summarised by the following statements;

1. There are no further units of labour to be assigned to the workforce.

2. The trade assigned to execute a given activity

cannot be changed.

3. Resource productivity is fixed.

4. The length of each trade's workday is fixed.

5. The likelihood of an extension of the critical path is acceptable.

These are the operating conditions in which levelling by activity delay takes place. They illustrate that it will usually only be one of a series of stages of refinement through which a plan progresses in the course of its development.

7.2 THE LEVELLING DILEMMA

The fundamental problem that must be addressed by any levelling system is the selection of the correct activity or activities to delay in the alleviation of an area of overscheduling. The 'correctness' of the choice of activity is to be judged by the impact of its new position in the schedule on other activities. The direct consequences (those immediately suffered by logically succeeding activities) could be loss of float, or, if the delay were to exceed float, extension of the critical path itself. Indirectly, the delays could create new overscheduling problems further down the programme amongst activities which previously had not been competing for the same resource at the same time.

As the number of activities and the periods of overscheduling increase, the number of possible outcomes multiplies dramatically, so that at a relatively low level of project complexity it becomes unfeasible to attempt to evaluate all possible permutations, even with the aid of a computer. If competing activities cannot then be assessed as candidates for delay on the basis of the actual results of their delay, then some other, more easily computed attribute of an activity, must be used as the discriminating criteria. The evaluation and comparison of such attributes in the course of levelling can be said to be the action of a decision rule, and it is the nature of the attribute that distinguishes one rule from another. The attribute may be simple, such as 'float', or may be derived by some algorithm from a composite of increasingly discriminatory simple attributes such as a 'criticality + start date + duration' rule. The best decision rule will be the one whose activity attribute is the most reliable indicator of the benefit or otherwise of selecting a particular activity to delay, in terms of overall effect on the schedule. Measuring this benefit becomes complicated when levelling takes place in the context of the multiproject schedule.

7.3 LEVELLING A MULTIPROJECT SCHEDULE

Submitting several logically unrelated projects for integration through the process of levelling increases the complexity of the problem to be solved, but requires no changes to be made in the basic method of levelling. Each contract may be simply regarded as an independent subproject of one unifying master project. However an adjustment does have to be made to the criteria by which the performance of a levelling rule is to be judged. When only one project is to undergo levelling, all those aspects of a contract which could conceivably be affected by the process, for better or worse, (overheads, damages, continuity of work, etc.), are directly linked to the resulting duration. They therefore need not be separately accounted for, as any improvement or deterioration in their values would simply be reflecting a loss or gain in duration. In the case of multiple projects, it is the cross-project totals that are significant, and these will not move in a simple relationship with the combined total of the durations, because of inevitable differences between the projects in the rates at which these measures increase or decrease with each project's duration. Thus it is possible with rescheduling, that by the lengthening of one project's duration and the shortening of another's, although total duration may show a slight overall increase, an improvement may be achieved in some other measure of performance as a result.

For this reason there was no single criterion upon which the success or otherwise of the application of a rule could be assessed, a fact the diversity of rules tested was to reflect. Instead five indicators, each an estimate of some aspect of performance, were monitored to provide a record of the outcome of each trial. These are as follows;

1. Total Duration.
2. Total Float Loss.
3. Total Overrun of Contract Completion Dates.
4. Total Damages Scheduled to be Incurred.
5. Total Apportionable Overheads.

Although a correlation between all of these measures was to be expected, there was no direct relationship between any two of them that would invariably cause one total to move in step with another.

Underscheduling, where a trade's demand falls below the level of its availability for a period, effectively represents a programmed break in the continuity of work for one or more men, and is therefore an undesirable occurrence in any schedule. Hence a figure for a trade's unscheduled manhours would have been relevant. However, a high quota of unscheduled hours would inevitably appear in the first and last few weeks of an experimental schedule, composed only of a few staggered projects, which were disconnected from the preceding and succeeding workloads which could otherwise be expected to have absorbed such 'unassigned' labour. It was therefore impossible to fix two dates, between which to measure unassigned hours, for which any significance could be claimed. In the absence of such data the total duration of the projects can be regarded as a good indicator of the efficiency of the utilisation of available manpower over all the projects.

7.4 LEVELLING USING 'SUPERPROJECT EXPERT'

Each rule would operate by passing the results of an analysis of project data to a project management package which would then level the schedule accordingly. The manner in which the chosen package, 'Superproject Expert', levelled resource assignments therefore constituted the final stage in the execution of any decision rule being implemented, and as such had to be fully understood before the rules could be formulated. No complete description of the procedure it follows is publicly available, but by experimentation with carefully devised primitive scheduling problems, the relatively simple rationale that underlies its operation was deduced.

Starting on the first day of the first activity of the first project, the resource utilization arising from the earliest start dates is calculated for each resource until one of the specified resource limits is found to be exceeded. The activities contributing to the overscheduling at this point are then examined for their 'priorities' - previously assigned values in the range 0 - 99, and the start dates of that or those with the lowest priorities are delayed until the resource's demand falls below the limit, normally on completion of one or more of the competing higher priority activities. The schedule is then recalculated using the new start dates, and the process of resource summation and activity delay repeats once more. Thus during levelling, 'Superproject' reports to the user that it is alternately 'levelling', then 'calculating' according to whichever phase of the iteration it is going through at a particular instant.

Once all resource conflicts have been resolved, the newly levelled schedule is substituted for the old, the differences between the two being entered into the activity delay fields.

It is therefore the aim of any decision rule to arrive at a priority for each activity, based on an attribute calculated from data relating to that activity, so that subsequently 'Superproject''s choice of activities to delay in an area of conflict will lead to the optimal solution.

7.5 THE RULES - A MODULAR APPROACH

Having decided on the performance criteria, the process of defining the rules began. It was soon apparent that there would be certain stages in the calculation of priorities that would be common to more than one rule. Firstly, assigning higher priorities to critical activities than those assigned to non-critical activities was an obvious starting point for a number of rules, the two activity subsets thus formed being further subdivided by the remainder of the rule (SEE '7.6 MODULE DESCRIPTIONS', 'COMMON' MODULE X). Secondly, it was hoped that by assigning higher priorities to all those activities using a category of resource characterised by a larger number of critical manhours, that the levelling process would then resolve resource conflicts that involved more critical activities first, and thus minimise overall delay (SEE '7.6 MODULE DESCRIPTIONS', 'COMMON' MODULE Y). This was considered to be a desirable component of a number of rules to be tested. Hence a modular approach was adopted, whereby a rule was the sum effect of the execution of a sequence of procedures, each refining the priority ranking of the activities to be levelled. Not only did this use of interchangeable modules lend itself to their programming using a spreadsheet, but the subsequent development of new rules was simplified. Figure 20 indicates the composition of each rule tested.

The code that identifies each rule is thus composed of a letter followed by a number. The letter (a,b,c,d,e) denotes the combination of the two 'common' modules, that are then followed by a 'final' module denoted by the number (1 - 9). Both the type and sequence of the modules have a crucial effect on the action of a rule, as is illustrated by the following 'walk-through' of one of the rules; [PTO]

Example;

RULE **'b4'**:-

F I R S T....

COMMON MODULE Y: THOSE ACTIVITIES SHARING THE RESOURCE WHICH HAS THE GREATER NUMBER OF CRITICAL MANHOURS ASSIGNED TO IT, ARE ASSIGNED HIGHER PRIORITIES,

'b' T H E N....,

COMMON MODULE X: (amongst activities as yet undifferentiated) ASSIGN HIGHER PRIORITIES TO THE CRITICAL ACTIVITIES THAN TO THOSE WITH FLOAT,

T H E N....,

'4' **FINAL MODULE 4:** (amongst activities still undifferentiated) ASSIGN A HIGHER PRIORITY TO THE ACTIVITY WITH THE EARLIER START DATE.

RULE SERIES PREFIX →	'a'	'b'	'c'	'd'	'e'	'f'
FIRST 'COMMON' MODULE	'X' CRITICAL ACTIVITY FIRST	'Y' MOST CRITICAL RESOURCE FIRST	'X' CRITICAL ACTIVITY FIRST	'Y' MOST CRITICAL RESOURCE FIRST	(NONE)	SOFT WARE'S OWN RULE
SECOND 'COMMON' MODULE	'Y' MOST CRITICAL RESOURCE FIRST	'X' CRITICAL ACTIVITY FIRST	(NONE)	(NONE)	(NONE)	
FINAL MODULE						
1 LEAST FLOAT FIRST	a1	b1	c1	d1	e1	
2 LEAST FREE FLOAT FIRST	a2	b2	c2	d2	e2	
3 GREATEST TOTAL MANHOURS FIRST	a3	b3	c3	d3	e3	
4 EARLIEST START FIRST	a4	b4	c4	d4	e4	
5 LEAST CONTRACT FLOAT FIRST	a5	b5	c5	d5	e5	
6 GREATEST DAMAGES FIRST	a6	b6	c6	d6	e6	
7 GREATEST [MANHRS/ FLOAT] FIRST	a7	b7	c7	d7	e7	
8 GREATEST OVERHEADS FIRST	a8	b8	c8	d8	e8	
9 LEAST DURATION FIRST	a9	b9	c9	d9	e9	

Figure 20. COMPOSITION OF DECISION RULES

7.6 MODULE DESCRIPTIONS

The following are descriptions of the effect on priority of each module, together with the rationale behind them.

'COMMON' MODULE X: Critical Tasks First

DESCRIPTION: Critical activities to have higher priorities than non-critical activities.

REASON: The delay of an activity on the critical path will retard the completion date of a contract by a greater amount than the same delay of an activity with float. Therefore in the competition between two or more activities sharing the same overscheduled resource, the critical activity should possess the higher priority.

'COMMON' MODULE Y: Most Critical Resource First

DESCRIPTION: Those activities sharing a resource which has the greater number of critical manhours assigned to it, should enjoy higher priorities.

REASON: When two or more resource types happen to be overscheduled at the same time, and the rescheduling of one resource's assignments could influence the rescheduling of another, that resource whose assignments are more critical should be levelled first. Those resources whose activities on average have more float and can therefore more readily absorb any delay enforced on them by the levelling of the logically related assignments of other resources, receive lower priorities. This was an attempt to concentrate the attention of the levelling program on resolving resource conflicts in such a sequence that the logical successors to activities directly delayed by levelling would be more likely to possess float with which to absorb delay.

MODULE: 1 - Least Total Float First

DESCRIPTION: The activity with the lesser total float receives the higher priority.

REASON: Simply, the greater the float an activity possesses, the more it could afford to be delayed by the action of levelling without influencing the critical path.

MODULE: 2 - Least Free Float First

DESCRIPTION: The activity with the lesser free float receives the higher priority.

REASON: Tasks that have greater free float may be delayed for longer without reducing the total float of any succeeding activities at all, which therefore leaves the successors in a better position when it comes to levelling the resources assigned to them.

MODULE: 3 - Greatest Total Manhours First

DESCRIPTION: The activity with the greater number of manhours is assigned the higher priority.

REASON: During the levelling process an activity is delayed until a 'gap' is found in the original labour demand profile that is big enough to absorb the activity, without the resource limit being exceeded. In any irregular demand profile, the small additional demand associated with an activity of few manhours duration is more likely to be accommodated earlier than a 'larger' activity for which a free space in the demand profile would be harder to find. Hence it is probable that an activity of less manhours would have to be delayed less, with the result that the critical path is put less at risk. Furthermore, in the more common situation where resource overscheduling is only marginal, the delay of a major activity could easily over-compensate and leave a severe underscheduling problem in its wake, signifying a loss of work continuity.

MODULE: 4 - Earliest Start First

DESCRIPTION: That activity which, according to the original schedule, has the earlier start date, is assigned the higher priority.

REASON: Of the activities which contribute to a period of overscheduling, those which start towards the end of this period will need to be delayed less to relieve the problem than those starting earlier. Thus to minimise delay, early-starting activities should be allotted higher priorities.

MODULE: 5 - Least Contract Float First

DESCRIPTION: The activity which belongs to the project which has least buffer time between its earliest contract finish date, ie as computed by CPA, and the contractually binding 'official' completion date, has the higher priority.

REASON: If a higher priority is always given to the activity belonging to the contract with less contract float, then that contract is likely to suffer less delay overall than would otherwise have been the case, and hence the likelihood of an overrun of any of the contracts' completion dates is reduced as those more able to absorb delay will consequently tend to be delayed the most.

MODULE: 6 - Greatest Damages First

DESCRIPTION: The activity which belongs to the contract which has the greatest weekly damages figure set against it has the higher priority.

REASON: This rule works on the assumption that there exists a significant differential between contracts' damages rates. By assigning priorities in this way, any overrun of the 'official' completion dates, resulting either from levelling or from unforeseen circumstances during construction, is more likely to occur on contracts with less punitive penalty clauses, thereby reducing the overall figure for damages.

MODULE: 7 - Greater [Manhours-divided-by-Float] First

DESCRIPTION: Assign the higher priority to the activity for which the result of dividing the manhours by the total float (+1) is greater.

REASON: This was a simple attempt to combine the advantages of modules 1 and 3, and the arguments for each apply to the resulting module.

REASON: If a higher priority is always given to the activity belonging to the contract with less contract float, then that contract is likely to suffer less delay overall than would otherwise have been the case, and hence the likelihood of an overrun of any of the contracts' completion dates is reduced as those more able to absorb delay will consequently tend to be delayed the most.

MODULE: 6 - Greatest Damages First

DESCRIPTION: The activity which belongs to the contract which has the greatest weekly damages figure set against it has the higher priority.

REASON: This rule works on the assumption that there exists a significant differential between contracts' damages rates. By assigning priorities in this way, any overrun of the 'official' completion dates, resulting either from levelling or from unforeseen circumstances during construction, is more likely to occur on contracts with less punitive penalty clauses, thereby reducing the overall figure for damages.

MODULE: 7 - Greater [Manhours-divided-by-Float] First

DESCRIPTION: Assign the higher priority to the activity for which the result of dividing the manhours by the total float (+1) is greater.

REASON: This was a simple attempt to combine the advantages of modules 1 and 3, and the arguments for each apply to the resulting module.

MODULE: 8 - Greatest Overheads First

DESCRIPTION: The activity belonging to the contract for which the sum of the direct and the apportionable indirect overheads is the greater, receives the higher priority.

REASON: If priorities are assigned in this way, levelling delay should be reduced on those jobs with comparatively high overhead rates, tending to minimise the overall delay on these jobs. Consequently the firm's total site overheads are kept to a minimum, and in theory the fixed general overheads could be apportioned over a greater volume of work. Again this approach relies on a significant differential between contract overheads.

MODULE: 9 - Least Duration First

DESCRIPTION: The activity with the shorter duration has the higher priority.

REASON: The earliest date at which an activity being delayed by levelling can be scheduled to start can only be when the resource demand from the other activities reduces, ie when one or more of the competing activities is scheduled to finish. Hence the sooner other activities finish, the less need be the start delay of the task or activities being rescheduled. The shorter activity is assigned the higher priority, because it is more likely to finish earliest, and therefore cause less delay to the lower priority activity(s) being rescheduled.

MODULE: f - Superproject's Own Float-First Levelling Facility

DESCRIPTION: Assign higher priority to the activity with less total float. As part of the software this self-contained rule could not be combined with other modules.

REASON: The software's own optional in-built rule was the same as module 1 with the important difference that this rule made its analysis during levelling, rather than before. The floats it compared at a particular point during levelling had been recalculated to take account of the levelling that had already taken place. This placed it at a considerable advantage over the other rules.

7.7 IMPLEMENTATION AND TESTING OF THE RULES

7.7.1 'Superproject Expert' and 'Supercalc4'

'Superproject Expert' (SPJ) was used in conjunction with 'Supercalc4' (SC4), a spreadsheet package, to implement the rules on an IBM compatible PC. Each package had its own uncomplicated language in which routines or 'macros' were programmed to effect the considerable data processing involved, with the minimum keyboard input. A few simple menu screens were incorporated within the macros to speed the development of individual rules and projects. For the trials of large numbers of rules on several workloads, the system was amended to operate in a more automated fashion.

Within SPJ, the projects to be levelled were combined into a single 'holding' project, each activity remaining at its earliest start time as calculated by SPJ according to precedence. Those fields in the holding project containing the data upon which the decisions would operate were then exported in SC4 format. Once SC4 was booted, and the project data was loaded, one or all of the decision rules could then be run as spreadsheet routines producing listings of activity priorities that were then grouped and saved in project/rule-specific files. SPJ was then re-entered and each priority file was imported back into the appropriate individual project. Using the linked project facility by which a common resource base can be specified for any number of projects, whilst the independence of their networks is maintained, all the projects were simultaneously levelled as one workload. Each project's new schedule could then be saved in its entirety, or the contents of the necessary data fields could be exported to SC4 where the performance criteria described earlier could be computed and saved by macros as a compact record of the application of a given rule on a given workload. For reasons of limited storage space, and for the speed and convenience of access to the results, the latter method of recording them was adopted for the large number of test runs undertaken.

7.7.2 Test Data

The projects and resource limits that were to act as test data had to satisfy the following conditions;

(i) The data had to reflect the range and complexity of real-life scheduling problems;

(ii) The data should not contain any peculiar characteristics that would consistently favour any one rule or rules;

(iii) The task of manually tracing the action of a rule through a multiproject schedule should not be excessively laborious.

Actual project data provided by the participating firms would have been likely to have failed in respect of at least one, and possibly all three of these conditions, so instead it was decided to artificially create 'token' projects with which to experiment.

With respect to the size and number of such projects to make up a test workload, the requirements for both complexity and simplicity, stemming from conditions (i) and (iii) respectively, were of course in opposition. A suitable compromise was reached, whereby each **WORKLOAD** comprised **THREE PROJECTS** with **TWELVE ACTIVITIES** in each, to which one of **FOUR RESOURCES** was assigned.

A list of twelve activities, of likely manhours and manpower assignments, was gleaned from a study of programmes provided by the participating firms [Fig. 21].

Task ID	Number of Operatives	Total Hours
1	2	80
2	4	320
3	1	16
4	2	240
5	1	48
6	2	192
7	3	144
8	1	64
9	3	336
10	1	96
11	2	96
12	4	128

Figure 21. ACTIVITY LISTING FOR RULE TRIALS

At the same time four common network types were identified and used as a basis for the creation of projects (initially void of labour content and resource assignment) that would present different challenges to a rule by the differences in the way in which activities were related within them [Fig. 22].

To generate the number of sufficiently diverse projects needed to make up the workloads, the three components, (i) labour content (manhours, no. of men), (ii) resource type, and (iii) network position, were randomly combined using a spreadsheet to produce unique project programmes. The resource limits were set on inspection of the first workload's resource build-up, and remained fixed for the duration of the experiment. Minor and major overscheduling problems were simulated by expanding and contracting the lags between the projects' start dates for each workload. Daily overhead rates, weekly damages rates, and contract

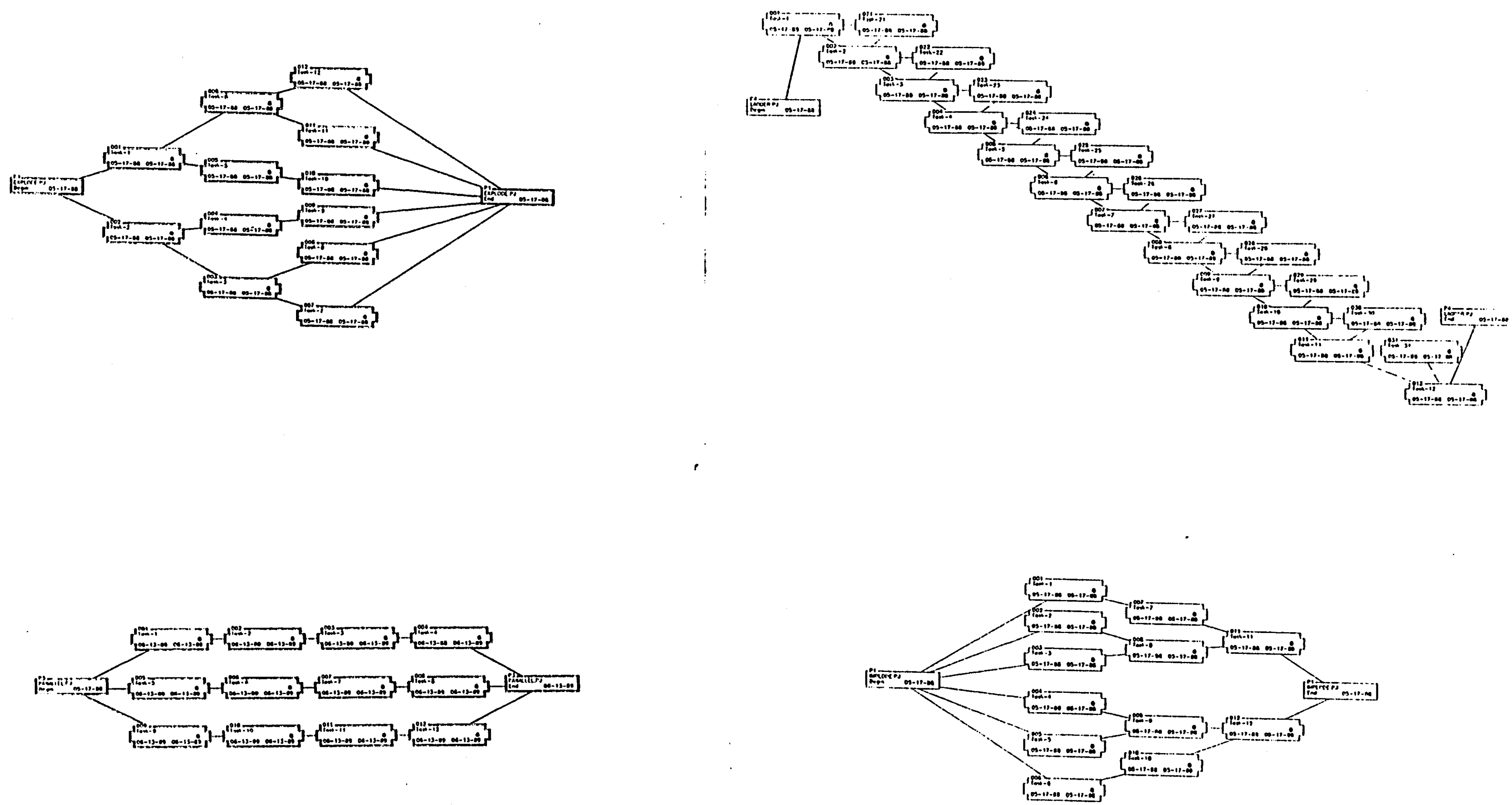


Figure 22. FOUR NETWORK TYPES

completion dates were specified as realistically as possible on a project by project basis. In this way, the multiproject schedules for an initial six workloads (W1 - W6) were generated as source data for the testing of the decision rules. [SEE Figure 23].

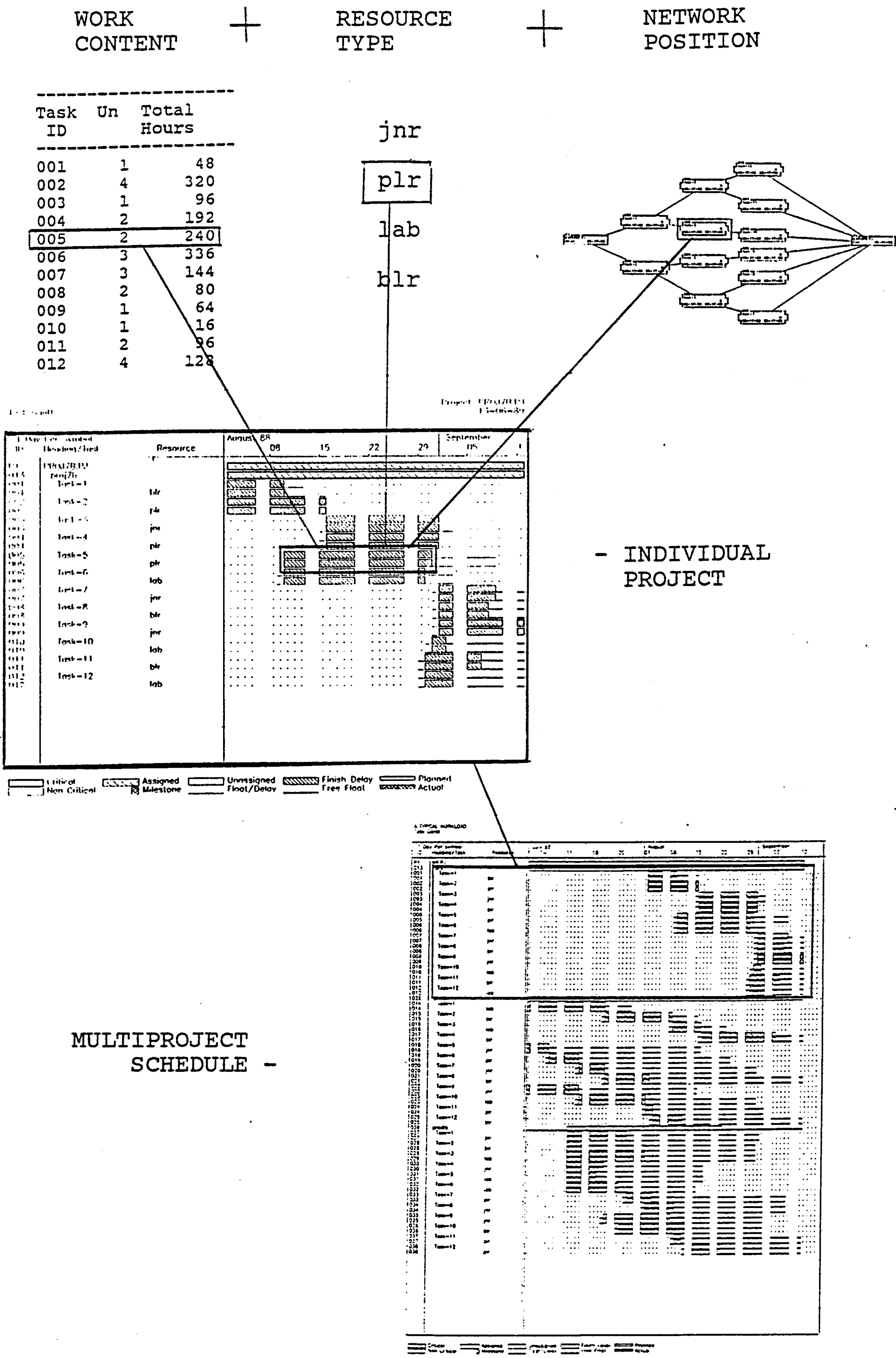


Figure 23. SCHEMATIC BUILD UP OF A WORKLOAD

8 RESULTS OF THE FIRST TRIAL

8.1 ANALYSIS AND PRESENTATION

The significance of each rule's set of results lay in its superiority/inferiority to that of every other rule. A comparative analysis of numerical results was achieved by the application of simple statistical techniques. Two complementary strategies were pursued.

8.1.1 Ranking

Figure 24 shows the impact of a rule on a typical workload, according to each criterion, for each project. The bottom line shows the workload totals.

PROJECTS	DURATION	OVERRUN	FLOAT LOSS	DAMAGES	OVERHEADS
proj4b	40 days	0 days	-82	0	3,600
proj5b	45 days	7 days	-39	4,200	1,800
proj6b	49 days	15 days	-125	4,500	980
TOTALS:	134 days	22 days	-246	8,700	6,380

Figure 24. A TYPICAL RESULT: RULE 'N1', WORKLOAD 'W6'

The totals for all the results appear in Table 1.

(Hereafter all analysis excluded the 'Float Loss' results, as their significance as a performance indicator was found to be considerably less than that of the other criteria [SEE '8.3 GENERAL FINDINGS']

Each total was then ranked to indicate a rule's performance relative to that of every other rule, for each workload. Thus for a given workload the best rule has a ranking of 1, the worst (there being 46 rules) is assigned a ranking of 46.

The bar charts in Figure 25 show the average ranking achieved by each rule for each criterion. An overall ranking for each rule is illustrated in Figure 26. As the average of the criterion rankings, this measure of overall success necessarily assumes an equal weighting for all the criteria. The results were further grouped on the basis of the five possible combinations of common modules (prefixes a - e) to provide an indication of the success or failure of each combination [Fig. 27].

RULE	DURATION	OVERRUN	FLOAT LOSS	DAMAGES	OVERHEADS
a1	148 days	1 days	-171 days	800	7,570
a2	133 days	0 days	-54 days	0	7,320
a3	209 days	56 days	-759 days	4,400	11,680
a4	189 days	37 days	-688 days	2,400	10,040
a5	148 days	1 days	-171 days	800	7,570
a6	133 days	0 days	-54 days	0	7,320
a7	205 days	50 days	-705 days	6,000	11,000
a8	171 days	25 days	-365 days	6,800	8,930
a9	133 days	0 days	-54 days	0	7,320
b1	148 days	1 days	-171 days	800	7,570
b2	133 days	0 days	-54 days	0	7,320
b3	209 days	56 days	-759 days	4,400	11,680
b4	189 days	37 days	-588 days	2,400	10,040
b5	148 days	1 days	-171 days	800	7,570
b6	133 days	0 days	-54 days	0	7,320
b7	205 days	50 days	-705 days	6,000	11,000
b8	218 days	67 days	-876 days	6,800	12,220
b9	159 days	22 days	-260 days	0	9,140
c1	148 days	1 days	-171 days	800	7,570
c2	133 days	0 days	-54 days	0	7,320
c3	209 days	56 days	-759 days	4,400	11,680
c4	189 days	37 days	-588 days	2,400	10,040
c5	148 days	1 days	-171 days	800	7,570
c6	133 days	0 days	-54 days	0	7,320
c7	205 days	50 days	-705 days	6,000	11,000
c8	171 days	25 days	-365 days	6,800	8,930
c9	133 days	0 days	-54 days	0	7,320
d1	133 days	0 days	-54 days	0	7,320
d2	148 days	1 days	-171 days	800	7,570
d3	175 days	14 days	-418 days	4,400	9,300
d4	132 days	0 days	-15 days	0	7,090
d5	148 days	1 days	-171 days	800	7,570
d6	148 days	1 days	-171 days	800	7,570
d7	209 days	56 days	-759 days	4,400	11,680
d8	223 days	99 days	-776 days	21,200	12,050
d9	133 days	0 days	-54 days	0	7,320
e1	148 days	1 days	-171 days	800	7,570
e2	133 days	0 days	-54 days	0	7,320
e3	192 days	33 days	-543 days	6,000	10,130
e4	140 days	0 days	-54 days	0	7,370
e5	148 days	1 days	-171 days	800	7,570
e6	133 days	0 days	-54 days	0	7,320
e7	205 days	50 days	-705 days	6,000	11,000
e8	170 days	38 days	-302 days	8,400	9,200
e9	133 days	0 days	-54 days	0	7,320
f	167 days	14 days	-376 days	0	9,140

Table 1(a). RESULTS FOR WORKLOAD 'W1' (1ST TRIAL)

RULE	DURATION	OVERRUN	FLOAT LOSS	DAMAGES	OVERHEADS
a1	184 days	26 days	-477 days	3,200	9,690
a2	188 days	30 days	-526 days	1,600	10,370
a3	209 days	56 days	-626 days	7,600	11,600
a4	224 days	77 days	-752 days	9,200	11,830
a5	155 days	5 days	-182 days	0	8,820
a6	155 days	5 days	-182 days	0	8,820
a7	204 days	51 days	-560 days	9,200	10,890
a8	196 days	39 days	-519 days	3,600	10,990
a9	184 days	26 days	-467 days	3,200	9,690
b1	184 days	26 days	-477 days	3,200	9,690
b2	188 days	30 days	-526 days	1,600	10,370
b3	209 days	56 days	-626 days	7,600	11,600
b4	224 days	77 days	-752 days	9,200	11,830
b5	155 days	5 days	-182 days	0	8,820
b6	155 days	5 days	-182 days	0	8,820
b7	204 days	51 days	-560 days	9,200	10,890
b8	197 days	40 days	-614 days	4,000	10,910
b9	189 days	42 days	-527 days	6,000	10,750
c1	184 days	26 days	-477 days	3,200	9,690
c2	188 days	30 days	-526 days	1,600	10,370
c3	209 days	56 days	-626 days	7,600	11,600
c4	224 days	77 days	-752 days	9,200	11,830
c5	155 days	5 days	-182 days	0	8,820
c6	155 days	5 days	-182 days	0	8,820
c7	204 days	51 days	-560 days	9,200	10,890
c8	196 days	39 days	-519 days	3,600	10,990
c9	184 days	26 days	-467 days	3,200	9,690
d1	171 days	20 days	-315 days	4,400	9,120
d2	188 days	30 days	-531 days	1,600	10,370
d3	208 days	67 days	-442 days	14,400	11,510
d4	175 days	42 days	-203 days	8,400	9,050
d5	155 days	5 days	-182 days	0	8,820
d6	178 days	13 days	-393 days	3,200	9,710
d7	209 days	56 days	-626 days	7,600	11,600
d8	248 days	111 days	-990 days	18,400	13,970
d9	208 days	55 days	-709 days	8,000	11,660
e1	184 days	26 days	-477 days	3,200	9,690
e2	188 days	30 days	-526 days	1,600	10,370
e3	235 days	98 days	-775 days	19,600	12,560
e4	175 days	42 days	-303 days	8,400	9,050
e5	155 days	5 days	-182 days	0	8,820
e6	155 days	5 days	-182 days	0	8,820
e7	204 days	51 days	-560 days	9,200	10,890
e8	184 days	56 days	-240 days	11,600	9,440
e9	178 days	13 days	-404 days	3,200	9,710
f	167 days	14 days	-251 days	3,200	8,850

Table 1(b). RESULTS FOR WORKLOAD 'W2' (1ST TRIAL)

RULE	DURATION	OVERRUN	FLOAT LOSS	DAMAGES	OVERHEADS
a1	120 days	11 days	-154 days	3,000	5,450
a2	120 days	11 days	-160 days	3,000	5,450
a3	120 days	11 days	-167 days	3,000	5,450
a4	117 days	3 days	-144 days	1,500	5,450
a5	120 days	11 days	-175 days	3,000	5,450
a6	120 days	11 days	-175 days	3,000	5,450
a7	120 days	11 days	-163 days	3,000	5,450
a8	120 days	11 days	-175 days	3,000	5,450
a9	120 days	11 days	-160 days	3,000	5,450
b1	120 days	11 days	-154 days	3,000	5,450
b2	120 days	11 days	-160 days	3,000	5,450
b3	120 days	11 days	-167 days	3,000	5,450
b4	117 days	3 days	-144 days	1,500	5,450
b5	120 days	11 days	-175 days	3,000	5,450
b6	120 days	11 days	-175 days	3,000	5,450
b7	120 days	11 days	-163 days	3,000	5,450
b8	120 days	11 days	-175 days	3,000	5,450
b9	120 days	11 days	-160 days	3,000	5,450
c1	120 days	11 days	-154 days	3,000	5,450
c2	120 days	11 days	-160 days	3,000	5,450
c3	120 days	11 days	-167 days	3,000	5,450
c4	117 days	3 days	-144 days	1,500	5,450
c5	120 days	11 days	-175 days	3,000	5,450
c6	120 days	11 days	-175 days	3,000	5,450
c7	120 days	11 days	-163 days	3,000	5,450
c8	120 days	11 days	-175 days	3,000	5,450
c9	120 days	11 days	-160 days	3,000	5,450
d1	120 days	11 days	-154 days	3,000	5,450
d2	120 days	11 days	-133 days	3,000	5,450
d3	112 days	8 days	-75 days	4,200	5,490
d4	112 days	8 days	-75 days	4,200	5,490
d5	160 days	67 days	-506 days	18,000	6,250
d6	135 days	32 days	-273 days	9,000	5,750
d7	120 days	11 days	-163 days	3,000	5,450
d8	160 days	67 days	-506 days	18,000	6,250
d9	160 days	67 days	-506 days	18,000	6,250
e1	120 days	11 days	-154 days	3,000	5,450
e2	120 days	11 days	-133 days	3,000	5,450
e3	112 days	8 days	-75 days	4,200	5,490
e4	112 days	8 days	-75 days	4,200	5,490
e5	160 days	67 days	-506 days	18,000	6,250
e6	135 days	32 days	-273 days	9,000	5,750
e7	120 days	11 days	-163 days	3,000	5,450
e8	160 days	67 days	-506 days	18,000	6,250
e9	160 days	67 days	-506 days	18,000	6,250
f	120 days	11 days	-167 days	3,000	5,450

Table 1(c). RESULTS FOR WORKLOAD 'W3' (1ST TRIAL)

RULE	DURATION	OVERRUN	FLOAT LOSS	DAMAGES	OVERHEADS
a1	152 days	59 days	-448 days	20,100	6,570
a2	167 days	80 days	-535 days	26,100	6,870
a3	124 days	19 days	-143 days	6,600	5,630
a4	134 days	22 days	-246 days	8,700	6,380
a5	147 days	52 days	-318 days	15,600	6,070
a6	147 days	52 days	-318 days	15,600	6,070
a7	132 days	31 days	-231 days	9,600	5,770
a8	167 days	80 days	-535 days	26,100	6,870
a9	167 days	80 days	-535 days	26,100	6,870
b1	152 days	59 days	-448 days	20,100	6,570
b2	167 days	80 days	-535 days	26,100	6,870
b3	124 days	19 days	-143 days	6,600	5,630
b4	134 days	22 days	-246 days	8,700	6,380
b5	147 days	52 days	-318 days	15,600	6,070
b6	147 days	52 days	-318 days	15,600	6,070
b7	132 days	31 days	-231 days	9,600	5,770
b8	167 days	80 days	-535 days	26,100	6,870
b9	167 days	80 days	-535 days	26,100	6,870
c1	152 days	59 days	-448 days	20,100	6,570
c2	167 days	80 days	-535 days	26,100	6,870
c3	124 days	19 days	-143 days	6,600	5,630
c4	134 days	22 days	-246 days	8,700	6,380
c5	147 days	52 days	-318 days	15,600	6,070
c6	147 days	52 days	-318 days	15,600	6,070
c7	132 days	31 days	-231 days	9,600	5,770
c8	167 days	80 days	-535 days	26,100	6,870
c9	167 days	80 days	-535 days	26,100	6,870
d1	152 days	59 days	-448 days	20,100	6,570
d2	167 days	80 days	-442 days	26,100	6,870
d3	163 days	65 days	-554 days	21,700	7,640
d4	131 days	29 days	-182 days	9,200	6,950
d5	137 days	41 days	-157 days	9,800	6,280
d6	137 days	41 days	-157 days	9,800	6,280
d7	132 days	31 days	-231 days	9,600	5,770
d8	173 days	88 days	-493 days	27,600	6,990
d9	153 days	51 days	-415 days	13,500	6,520
e1	152 days	59 days	-448 days	20,100	6,570
e2	167 days	80 days	-442 days	26,100	6,870
e3	163 days	65 days	-554 days	21,700	7,640
e4	131 days	29 days	-182 days	9,200	6,950
e5	137 days	41 days	-157 days	9,800	6,280
e6	137 days	41 days	-157 days	9,800	6,280
e7	132 days	31 days	-231 days	9,600	5,770
e8	173 days	88 days	-493 days	27,600	6,990
e9	153 days	51 days	-415 days	13,500	6,520
f	129 days	27 days	-215 days	8,700	5,810

Table 1(d). RESULTS FOR WORKLOAD 'W4' (1ST TRIAL)

RULE	DURATION	OVERRUN	FLOAT LOSS	DAMAGES	OVERHEADS
a1	147 days	22 days	-252 days	6,000	7,260
a2	140 days	18 days	-190 days	5,200	6,770
a3	134 days	26 days	-66 days	4,000	7,170
a4	127 days	4 days	-95 days	2,100	6,480
a5	140 days	18 days	-190 days	5,200	6,770
a6	139 days	32 days	-56 days	4,800	7,470
a7	135 days	26 days	-76 days	4,000	7,190
a8	140 days	18 days	-190 days	5,200	6,770
a9	180 days	76 days	-541 days	15,700	9,440
b1	147 days	22 days	-252 days	6,000	7,260
b2	140 days	18 days	-190 days	5,200	6,770
b3	134 days	26 days	-66 days	4,000	7,170
b4	127 days	4 days	-95 days	2,100	6,480
b5	140 days	18 days	-190 days	5,200	6,770
b6	139 days	32 days	-56 days	4,800	7,470
b7	135 days	26 days	-76 days	4,000	7,190
b8	140 days	18 days	-190 days	5,200	6,770
b9	180 days	76 days	-541 days	15,700	9,440
c1	147 days	22 days	-252 days	6,000	7,260
c2	140 days	18 days	-190 days	5,200	6,770
c3	134 days	26 days	-66 days	4,000	7,170
c4	127 days	4 days	-95 days	2,100	6,480
c5	140 days	18 days	-190 days	5,200	6,770
c6	139 days	32 days	-56 days	4,800	7,470
c7	135 days	26 days	-76 days	4,000	7,190
c8	140 days	18 days	-190 days	5,200	6,770
c9	180 days	76 days	-541 days	15,700	9,440
d1	147 days	22 days	-252 days	6,000	7,260
d2	162 days	55 days	-365 days	13,000	8,020
d3	134 days	26 days	-66 days	4,000	7,170
d4	151 days	31 days	-391 days	6,600	7,830
d5	146 days	33 days	-207 days	7,800	7,220
d6	155 days	25 days	-245 days	4,500	7,750
d7	135 days	26 days	-76 days	4,000	7,190
d8	146 days	33 days	-207 days	7,800	7,220
d9	192 days	96 days	-677 days	18,100	10,380
e1	147 days	22 days	-252 days	6,000	7,260
e2	162 days	55 days	-365 days	13,000	8,020
e3	134 days	26 days	-66 days	4,000	7,170
e4	151 days	31 days	-391 days	6,600	7,830
e5	146 days	33 days	-207 days	7,800	7,220
e6	155 days	25 days	-245 days	4,500	7,750
e7	135 days	26 days	-76 days	4,000	7,190
e8	146 days	33 days	-207 days	7,800	7,220
e9	192 days	96 days	-677 days	18,100	10,380
f	136 days	25 days	-212 days	6,500	6,840

Table 1(e). RESULTS FOR WORKLOAD 'W5' (1ST TRIAL)

RULE	DURATION	OVERRUN	FLOAT LOSS	DAMAGES	OVERHEADS
a1	161 days	40 days	-275 days	8,400	8,380
a2	160 days	31 days	-306 days	7,600	8,050
a3	159 days	28 days	-248 days	4,500	8,060
a4	133 days	3 days	-55 days	800	6,540
a5	147 days	18 days	-192 days	5,200	7,090
a6	148 days	24 days	-70 days	4,000	7,350
a7	158 days	37 days	-224 days	6,100	8,390
a8	147 days	18 days	-192 days	5,200	7,090
a9	172 days	50 days	-417 days	11,000	8,740
b1	161 days	40 days	-275 days	8,400	8,380
b2	160 days	31 days	-306 days	7,600	8,050
b3	159 days	28 days	-248 days	4,500	8,060
b4	133 days	3 days	-55 days	800	6,540
b5	147 days	18 days	-192 days	5,200	7,090
b6	148 days	24 days	-70 days	4,000	7,350
b7	158 days	37 days	-224 days	6,100	8,390
b8	147 days	18 days	-192 days	5,200	7,090
b9	172 days	50 days	-417 days	11,000	8,740
c1	161 days	40 days	-275 days	8,400	8,380
c2	160 days	31 days	-306 days	7,600	8,050
c3	159 days	28 days	-248 days	4,500	8,060
c4	133 days	3 days	-55 days	800	6,540
c5	147 days	18 days	-192 days	5,200	7,090
c6	148 days	24 days	-70 days	4,000	7,350
c7	158 days	37 days	-224 days	6,100	8,390
c8	147 days	18 days	-192 days	5,200	7,090
c9	172 days	50 days	-417 days	11,000	8,740
d1	161 days	40 days	-275 days	8,400	8,380
d2	158 days	31 days	-329 days	7,300	7,850
d3	151 days	23 days	-176 days	3,200	7,810
d4	146 days	12 days	-261 days	2,400	7,270
d5	152 days	18 days	-293 days	5,200	7,190
d6	147 days	12 days	-253 days	2,400	7,290
d7	158 days	37 days	-224 days	6,100	8,390
d8	152 days	18 days	-293 days	5,200	7,190
d9	193 days	79 days	-603 days	13,200	10,370
e1	161 days	40 days	-275 days	8,400	8,380
e2	158 days	31 days	-329 days	7,300	7,850
e3	151 days	23 days	-176 days	3,200	7,810
e4	146 days	12 days	-261 days	2,400	7,270
e5	152 days	18 days	-293 days	5,200	7,190
e6	147 days	12 days	-253 days	2,400	7,290
e7	158 days	37 days	-224 days	6,100	8,390
e8	152 days	18 days	-293 days	5,200	7,190
e9	193 days	79 days	-603 days	13,200	10,370
f	150 days	23 days	-277 days	4,500	7,750

Table 1(f). RESULTS FOR WORKLOAD 'W6' (1ST TRIAL)

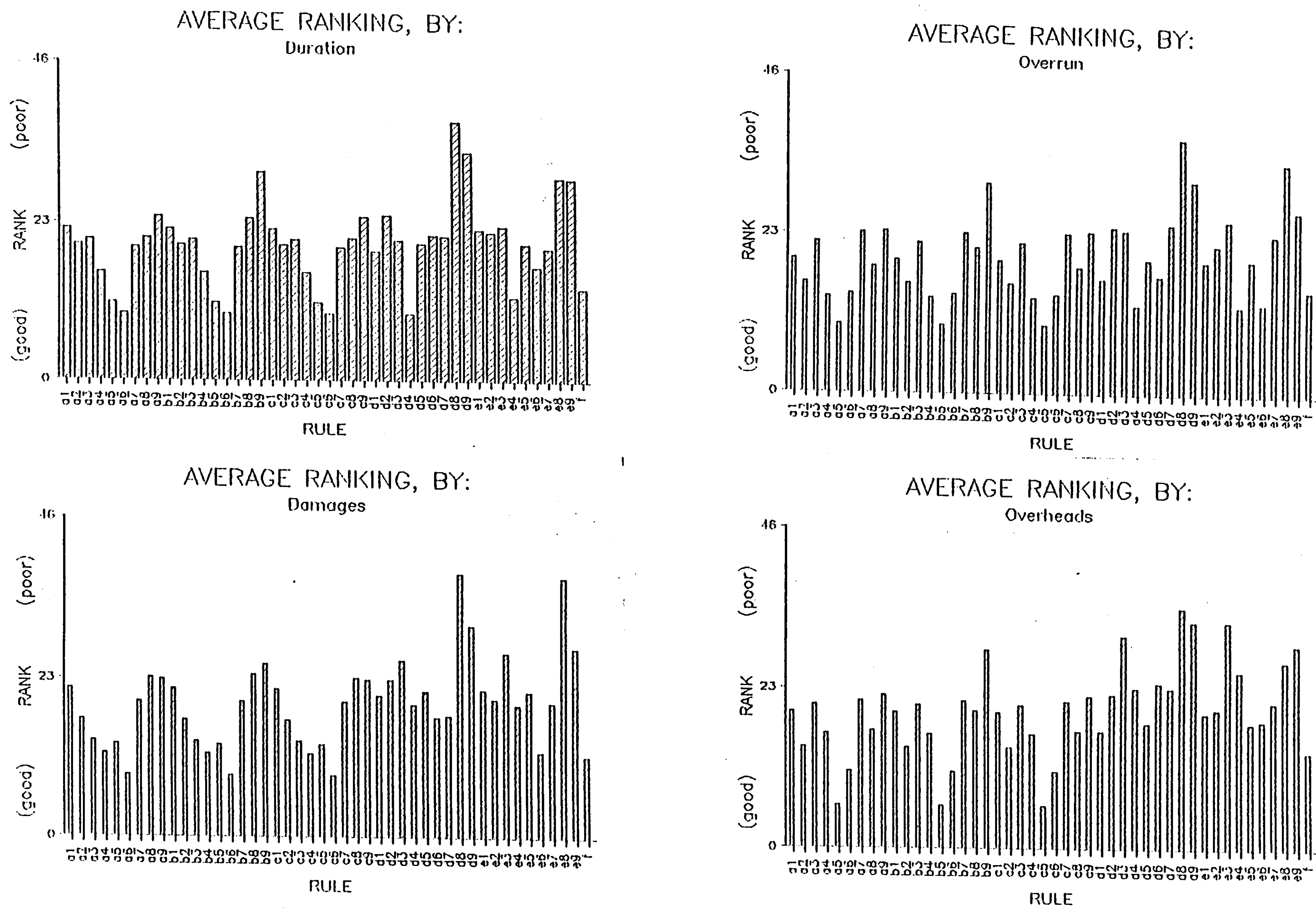


Figure 25. AVERAGE RANKING ACHIEVED BY EACH RULE FOR EACH CRITERION, AFTER FIRST TRIAL

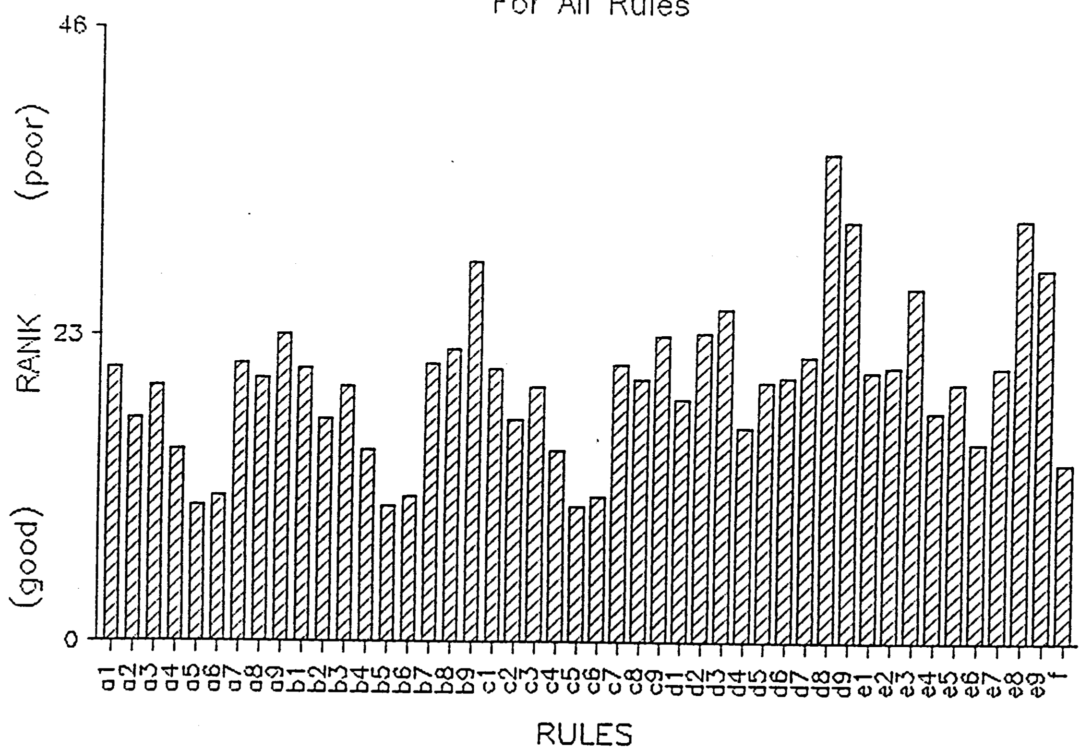


Figure 26. OVERALL RULE RANKINGS FOR ALL RULES AFTER FIRST TRIAL

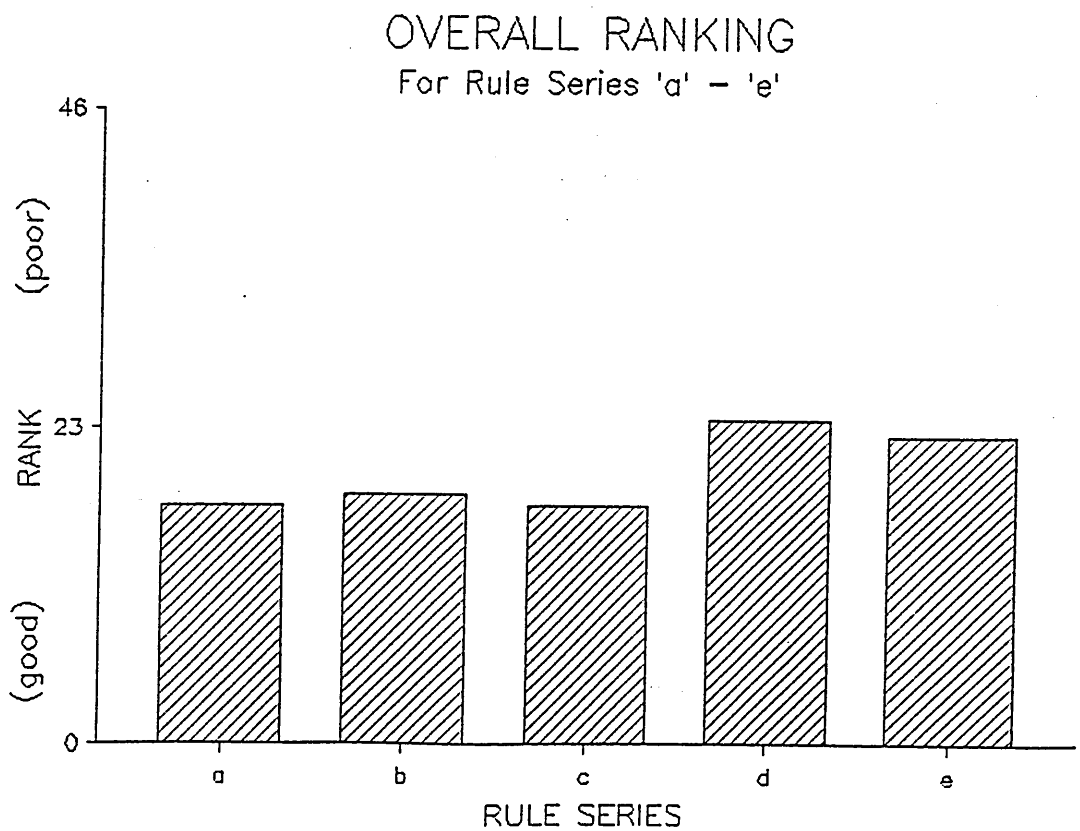


Figure 27. OVERALL RANKINGS FOR RULE SERIES AFTER FIRST TRIAL

8.1.2 Dispersion and Regression

(i) Variance Analysis;

Ranking in this way provided no measure of the variability in each rules results, and hence no measure of the significance of the differences between rules. The original unprocessed results (days of delay, cost of overheads, etc.) could not be used directly to evaluate a rule's variability, as the unlevelled workloads themselves represent problems of differing degree. They therefore introduce an element of variability into the results which is distinct, but inseparable from that which it is intended to measure. It would be incorrect, for example, to compare the projected damages for a workload whose contracts enjoyed contract completion dates that were easily met, with those for a workload with more pressing completion dates, and to then conclude that the difference between the two represented variability in the performance of the rule that levelled them. Like would not be compared with like. In statistical terms, the population from which each rule's sample is drawn varies from workload to workload.

To compensate for this it was necessary to transform the data set in some way that would render the results for one workload more comparable with those of another. A result could not be expressed as a percentage of a minimum which for some criteria, eg. damages, could take the value of zero. Another alternative of taking the maximum as a benchmark would have severely skewed the range of values created, reflecting the fact that some rules occasionally performed extremely poorly.

Instead the mean result was chosen as the base. For each workload the average of all the results obtained for each criterion was calculated, and the result achieved by each rule was then expressed as a percentage of this average. Thus, if an individual result was less than the average for the workload, its new rating would be less than 100. If it was more than the average, the rating would be greater than 100.

The individual results were combined to derive each rule's mean rating and standard deviation on each criterion according to formulae 1 and 2;

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad (1)$$

$$S = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1} \qquad (2)$$

where $\bar{x}$ = sample mean
n = no. of results
S = sample standard deviation

As, there being only six workloads, the sample size (n) was less than 30, and as the population standard deviation (S) was unknown, the t-distribution was considered appropriate to further analysis (BLAND,J.A.:85). Thus, assuming an infinite population, the 95% confidence limits for each rule's criteria mean were evaluated by formula 3;

$$u = \bar{x} +/- t_c \frac{S}{\sqrt{n}} \qquad (3)$$

where u = population mean
t_c is taken from tables

These results appear in Table 2.

To test for significant differences between rules, the null hypothesis was formulated;

$$Ho : Ua = Ub$$

where Ua = mean of pop.(a)
Ub = mean of pop.(b)

Neither of the standard deviations of the populations under test were known, nor could be assumed to be equal. This necessitated the adoption of formula 4 for the calculation of 'T', and formula 5 for the calculation of the no. of degrees of freedom (f), with which to look up 'tf' (BETHEA,R.M.+DURAN,B.S.+BOULLION,T.L.:85).

$$T = \frac{x_1 - x_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \tag{4}$$

$$f = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\frac{\left(\frac{S_1^2}{n_1}\right)^2}{n_1-1} + \frac{\left(\frac{S_2^2}{n_2}\right)^2}{n_2-1}} \tag{5}$$

A two-tailed test was performed on every pair of rules, because either mean could be greater than the other, and the 95% confidence level was adhered to, giving a value for p of 0.975. Thus, in all, 46*45 = 2070 tests were carried out for each criterion.

If T was found to be greater than the modulus of tf, the null hypothesis was rejected and at the chosen confidence level it can be said that there was a significant difference between the two rule means under test. All instances of such significant differences are recorded in the charts contained in Figures 28 (i) - (iv).

(ii) Correlation With Duration;

Correlations between duration and the other criteria were bound to exist, but their strengths were unknown. If they were found to be very close then it could be argued that the emphasis of a rule should be entirely on minimising duration, success on other criteria being the natural consequence of success in this primary objective. Hence for each criterion, every result (after processing as above) was paired with its associated duration, and used to compute a correlation coefficient - a measure of the strength of a linear relationship - using equations 6 - 9 (BLAND,J.A.:85);

$$r = \frac{Sxy}{\sqrt{SxxSyy}} \qquad (6)$$

$$\text{where } Sxx = \sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n} \qquad (7)$$

$$Syy = \sum_{i=1}^{n} y_i^2 - \frac{\left(\sum_{i=1}^{n} y_i\right)^2}{n} \qquad (8)$$

$$Sxy = \sum_{i=1}^{n} x_i y_i - \frac{\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n} \qquad (9)$$

where x,y are paired results
n = no. of pairings

The closer r is to 1, the stronger is the relationship. [SEE Figure 29].

MEAN RATINGS AND DISPERSION

DURATION

RULE	Mean	SD	95% Conf Lmts	(min)	(max)
a1	98	4.4	+/- 4.6	93.4	102.6
a2	97.7	9.3	+/- 9.8	87.9	107.5
a3	101.7	14.5	+/- 15.2	86.5	116.9
a4	97.8	13.5	+/- 14.2	83.6	112
a5	92.7	5.5	+/- 5.8	86.9	98.5
a6	91.3	7.1	+/- 7.4	83.9	98.7
a7	101.7	12.2	+/- 12.8	88.9	114.5
a8	100.8	6.4	+/- 6.7	94.1	107.5
a9	103.2	13.5	+/- 14.2	89	117.4
b1	98	4.4	+/- 4.6	93.4	102.6
b2	97.7	9.3	+/- 9.8	87.9	107.5
b3	101.7	14.5	+/- 15.2	86.5	116.9
b4	97.8	13.5	+/- 14.2	83.6	112
b5	92.7	5.5	+/- 5.8	86.9	98.5
b6	91.3	7.1	+/- 7.4	83.9	98.7
b7	101.7	12.2	+/- 12.8	88.9	114.5
b8	105.7	13.7	+/- 14.4	91.3	120.1
b9	106.3	9.6	+/- 10.1	96.2	116.4
c1	98	4.4	+/- 4.6	93.4	102.6
c2	97.7	9.3	+/- 9.8	87.9	107.5
c3	101.7	14.5	+/- 15.2	86.5	116.9
c4	97.8	13.5	+/- 14.2	83.6	112
c5	92.7	5.5	+/- 5.8	86.9	98.5
c6	91.3	7.1	+/- 7.4	83.9	98.7
c7	101.7	12.2	+/- 12.8	88.9	114.5
c8	100.8	6.4	+/- 6.7	94.1	107.5
c9	103.2	13.5	+/- 14.2	89	117.4
d1	95.3	7.7	+/- 8.1	87.2	103.4
d2	101.3	7.7	+/- 8.1	93.2	109.4
d3	100.5	8.6	+/- 9.0	91.5	109.5
d4	91	6.9	+/- 7.2	83.8	98.2
d5	98	14.5	+/- 15.2	82.8	113.2
d6	97.3	7	+/- 7.3	90	104.6
d7	102.5	13.4	+/- 14.1	88.4	116.6
d8	117.8	15.3	+/- 16.1	101.7	133.9
d9	112.8	17.3	+/- 18.2	94.6	131
e1	98	4.4	+/- 4.6	93.4	102.6
e2	99.8	10.2	+/- 10.7	89.1	110.5
e3	104.5	13.1	+/- 13.7	90.8	118.2
e4	91.8	5.8	+/- 6.1	85.7	97.9
e5	98	14.5	+/- 15.2	82.8	113.2
e6	93.8	10.5	+/- 11.0	82.8	104.8
e7	101.7	12.2	+/- 12.8	88.9	114.5
e8	106.8	11.5	+/- 12.1	94.7	118.9
e9	110.2	18.7	+/- 19.6	90.6	129.8
f	93.5	5.3	+/- 5.6	87.9	99.1

Table 2(a). MEAN RATINGS, AND DISPERSIONS
EVALUATED FOR: Duration

OVERRUN

RULE	Mean	SD	95% Conf Lmts	(min)	(max)
a1	76	42.4	+/- 44.5	31.5	120.5
a2	76	46.7	+/- 49.0	27	125
a3	119.7	84.5	+/- 88.7	31	208.4
a4	79.8	85.7	+/- 89.9	-10.1	169.7
a5	49.2	31.6	+/- 33.2	16	82.4
a6	59.3	40	+/- 42.0	17.3	101.3
a7	121	69.4	+/- 72.8	48.2	193.8
a8	94.2	37	+/- 38.8	55.4	133
a9	116.2	81	+/- 85.0	31.2	201.2
b1	76	42.4	+/- 44.5	31.5	120.5
b2	76	46.7	+/- 49.0	27	125
b3	119.7	84.5	+/- 88.7	31	208.4
b4	79.8	85.7	+/- 89.9	-10.1	169.7
b5	49.2	31.6	+/- 33.2	16	82.4
b6	59.3	40	+/- 42.0	17.3	101.3
b7	121	69.4	+/- 72.8	48.2	193.8
b8	131.2	103.1	+/- 108.2	23	239.4
b9	142.3	57.3	+/- 60.1	82.2	202.4
c1	76	42.4	+/- 44.5	31.5	120.5
c2	76	46.7	+/- 49.0	27	125
c3	119.7	84.5	+/- 88.7	31	208.4
c4	79.8	85.7	+/- 89.9	-10.1	169.7
c5	49.2	31.6	+/- 33.2	16	82.4
c6	59.3	40	+/- 42.0	17.3	101.3
c7	121	69.4	+/- 72.8	48.2	193.8
c8	94.2	37	+/- 38.8	55.4	133
c9	116.2	81	+/- 85.0	31.2	201.2
d1	72.5	44.5	+/- 46.7	25.8	119.2
d2	96.5	56.7	+/- 59.5	37	156
d3	97	44.3	+/- 46.5	50.5	143.5
d4	58.7	37.8	+/- 39.7	19	98.4
d5	104.3	120.8	+/- 126.7	-22.4	231
d6	68.5	53.2	+/- 55.8	12.7	124.3
d7	128.5	80.4	+/- 84.4	44.1	212.9
d8	252.2	157.2	+/- 164.9	87.3	417.1
d9	198.3	127.3	+/- 133.6	64.7	331.9
e1	76	42.4	+/- 44.5	31.5	120.5
e2	95.7	58.1	+/- 61.0	34.7	156.7
e3	127.5	73.3	+/- 76.9	50.6	204.4
e4	58.7	37.8	+/- 39.7	19	98.4
e5	104.3	120.8	+/- 126.7	-22.4	231
e6	64	56.9	+/- 59.7	4.3	123.7
e7	121	69.4	+/- 72.8	48.2	193.8
e8	174.3	94.8	+/- 99.5	74.8	273.8
e9	179.5	141	+/- 147.9	31.6	327.4
f	63	15.6	+/- 16.4	46.6	79.4

Table 2(b). MEAN RATINGS, AND DISPERSIONS
EVALUATED FOR: Overrun

DAMAGES

RULE	Mean	SD	95% Conf Lmts	(min)	(max)
a1	83.3	38.5	+/- 40.4	42.9	123.7
a2	74.8	53.9	+/- 56.6	18.2	131.4
a3	91	48.9	+/- 51.3	39.7	142.3
a4	65.2	54.9	+/- 57.6	7.6	122.8
a5	57.7	33.1	+/- 34.7	23	92.4
a6	48.2	35.7	+/- 37.5	10.7	85.7
a7	114	67.6	+/- 70.9	43.1	184.9
a8	118.5	72.9	+/- 76.5	42	195
a9	115.8	82.5	+/- 86.6	29.2	202.4
b1	83.3	38.5	+/- 40.4	42.9	123.7
b2	74.8	53.9	+/- 56.6	18.2	131.4
b3	91	48.9	+/- 51.3	39.7	142.3
b4	65.2	54.9	+/- 57.6	7.6	122.8
b5	57.7	33.1	+/- 34.7	23	92.4
b6	48.2	35.7	+/- 37.5	10.7	85.7
b7	114	67.6	+/- 70.9	43.1	184.9
b8	119.8	72	+/- 75.5	44.3	195.3
b9	124.8	78.8	+/- 82.7	42.1	207.5
c1	83.3	38.5	+/- 40.4	42.9	123.7
c2	74.8	53.9	+/- 56.6	18.2	131.4
c3	91	48.9	+/- 51.3	39.7	142.3
c4	65.2	54.9	+/- 57.6	7.6	122.8
c5	57.7	33.1	+/- 34.7	23	92.4
c6	48.2	35.7	+/- 37.5	10.7	85.7
c7	114	67.6	+/- 70.9	43.1	184.9
c8	118.5	72.9	+/- 76.5	42	195
c9	115.8	82.5	+/- 86.6	29.2	202.4
d1	82	45.8	+/- 48.1	33.9	130.1
d2	98.7	63.3	+/- 66.4	32.3	165.1
d3	127.8	76.8	+/- 80.6	47.2	208.4
d4	72	49.7	+/- 52.1	19.9	124.1
d5	106.2	112.7	+/- 118.2	-12	224.4
d6	71.3	46.7	+/- 49.0	22.3	120.3
d7	98.7	45.4	+/- 47.6	51.1	146.3
d8	314.7	250.6	+/- 262.9	51.8	577.6
d9	178.7	115.7	+/- 121.4	57.3	300.1
e1	83.3	38.5	+/- 40.4	42.9	123.7
e2	93.5	69.6	+/- 73.0	20.5	166.5
e3	154.7	114.6	+/- 120.2	34.5	274.9
e4	72	49.7	+/- 52.1	19.9	124.1
e5	106.2	112.7	+/- 118.2	-12	224.4
e6	56.2	57.9	+/- 60.7	-4.5	116.9
e7	114	67.6	+/- 70.9	43.1	184.9
e8	210	97.9	+/- 102.7	107.3	312.7
e9	163.3	124.1	+/- 130.2	33.1	293.5
f	57	29.6	+/- 31.1	25.9	88.1

Table 2(c). MEAN RATINGS, AND DISPERSIONS
EVALUATED FOR: Damages

OVERHEADS

RULE	Mean	SD	95% Conf Lmts	(min)	(max)
a1	96.8	6.1	+/- 6.4	90.4	103.2
a2	96.3	7.7	+/- 8.1	88.2	104.4
a3	104.5	14.8	+/- 15.5	89	120
a4	98.8	12.3	+/- 12.9	85.9	111.7
a5	90.3	4.2	+/- 4.4	85.9	94.7
a6	92	6.1	+/- 6.4	85.6	98.4
a7	103.2	11.4	+/- 12.0	91.2	115.2
a8	98.3	6.6	+/- 6.9	91.4	105.2
a9	102.8	13.7	+/- 14.4	88.4	117.2
b1	96.8	6.1	+/- 6.4	90.4	103.2
b2	96.3	7.7	+/- 8.1	88.2	104.4
b3	104.5	14.8	+/- 15.5	89	120
b4	98.8	12.3	+/- 12.9	85.9	111.7
b5	90.3	4.2	+/- 4.4	85.9	94.7
b6	92	6.1	+/- 6.4	85.6	98.4
b7	103.2	11.4	+/- 12.0	91.2	115.2
b8	104.7	16.7	+/- 17.5	87.2	122.2
b9	108	9	+/- 9.4	98.6	117.4
c1	96.8	6.1	+/- 6.4	90.4	103.2
c2	96.3	7.7	+/- 8.1	88.2	104.4
c3	104.5	14.8	+/- 15.5	89	120
c4	98.8	12.3	+/- 12.9	85.9	111.7
c5	90.3	4.2	+/- 4.4	85.9	94.7
c6	92	6.1	+/- 6.4	85.6	98.4
c7	103.2	11.4	+/- 12.0	91.2	115.2
c8	98.3	6.6	+/- 6.9	91.4	105.2
c9	102.8	13.7	+/- 14.4	88.4	117.2
d1	95.3	7.7	+/- 8.1	87.2	103.4
d2	99.3	6.9	+/- 7.2	92.1	106.5
d3	104.7	7.9	+/- 8.3	96.4	113
d4	94.8	9.6	+/- 10.1	84.7	104.9
d5	94.5	9	+/- 9.4	85.1	103.9
d6	96	5.9	+/- 6.2	89.8	102.2
d7	105.7	14.3	+/- 15.0	90.7	120.7
d8	113.2	17.6	+/- 18.5	94.7	131.7
d9	113.3	18.6	+/- 19.5	93.8	132.8
e1	96.8	6.1	+/- 6.4	90.4	103.2
e2	98.8	7.9	+/- 8.3	90.5	107.1
e3	108	10.6	+/- 11.1	96.9	119.1
e4	95.5	8.6	+/- 9.0	86.5	104.5
e5	94.5	9	+/- 9.4	85.1	103.9
e6	94	7.9	+/- 8.3	85.7	102.3
e7	103.2	11.4	+/- 12.0	91.2	115.2
e8	100.5	8.3	+/- 8.7	91.8	109.2
e9	110.2	20	+/- 21.0	89.2	131.2
f	94.3	6	+/- 6.3	88	100.6

Table 2(d). MEAN RATINGS, AND DISPERSIONS EVALUATED FOR: Overheads

+ SIGNIFICANTLY BETTER

- SIGNIFICANTLY WORSE

Example;

a6 [+] d8

+ a6 performed better than d8 at 95% confidence level.

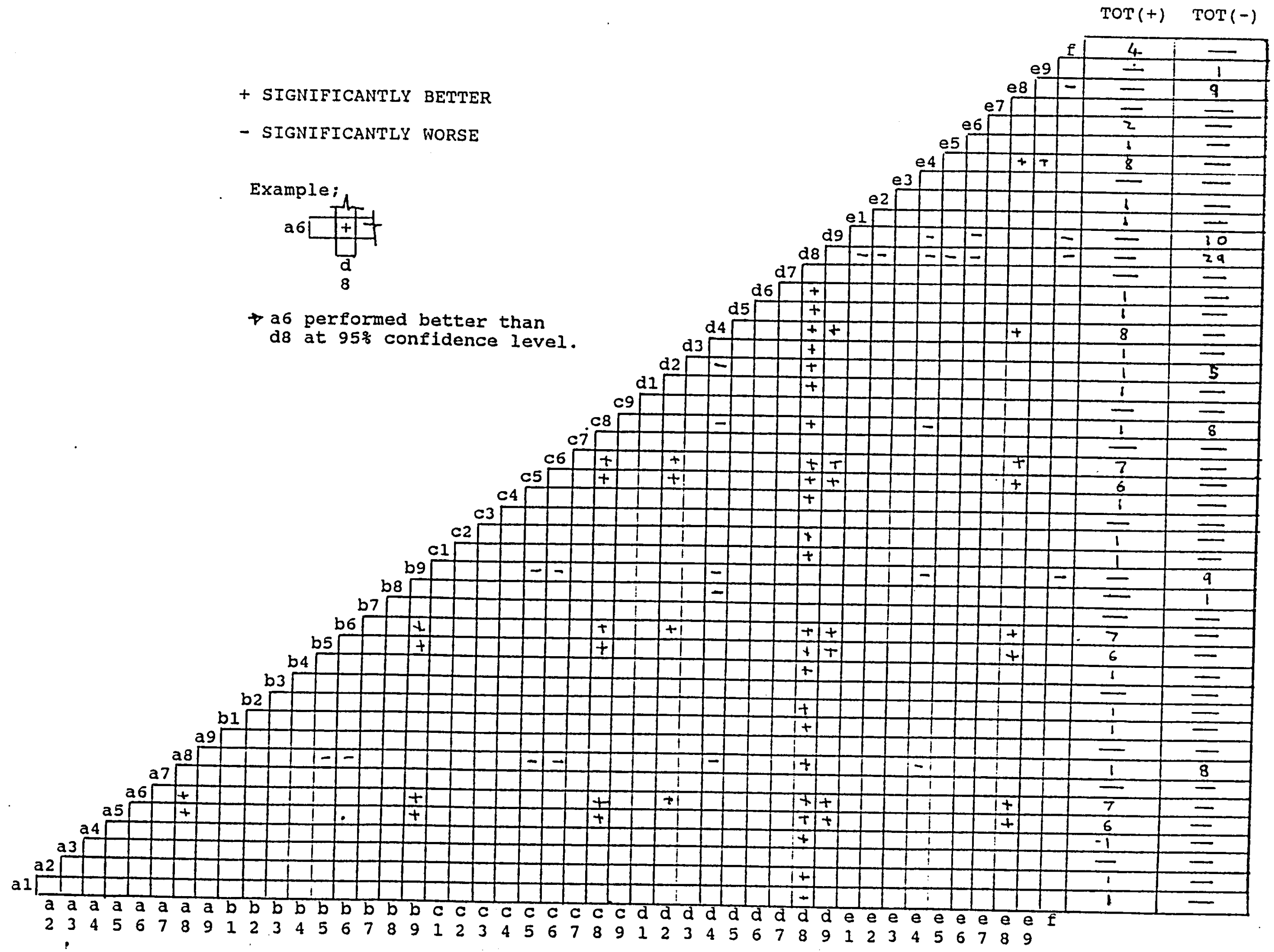


Figure 28 (i). SIGNIFICANT DIFFERENCES BETWEEN RULES ACCORDING TO: DURATION

(AFTER FIRST TRIAL)

+ SIGNIFICANTLY BETTER

- SIGNIFICANTLY WORSE

Example;

→ a6 performed better than d8 at 95% confidence level.

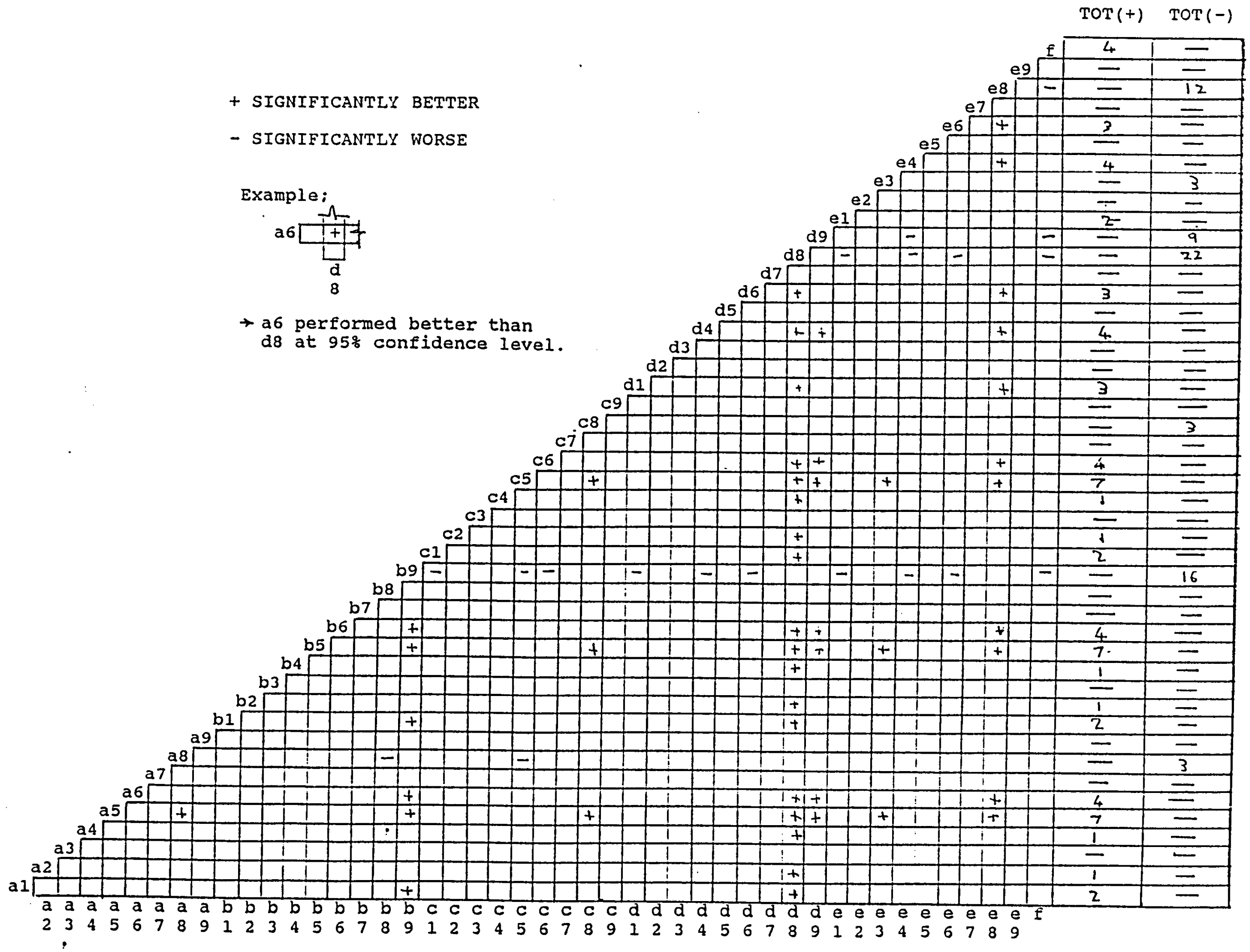


Figure 28 (ii). SIGNIFICANT DIFFERENCES BETWEEN RULES ACCORDING TO: Overrun

(AFTER FIRST TRIAL)

+ SIGNIFICANTLY BETTER

- SIGNIFICANTLY WORSE

Example;

→ a6 performed better than d8 at 95% confidence level.

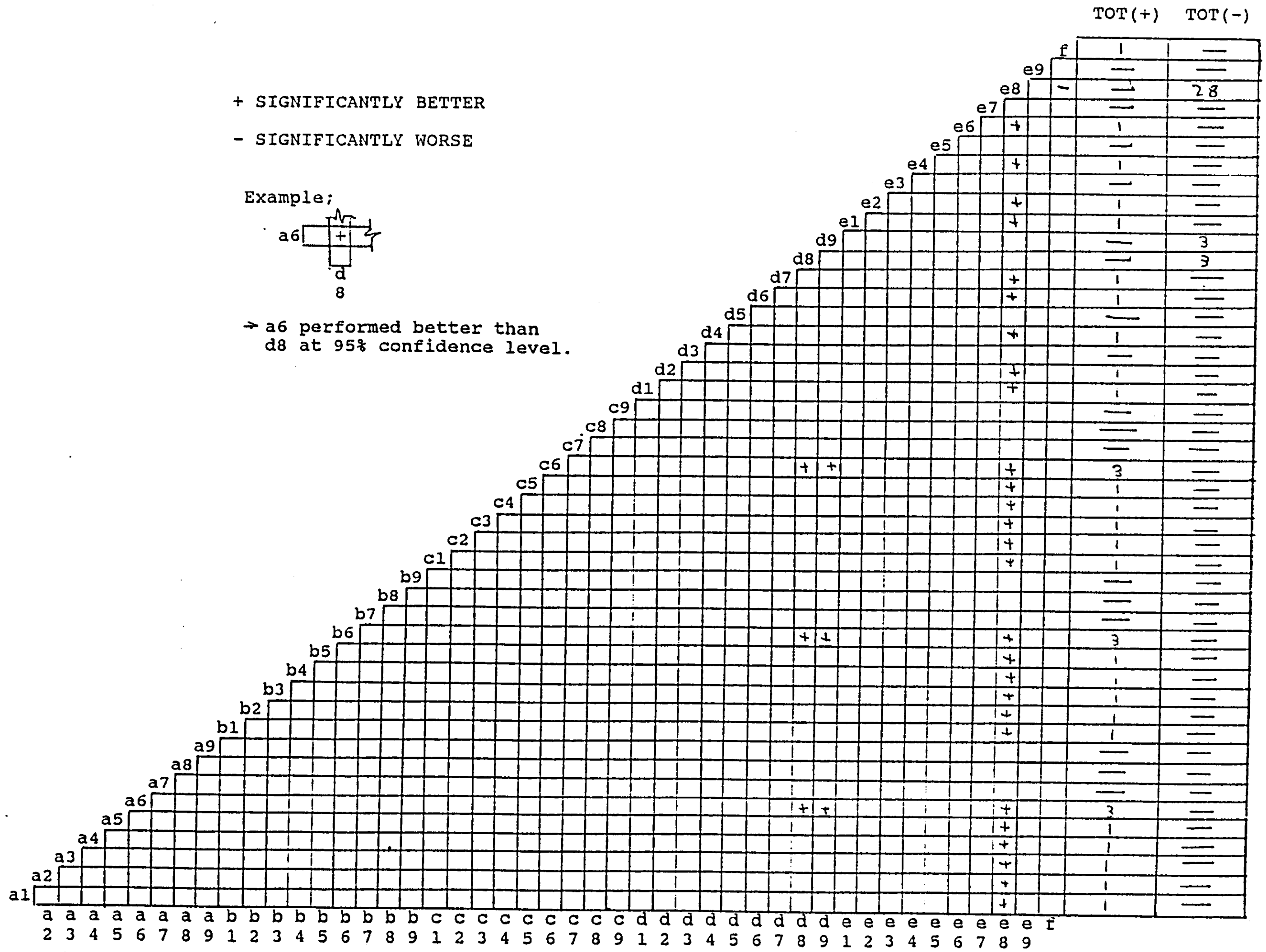


Figure 28 (iii). SIGNIFICANT DIFFERENCES BETWEEN RULES ACCORDING TO: DAMAGES

(AFTER FIRST TRIAL)

+ SIGNIFICANTLY BETTER

- SIGNIFICANTLY WORSE

Example;

+ a6 performed better than d8 at 95% confidence level.

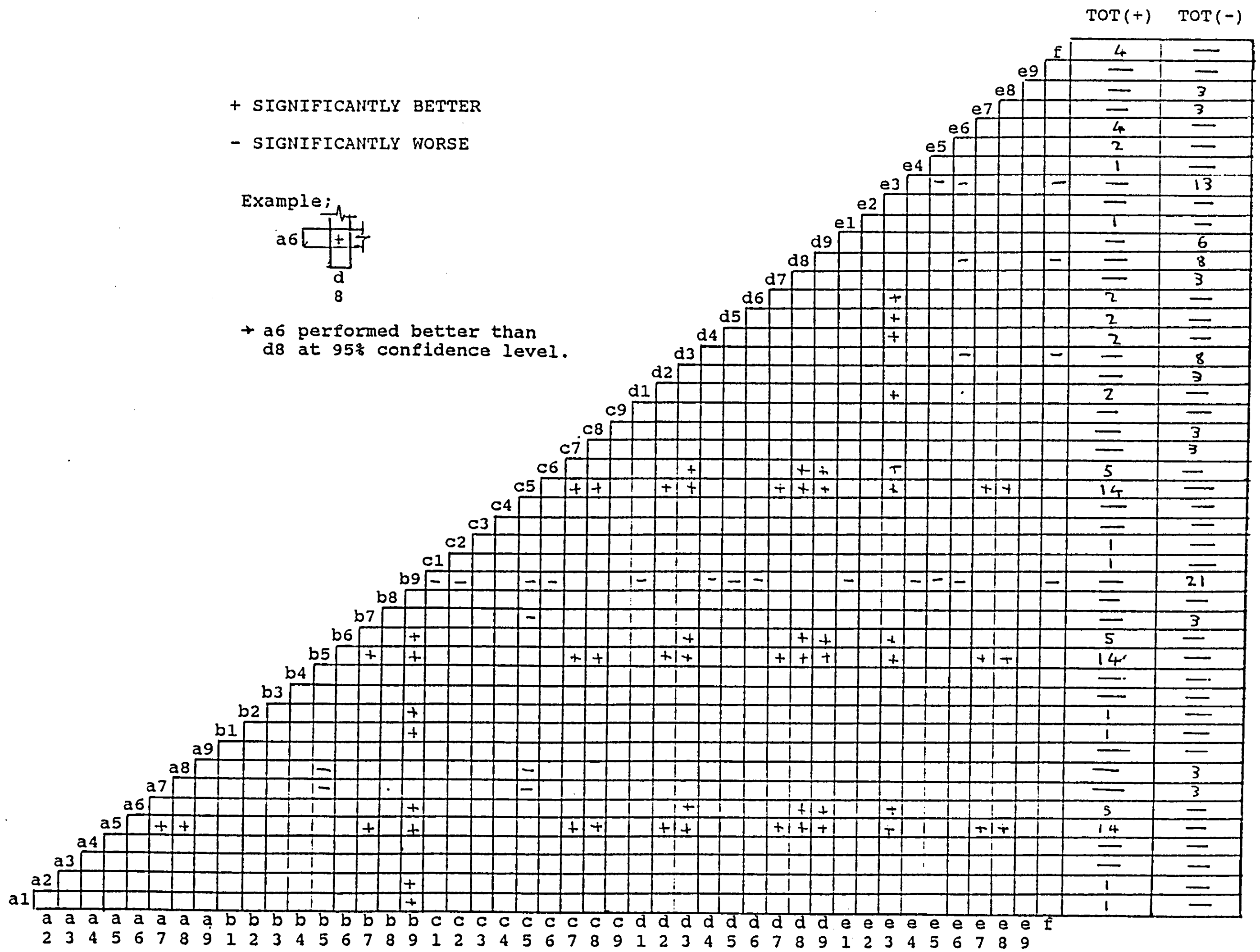


Figure 28 (iv). SIGNIFICANT DIFFERENCES BETWEEN RULES ACCORDING TO: OVERHEADS

(AFTER FIRST TRIAL)

	(correlation coefficient) r
OVERRUN	.94
DAMAGES	.83
OVERHEADS	.92

Figure 29. CORRELATION OF CRITERIA WITH DURATION

8.2 SUMMARY OF INDIVIDUAL RESULTS (FIRST TRIAL)

The rules have been grouped for review according to whichever final module (1 - 9) they share. The 'RANK' column represents the overall performance rating. The first figure in the 'SIG.' column indicates the total number of instances where the rule has demonstrated a significant superiority over another rule by one of the criteria at the 95% confidence level. The second figure represents the number of instances of significant inferiority.

MODULE: 1 - Least Total Float First

RULE	RANK	SIG.	REMARKS
a1	20.6	5,0	A consistent but average performance by all criteria on all workloads.
b1	20.6	5,0	As 'a1'.
c1	20.6	5,0	As 'a1'.
d1	18.3	7,0	Better than 'a1' on workload W1, worse on W2, but otherwise the same.
e1	20.6	5,0	As 'a1'.

GENERAL REMARKS: This represents a surprisingly poor performance by a set of rules targetted directly at minimising duration. Its lack of success can be attributed to the changes in total float that occur as a result of each instance of rescheduling, which successively leaves the partially levelled schedule looking less like the original upon which the priority assignments were based. Thus the efficacy of the rule is compromised because its decisions are based on historical data that suffers considerable revision before the decision is actually implemented during levelling.

MODULE: 2 - Least Free Float First

RULE	RANK	SIG.	REMARKS
a2	16.7	4,0	Similar, but slightly better results than for 'a1'. Appeared to perform well on overheads.
b2	16.7	4,0	As 'a2'.
c2	16.7	4,0	As 'a2'.
d2	23.4	2,8	Moderate to poor for all workloads, no particular criteria fields favoured.
e2	20.9	2,0	Same results as 'a1' for W1 and W2, same as 'a2' for remainder.

GENERAL REMARKS: The same vulnerability to being outdated by rescheduling is suffered by a rule based on free float as a rule based on total float. Total float, free float, and the contract float are the three attributes used in the rules most susceptible to change in the course of levelling.

MODULE: 3 - Greatest No. Of Manhours First

RULE	RANK	SIG.	REMARKS
a3	19.2	1,0	Performed very well on three workloads, but very poorly on all others.
b3	19.2	1,0	As 'a3'.
c3	19.2	1,0	As 'a3'.

d3	25.3	1,8	Fared rather poorly on cost criteria, generally. Good on W3 and W6, otherwise poor.
e3	27	0,16	Very poor on W1, W2, otherwise, same as 'd3'.

GENERAL REMARKS: The variability in the results for this module demonstrates a capacity for making very serious errors. This may be because this is a heuristic module that ignores all network-related information (and cost information) and relies entirely on the probability that major activities will be the most difficult to accommodate in the resource schedule, and that therefore they are best scheduled first. This use of probability is an approach to decision making which might have been more successful had the workloads to which it was applied consisted of a very much larger number of activities, over a very much longer period of time.

MODULE: 4 - Earliest Start First

RULE	RANK	SIG.	REMARKS
a4	14.4	3,0	Top equal on W5 and W6, very good on W3 and W4, poor on W1 and W2. Seemed to do well on the damages criteria.
b4	14.4	3,0	As 'a4', except float increase on W1 is 100 days less.
c4	14.4	3,0	As 'b4'.
d4	16.3	15,0	Top equal on W1, good on W2, moderately

			good on W3 and W4, poor on W5 and very good on W6.. Let down by poor performance on cost fields.
e4	17.5	14,0	Worse on W1 and W2, but otherwise the same as 'd4'.

GENERAL REMARKS: The success of this module's rules may be attributed to the fact that the relative position of activity start positions - the attribute upon which the module is based - suffers only limited revision during levelling. This was not the case with other schedule related attributes, such as float, which instead altered radically. Thus the logic which underlies these rules will still largely hold true by the time the priorities are compared in the course of levelling. That 'd4' and 'e4' perform significantly better on the duration related fields than do the other three, is in contrast to the generally superior performance of the 'a', 'b', and 'c' series elsewhere. The implication is that activity criticality may not necessarily be of paramount importance when prioritising activities.

MODULE: 5 - Least Contract Float First

RULE	RANK	SIG.	REMARKS
a5	10.1	28,0	Top on W2, very good on W1 and W3, good on W6, fair on W5 and W4. Relatively poor on damages despite doing well on contract overrun. Did well on overheads.
b5	10.1	28,0	As 'a5'.

c5	10.1	28,0	As 'a5'.
d5	19.7	3,0	As 'a5' for W1 and W2, but otherwise worse on three of the remaining four.
e5	19.7	3,0	As 'd5'.

GENERAL REMARKS: SEE MODULE 6.

MODULE: 6 - Greatest Damages First

RULE	RANK	SIG.	REMARKS
a6	11	19,0	Best result of all on duration, and on damages, despite poor showing on contract overrun. No markedly poor performances.
b6	11	19,0	As 'a6'.
c6	11	19,0	As 'a6'.
d6	20	7,0	Moderately good to poor for all workloads,by all criteria.Some evidence of having sacrificed other criteria for an improvement in damages but the damages are still only moderately good compared to those of other rules.
e6	15.1	10,0	As 'a6' for W1, W2, same as 'd6' fo remainder.

GENERAL REMARKS: The rules 'a5','b5', 'c5', 'a6', 'b6' and 'c6' are the only rules to have performed significantly better than the average, for all the criteria. There was little difference between their results on duration and those achieved on their target criteria, contract overrun and damages.This suggests that the good all-round success that these two sets of rules achieved was due primarily to their initial success in minimising total delay. It was not therefore due to their efficacy in allocating delay in such a way as to minimise the projected damages, as had been anticipated. A good rating on damages is the result of having scored well on duration, not, as was thought possible, of having selected the right contract to delay. There was no logical link between the attributes (contract float, damages) upon which these rules operate, and the suitability of activities to being delayed when the sole objective is that of reducing duration. Therefore such good results can only be put down to the chance pattern of contract float and penalty rates assigned to each of the projects at the time they were created.

MODULE: 7 - Greatest [Manhours-divided-by-Float] Factor First

RULE	RANK	SIG.	REMARKS
a7	20.9	0,3	Poor on W1, W2, and W6, moderately good elsewhere. Little variability between fields.
b7	20.9	0,3	As 'a7'.
c7	20.9	0,3	As 'a7'.
d7	21.7	1,3	Similar to 'a7' except for W1 and W2 which are both worse. Slightly better on damages than the other '7's, which

			gives rise to the one significant betterment.
e7	20.9	0,3	As 'a7'.

GENERAL REMARKS: To a lesser degree this module's set of rules suffered from the same handicap as those incorporating module 3. Again it depends for its success on the strength of the relationship presumed to exist between (1) the magnitiude of an activity's resource demand, (2) the profile of resource availability at a given moment during levelling, and (3) the length of the delay before the activity can be accomodated within the schedule. This relationship was not found to be strong. The introduction of float into the computation made no significant improvement.

MODULE: 8 - Greatest Overheads First

RULE	RANK	SIG.	REMARKS
a8	19.8	1,14	Good on W3 and W6, fair to poor elsewhere. Evidence of superior performance in overheads field.
b8	22	0,1	Very poor on W1, poor on W2, otherwise similar to 'a8'. Dispersion much greater than 'a8's hence the lack of significant differences.
c8	19.8	1,14	As 'a8'.
d8	37	0,62	Very poor on all contracts, by all criteria.

e8	32.1	0,52	Slightly better than 'd8' on W1, W2, otherwise the same.

GENERAL REMARKS: At the creation of each workload, it was deliberately contrived that the distributions of overhead rates, damages rates and contract float between the contracts were always different from each other. This eliminated the risk of one or more of the rules duplicating the action of others. This helps to explain why this module's rules were as unsuccessful, as modules 5 and 6 had been successful, in minimising duration - a criterion not targeted by any of the three. Taken together, these three sets of results serve to illustrate the arbitrary impact that a rule differentiating between projects rather than the individual activities can have on a schedule. The marginally better performance in the overheads field than in others was inadequate compensation for the failure to control duration.

MODULE: 9 - Least Duration First

RULE	RANK	SIG.	REMARKS
a9	23.1	0,0	Very good on W1 and W3, fair to poor elsewhere. Consistent across fields, but very variable between the workloads.
b9	28.6	0,46	Worse than 'a9' on W1 and W2, otherwise the same.
c9	23.1	0,0	As 'a9'.
d9	31.9.	0,28	Poor on all contracts, all fields.
e9	28.4	0,1	Same as 'a9' for W1, moderate for W2,

same as 'd9' for remainder. Results very variable.

GENERAL REMARKS: The poor showing of this set of rules was surprising. The module was directed towards minimising duration, and was based on data (activity durations) that was not vulnerable to being changed through levelling. The result may be ascribed to the difficulty of finding a new location in a resource's demand profile for a long activity delayed in preference to a shorter one, that does not then create a new overscheduling problem elsewhere. It was precisely to overcome this problem that module 3 (Greatest Manhours First) was created. However no significant differences were detected between these two modules in the results of any of the rules that incorporated them. Unlike No.'s 1,2,4, and 7, this module takes no account of how activities relate to each other, both within and between the networks, thereby ignoring circumstances of the activities which have a strong bearing on their qualification for delay.

MODULE: f - Superproject's Own Float-First Levelling Facility

RULE	RANK	SIG.	REMARKS
f	13.5	13,0	Performance ranged from fair to good. Variable on cost fields, but otherwise quite consistent.

GENERAL REMARKS: This proprietry rule enjoyed the advantage of being able to make its decisions immediately prior to their implementation, using data that described the actual circumstances of the overscheduling problem to be solved. A comparison between the results for this inbuilt decision making leveller and its priority based counterparts in the module 1 series demonstrates the significance of this distinction. For this rule, the fundamental problem faced by all the priority based rules, of having to implement their decisions on schedules altered in unpredictable ways from the originals upon which the decisions were based, does not apply. This rule was noticeably consistent in its performance from workload to workload, and did well by all criteria.

8.3 GENERAL FINDINGS (FIRST TRIAL)

None of the rules ever came close to rescheduling the contracts without both extending the critical path of at least two of the three projects, and incorporating significant breaks in the work continuity of the resources into their programmes. This does not necessarily prove that within the constraints of levelling the optimum solutions were never reached, but it does imply that in the real world those constraints would have to be relaxed, and that other ways of resolving resourcing problems that compliment the activity-delay approach (overtime, subcontracting, etc.), would have to be considered. Therefore none of the schedules produced could be said to be final.

8.3.1 The Partial Independence Of Damages.

The degree of correlation between duration and the other criteria was found to be generally high, with the exception of damages for which the relationship was markedly less strong (SEE Figure 29). As projected damages and contract overrun are clearly related, the difference between the correlations of each with duration must be explained. Although when the rules managed to minimise duration they also succeeded in minimising the period for which damages are due, the differences in the rates at which the damages accrue had a significant and adverse effect on the total of projected damages for which the contractor would be liable. Neither the rules targetted at contract overrun, nor those targeted at damages itself were able to take much advantage of this albeit limited independence of damages, in order to reduce the figure projected by accepting a less than optimum result for the duration. This was indicated by the lack of significant differences found between any of the rules in respect of damages [SEE Fig. 28(iii)].

8.3.2 A Consistent Increase In Total Float.

The float loss field, which had been expected to demonstrate the increased criticality of the new schedule, always returned a large negative value for the total. Although occasionally individual projects would show a loss, this indicated a consistent net gain in total float, resulting from the fact that no rule ever came near to resolving resource conflicts without extending at least two of the three original critical paths. The results for float loss did not seem to indicate either success or failure, so they were not included with the other criteria when evaluating the combined performance ratings.

8.3.3 The Failure Of Common Module Y.

The worst series was the 'd' series, which prefaced the action of the final module by assigning the highest priorities to those activities which used a category of resource whose assignments collectively had the least total float. This discrimination by resource type represented the effect of common module Y [SEE '7.6 MODULE DESCRIPTIONS']. The incorporation of this module was also the only difference between the 'a' and 'c' series, which were very similar to each other in their final results. Taken together, this suggests that so long as the subset of critical activities is assigned higher priorities than the remaining non-critical activities, any further distinction between activities on the basis of resource type will have little, if any, beneficial effect. The failure of the 'most-critical-resource-first' module stems from the revealed fact that SPJ will only compare the priority fields of activities in different resource categories if the overscheduling of each resource actually starts on the same day, a rare occurrence on any workload. Thus any distinction deliberately created between the priorities of different resource subsets of activities is likely to prove irrelevant when it comes to levelling.

8.3.4 Prioritisation By Activity Versus Prioritisation By Project.

The rules may be divided according to the behaviour of their final modules (1 - 9) into two categories; (i) those that progress the prioritisation by discriminating on the basis of an attribute specific in its value to each activity (1,2,3,4,7,9), and (ii) those which differentiate on the basis of some attribute specific only to the contract to which the activity belongs (5,6,8). This latter group of final modules, which are targeted at the cost criteria of damages and overheads, make no distinction between activities in the same project, although the common modules that precede them in all the rules but the 'e' series will have at least partially already done so. These rules, which complete their prioritisation on the basis of data unrelated to the activity or its position within a network were tested as much to gauge their negative effects on the network related criteria, as to determine their effectiveness with regard to their target, project-specific, criteria.

The results for this second group revealed a strong tendency for the contract with the highest priority to benefit considerably as intended, but at too great a cost to the individual programmes of the other two. Thus although the cost field for one contract was often successfully minimised, the extension of the contract periods of the other two, necessary to accommodate this, was so great that despite their slower rates of accumulation, the final values in their target cost fields usually more than cancelled any savings made on the first project when the combined total was computed. These results provide little evidence to suggest that a rule oriented towards prioritising projects rather than activities can perform any better on its target criterion than other rules can. Nor, it would appear, does it yield a better result on this target than it does on any other criterion. However, if it was the case that the differences between one contract and another in their rates of cost accrual were much greater than those incorporated in the artificial workloads, this conclusion might no longer hold true. Thus if the weekly damages, or the rate at which overheads are incurred, are very much greater on one contract than on another, an allocation of resources that favours this contract but forfeits an optimum schedule in terms of total duration, may nonetheless minimise total costs.

8.3.5 There Was No Outstanding Rule.

Considering that 30 of the 46 rules were, at the 95% confidence level, not proved to be any worse by any measure than any other rule, that the highest overall rank achieved was 10.1, and that the dispersion of even the best performing rules was still substantial, it was evident that no consistently 'good' rule had yet been found. Consequently there was scope for further rule development.

8.4 EARLY CONCLUSIONS

From these initial findings, a number of conclusions were drawn:-

1. Without being allowed the facility to examine the evolving schedule as levelling proceeds, a rule is deprived of the specific details of the problem it is expected to solve, and must therefore rely on a prediction of what this problem might be. This being the case, and without the means to evaluate all possible solutions, the optimum solution can only ever be reached by the conjunction of a good prediction and an element of chance. The better the prediction, the smaller the part chance will play, although it can never be eliminated. Under these circumstances, the best rule must be described as that which performs better than its rivals, more often.

2. The success of a rule is partially dependent on the degree to which the initial rationale that underlies its assignment of priorities survives the distortion associated with the rescheduling that occurs during levelling.

3. The primary objective of a rule should be the minimisation of total workload delay, not the allocation of delay to the contracts that for whatever reason are perceived to be better able to receive it. This approach will be most likely to produce the better solution, whichever criteria of success are

being applied.

4. The usefulness of considering an attribute of the project to which an activity belongs, eg. damages, which is therefore not a direct function of network position or activity magnitude, may be proportional to the variance between projects in the rate at which it accumulates with project duration.

5. A rule is unsatisfactory unless it specifies a unique priority to each activity.

6. Assigning higher priorities to critical activities than to non-critical activities will not always produce better results.

9 A SECOND TRIAL

9.1 THE NEED FOR FURTHER TESTING

Further testing of the better rules would establish the superiority of one over the others. Hence a further ten 'artificial' workloads were generated in the same manner as before, against which to test a selection of rules that had performed best to date. Those rules that were not considered in the second trial were rejected if any of the following three conditions were met;

1. The rule was significantly worse on one criterion than one or more other rules.

2. The rule had not been better than any other rule on any criterion.

3. The rule had duplicated the action of another simpler rule.

For more specific reasons other rules were either retained or rejected. 'e4' was dropped and 'd4' was retained because although the difference in effect between the 'd' and 'e' modules had been shown to be slight, the results of 'd4' did suggest some small advantage over 'e4'. By reason of its simplicity and its good showing, the '4' module (earliest start first) was of particular interest for its potential as a heuristic aid to decision making in situations where sophisticated tools of analysis are not available. 'c4' was maintained to substantiate the hypothesis that, as a rule which ensured that all critical activities were assigned higher priorities than all non-critical activities, it would do worse than a comparable one ('d4') that did not operate under this constraint.

Finally SPJ's own rule 'f', was entered into the second trial not only because of its good performance, but also because as a rule purposely encoded into a sophisticated and recently developed planning package, it had some value as a benchmark against which to judge the remainder. Thus those finally selected to go forward to the next stage in the process of elimination were 'c4','c5','c6','d4'and 'f'.

9.2 FURTHER RULES

The success of the rules dedicated to minimising total duration relied on the strength of the relationship between the value of an activity's attribute before levelling, and the extension to the critical path that its delay would cause during levelling. The results indicated that none of the relationships hypothesized had materialised with sufficient exactitude to form the basis of a dependable rule. To have recommended any of these rules unchanged would have been to recommend the acceptance that an appreciable proportion of the decisions taken by them would be incorrect, even if the sole criterion of assessment was that of minimising overall project delay.

It appeared that no rule had been able to successfully integrate the variables of activity duration, float, and start date that dictate the effect on the schedule of delaying a particular activity. Given the single objective of minimising total duration, an algorithm based on further analysis of the relationship between these elements seemed promising.

9.3 'NEWRULE'

9.3.1 An Algorithm To Produce A Near-optimal Solution.

Assuming, for each activity found to be in competition for a resource, that the number of resource units assigned to it is fixed over its duration, overscheduling can only be relieved by postponing the start of one or more of the competing activities to the moment of completion of one or more of the remainder. The simplest condition, where two activities, assigned the same number of units of a resource, are overlapping and thereby causing an overscheduling problem, is illustrated in Fig. 30.

The delay of activity A necessary to alleviate the excess demand is readily evaluated;

Delay of A = Earliest Finish of B - Earliest Start of A

=> DelA = EFB - ESA (1)

And conversely for Task B;

DelB = EFA - ESB (2)

This holds true irrespective of their relative positions at earliest start.

However it is the extension of the critical path associated with delay that is of greatest interest, and to evaluate this the floats of the activities must be taken into

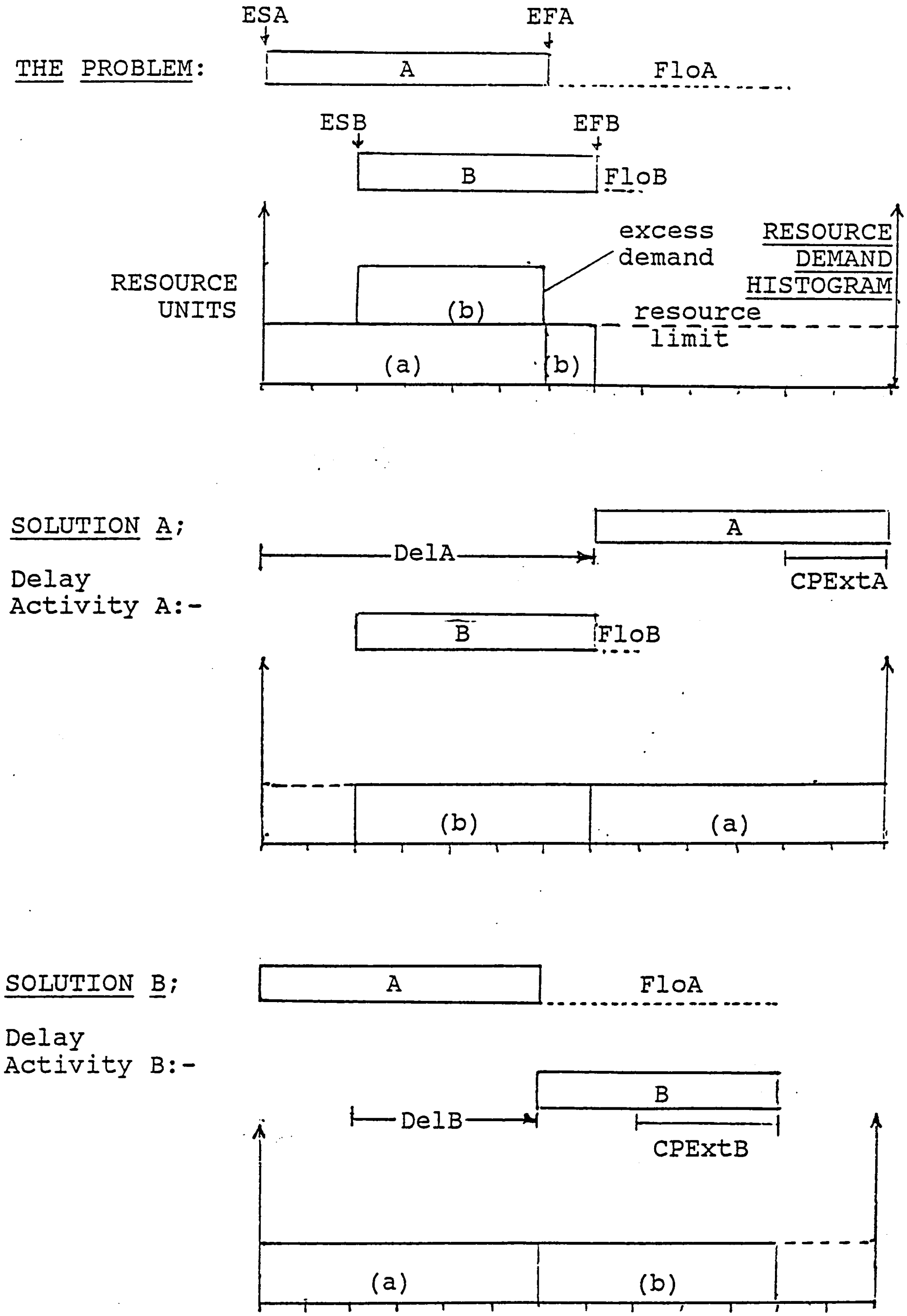


Figure 30. ALTERNATIVE SOLUTIONS TO THE SIMPLEST LEVELLING PROBLEM

account;

$$CPExtA = DelA - FloA \qquad (3)$$

$$CPExtB = DelB - FloB \qquad (4)$$

Substituting (1) and (2) into (3) and (4);

$$CPExtA = EFB - ESA - FloA \qquad (5)$$

$$CPExtB = EFA - ESB - FloB \qquad (6)$$

(When the delay is less than the float the magnitude of the result of this equation represents the remaining float)

As it is being assumed that no preference exists regarding which contract to delay, the least extension of either critical path is to be taken as the most favourable outcome. Hence;

if CPExtA - CPExtB > 0, delay activity B

=> if (EFB-ESA-FloA) - (EFA-ESB-FloB) > 0, delay activity B

=> if EFB-EFA+ESB-ESA+FloB-FloA > 0, delay activity B

And conversely;

if EFB-EFA+ESB-ESA+FloB-FloA < 0, delay activity A

Where more than two activities are contributing to the excess demand, making the comparisons necessary can be a little more involved, depending on the level of resource availability. Figure 31 illustrates, using three nominal activities, the levelling sequence that would be followed where sufficient resources are available for only one activity to proceed at a time. Using the same three activities, Figure 32 demonstrates how the priorities would be decided in a situation where there were sufficient resources for two or more activities to proceed

AGGREGATE RESOURCE DEMAND UNTIL EXCESS DETECTED. COMPARE ACTIVITIES CONTRIBUTING TO DEMAND AT THIS POINT (A,B) USING ALGORITHM + DELAY APPROPRIATE ACTIVITY (B). RECALCULATE NEW START TIMES AND FLOATS.

Step 2: REPEAT STEP 1. THIS TIME ACTIVITIES TO BE COMPARED ARE A AND C. THE RESULT IS THE DELAY OF C.

Step 3: REPEAT STEP 1. ACTIVITIES TO BE COMPARED ARE B AND C. B IS DELAYED.

LEVELLING IS NOW COMPLETE.

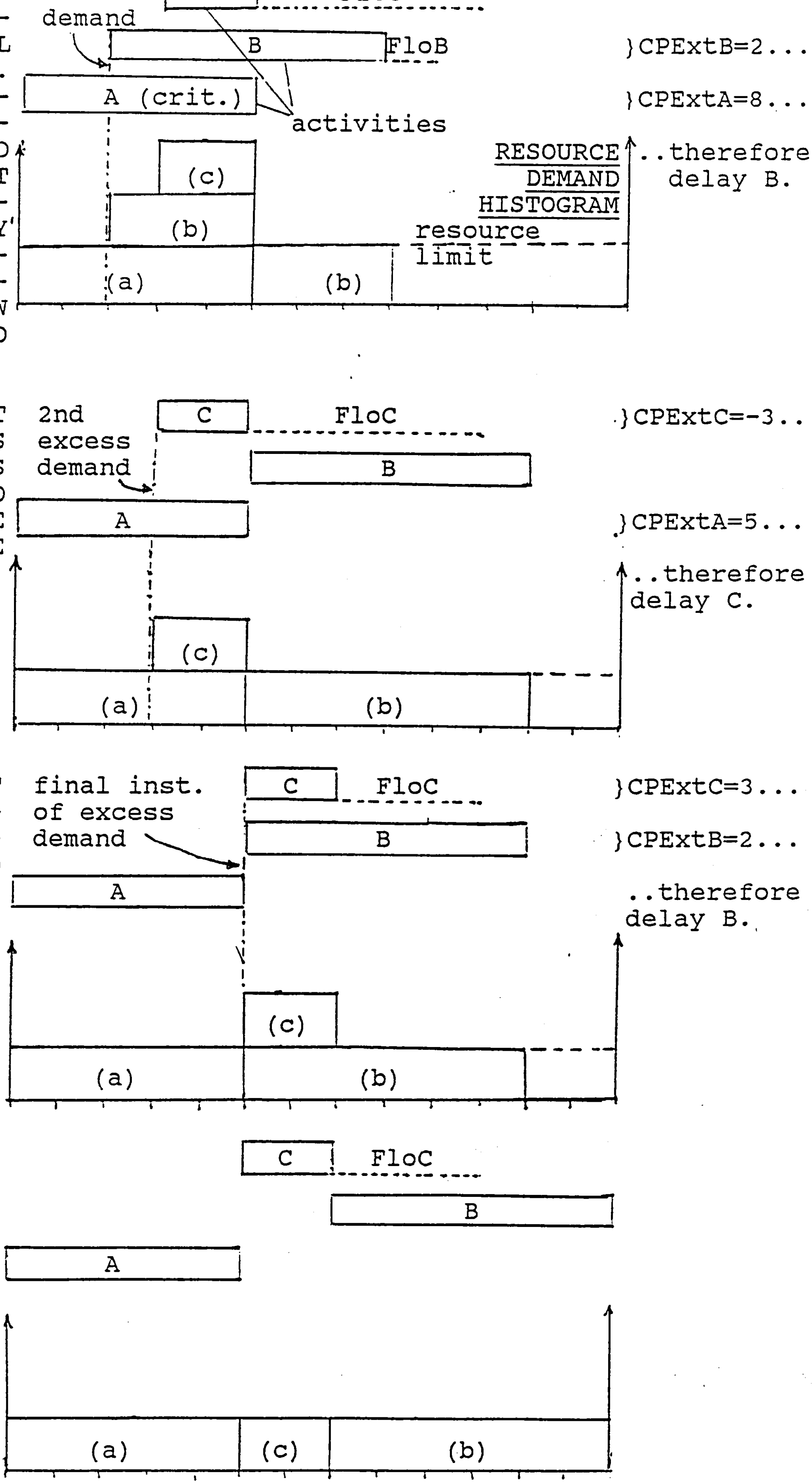
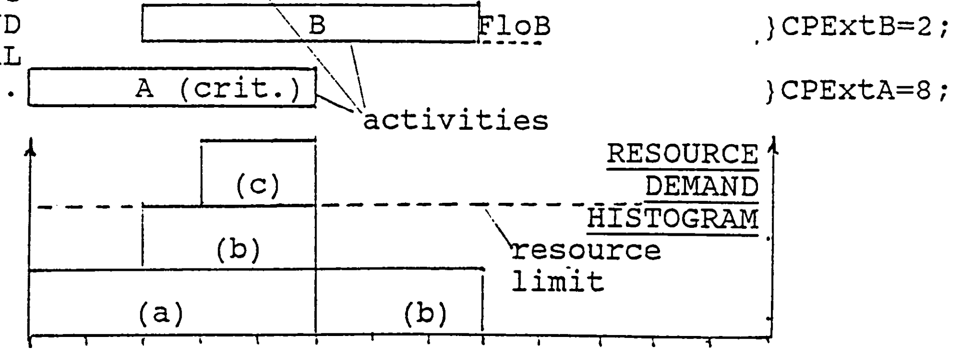
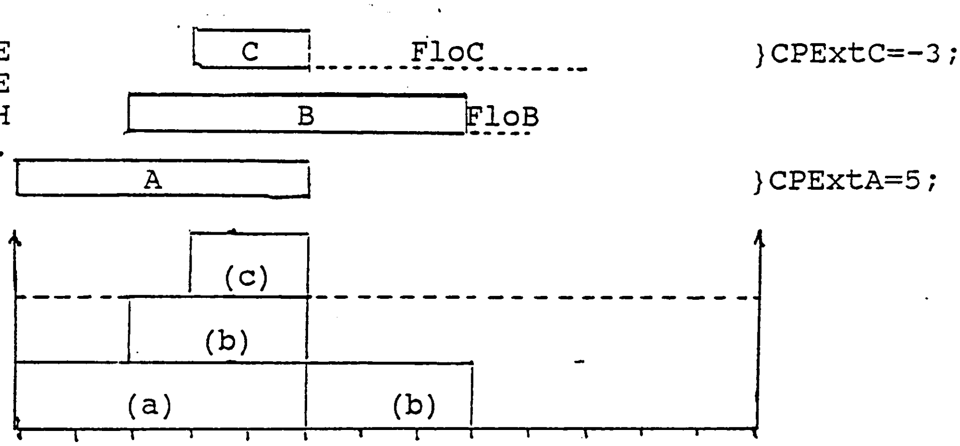


Figure 31. LEVELLING PROCEDURE USING ALGORITHM WHERE RESOURCE AVAILABILITY PREVENTS CONCURRENT SCHEDULING OF ACTIVITIES

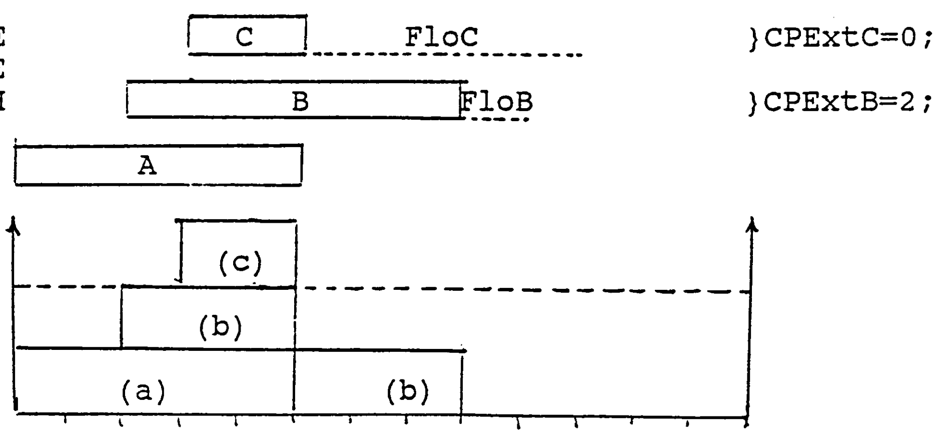
ALGORITHM, AND NOTE CRITICAL PATH EXTENSIONS.



Step 2: COMPARE A AND C AND NOTE CRITICAL PATH EXTENSION TIMES.



Step 3: COMPARE B AND C AND NOTE CRITICAL PATH EXTENSION TIMES.



Step 4: ASSIGN PRIORITIES IN PROPORTION TO THE MINIMUM CRITICAL PATH EXTENSIONS RECORDED FOR EACH ACTIVITY. DELAY LOWEST PRIORITY ACTIVITY [C].

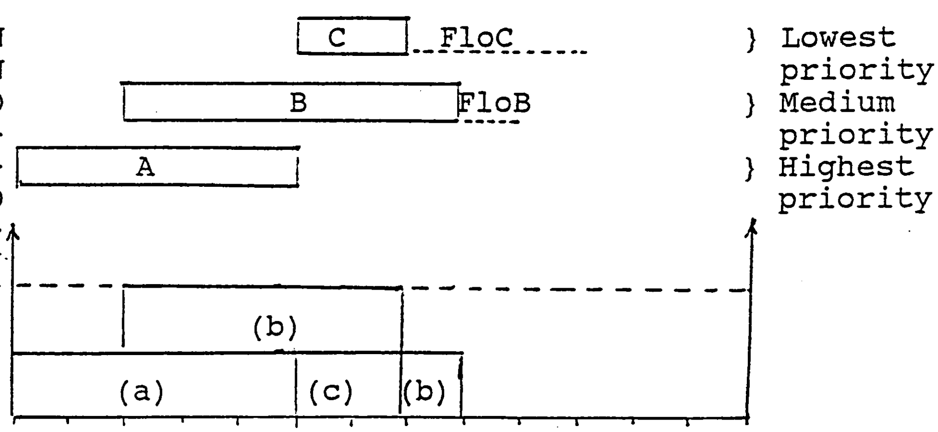


Figure 32. LEVELLING PROCEDURE USING ALGORITHM WHERE RESOURCE AVAILABILITY ALLOWS CONCURRENT SCHEDULING OF ACTIVITIES

9.3.2 The Effect Of Variation In Gang Sizes

For any given instance of overscheduling, where gang sizes assigned to activities are of the same magnitude, this algorithm will yield an optimum solution.

Where there is some difference in gang sizes, the optimum solution may not be reached. This represents a situation where the delay of one activity scheduled to be undertaken by a large number of men may be equivalent in terms of the resulting reduction in excess labour demand to the delay of two or more competing activities which individually had been assigned a lesser number of men. All else being equal it is desirable that as few activities should be delayed as possible. Hence a preference ought to be shown to the delay of activities assigned large numbers of men.

The importance of this phenomenon is proportional to the variation in gang sizes, which cannot be expected to be very great in the case of a small builder drawing upon a small workforce. Thus no amendment to the algorithm was made, although its capacity for imperfect decision-making in certain circumstances was recognised.

9.3.3 Two Versions Of A New Rule: 'N1' and 'N2'

A new rule would be subject to the same handicap as all previous rules (except 'f') in relation to the quality of the data upon which to base decisions (SEE '8.4 EARLY CONCLUSIONS', No. 1). Accepting this constraint upon performance, a new rule incorporating the algorithm was devised, exploiting the fact that the transformation that occurred during levelling was gradual, and limited in its final extent. Labelled 'Newrule', two promising versions were conceived, 'n1' and 'n2'

'N1'

Using the algorithm, 'n1' compared each activity in its pre-levelling position with every other that shared the same resource, and with which it overlapped in time. The result of each comparison was the awarding of a 'point' to the accumulating priority rating of whichever activity had consequently been accorded the higher priority. Once all such comparisons had been made, the total rating for each activity became the priority examined by SPJ in the course of levelling.

'N2'

'N2' differed only in that each activity was compared with all those other activities with which it shared the same resource, and not just those with which it ran parallel. This was an attempt to estimate the appropriate relative priorities of activities which were not at conflict before levelling, but which might be brought into conflict by changes to the programme initiated by the levelling of preceding activities. Inevitably the application of the algorithm to two activities distant from each other tends to favour the earlier activity. This is acceptable, as if they should come into conflict with each other it will be as a result of the considerable delay of the first activity, which is likely to leave it with less float than the second activity with which it now competes.

The risk inherent in moving from the 'n1' strategy to that of 'n2' was that the relative priorities established for activities actually known to be in a state of conflict before levelling, and which occurred early enough in the schedule as to be relatively unaffected by changes arising from the resolution of earlier conflicts, might be swamped and hence distorted by trying to take account of every possible eventuality in a single rating.

These new rules were applied to the same six workloads that had formed the test data for the other rules. The full complement of selected rules ('c4', 'c5', 'c6', 'd4', 'n1', 'n2', 'f') were then tested on ten new workloads to provide a total of sixteen sets of results each with which to make the final assessment.

The results for the second trial were processed in the same way as were those for the first. [SEE Tables 3 & 4, Figures 33 - 36].

Totalled Results For Workload: W1

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	189 days	73 days	2,400	10,040
c5	148 days	32 days	800	7,570
c6	133 days	17 days	0	7,320
d4	132 days	16 days	0	7,090
n1	161 days	45 days	0	8,560
n2	135 days	19 days	0	7,180
f	167 days	51 days	0	9,140

Totalled Results For Workload: W2

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	224 days	108 days	9,200	11,830
c5	155 days	39 days	0	8,820
c6	155 days	39 days	0	8,820
d4	175 days	59 days	8,400	9,050
n1	165 days	49 days	2,000	8,900
n2	160 days	44 days	1,200	8,750
f	167 days	51 days	3,200	8,850

Totalled Results For Workload: W3

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	117 days	23 days	1,500	5,450
c5	120 days	26 days	3,000	5,450
c6	120 days	26 days	3,000	5,450
d4	112 days	18 days	4,200	5,490
n1	117 days	23 days	1,500	5,450
n2	112 days	18 days	4,200	5,490
f	120 days	26 days	3,000	5,450

Totalled Results For Workload: W4

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	134 days	40 days	8,700	6,380
c5	147 days	53 days	15,600	6,070
c6	147 days	53 days	15,600	6,070
d4	131 days	37 days	9,200	6,950
n1	131 days	37 days	9,200	6,950
n2	131 days	37 days	9,200	6,950
f	129 days	35 days	8,700	5,810

Tables 3(a) - (d). WORKLOAD RESULTS (2ND TRIAL)

Totalled Results For Workload: W5

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	127 days	20 days	2,100	6,480
c5	140 days	33 days	5,200	6,770
c6	139 days	32 days	4,800	7,470
d4	151 days	44 days	6,600	7,830
n1	140 days	33 days	4,200	7,060
n2	123 days	16 days	1,600	6,360
f	136 days	29 days	6,500	6,840

Totalled Results For Workload: W6

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	133 days	26 days	800	6,540
c5	147 days	40 days	5,200	7,090
c6	148 days	41 days	4,000	7,350
d4	146 days	39 days	2,400	7,270
n1	137 days	30 days	800	6,620
n2	141 days	34 days	1,600	6,900
f	150 days	43 days	4,500	7,750

Totalled Results For Workload: W7

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	168 days	51 days	13,000	9,860
c5	167 days	50 days	13,000	9,850
c6	187 days	70 days	6,000	9,130
d4	142 days	25 days	1,000	8,560
n1	167 days	50 days	13,000	9,850
n2	159 days	42 days	10,300	9,000
f	144 days	27 days	1,000	8,700

Totalled Results For Workload: W8

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	177 days	60 days	16,200	10,390
c5	185 days	68 days	19,600	11,250
c6	193 days	76 days	4,900	11,860
d4	201 days	84 days	21,400	11,280
n1	193 days	76 days	4,900	11,860
n2	176 days	59 days	12,300	9,210
f	168 days	51 days	4,600	10,340

Tables 3(e) - (h). WORKLOAD RESULTS (2ND TRIAL)

Totalled Results For Workload: W9

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	158 days	65 days	5,000	8,580
c5	139 days	46 days	3,000	8,020
c6	150 days	57 days	3,000	8,780
d4	132 days	39 days	0	7,020
n1	156 days	63 days	0	8,340
n2	127 days	34 days	0	6,620
f	136 days	43 days	0	7,280

Totalled Results For Workload: W10

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	165 days	72 days	5,000	9,000
c5	141 days	48 days	1,000	8,220
c6	151 days	58 days	1,000	8,840
d4	139 days	46 days	0	7,440
n1	139 days	46 days	0	7,440
n2	125 days	32 days	0	6,680
f	162 days	69 days	0	8,840

Totalled Results For Workload: W11

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	131 days	21 days	1,200	6,630
c5	131 days	21 days	1,200	6,630
c6	220 days	110 days	22,100	10,750
d4	135 days	25 days	1,200	6,820
n1	146 days	36 days	3,600	7,480
n2	123 days	13 days	0	6,100
f	133 days	23 days	1,200	6,760

Totalled Results For Workload: W12

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	179 days	69 days	7,900	9,230
c5	158 days	48 days	3,600	8,110
c6	207 days	97 days	10,400	10,230
d4	156 days	46 days	1,900	7,870
n1	162 days	52 days	2,600	8,110
n2	157 days	47 days	1,400	7,820
f	158 days	48 days	2,600	7,920

Tables 3(i) - (l). WORKLOAD RESULTS (2ND TRIAL)

Totalled Results For Workload: W13

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	135 days	29 days	0	6,280
c5	141 days	35 days	0	6,440
c6	141 days	35 days	0	6,440
d4	136 days	30 days	0	6,290
n1	136 days	30 days	0	6,290
n2	139 days	33 days	0	6,350
f	133 days	27 days	0	6,180

Totalled Results For Workload: W14

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	147 days	41 days	2,700	6,570
c5	170 days	64 days	2,400	7,480
c6	167 days	61 days	2,400	7,180
d4	149 days	43 days	3,000	6,580
n1	156 days	50 days	3,600	6,710
n2	149 days	43 days	3,000	6,580
f	141 days	35 days	2,400	6,480

Totalled Results For Workload: W15

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	135 days	29 days	800	6,860
c5	135 days	29 days	800	6,860
c6	135 days	29 days	800	6,860
d4	132 days	26 days	0	6,160
n1	130 days	24 days	0	6,100
n2	132 days	26 days	0	6,160
f	134 days	28 days	0	6,220

Totalled Results For Workload: W16

RULE	DURATION	OVERRUN	DAMAGES	OVERHEADS
c4	154 days	48 days	4,200	7,570
c5	165 days	59 days	8,000	8,130
c6	163 days	57 days	2,700	8,150
d4	146 days	40 days	3,900	6,430
n1	149 days	43 days	4,900	6,430
n2	147 days	41 days	3,900	6,510
f	147 days	41 days	3,900	6,510

Tables 3(m) - (p). WORKLOAD RESULTS (2ND TRIAL)

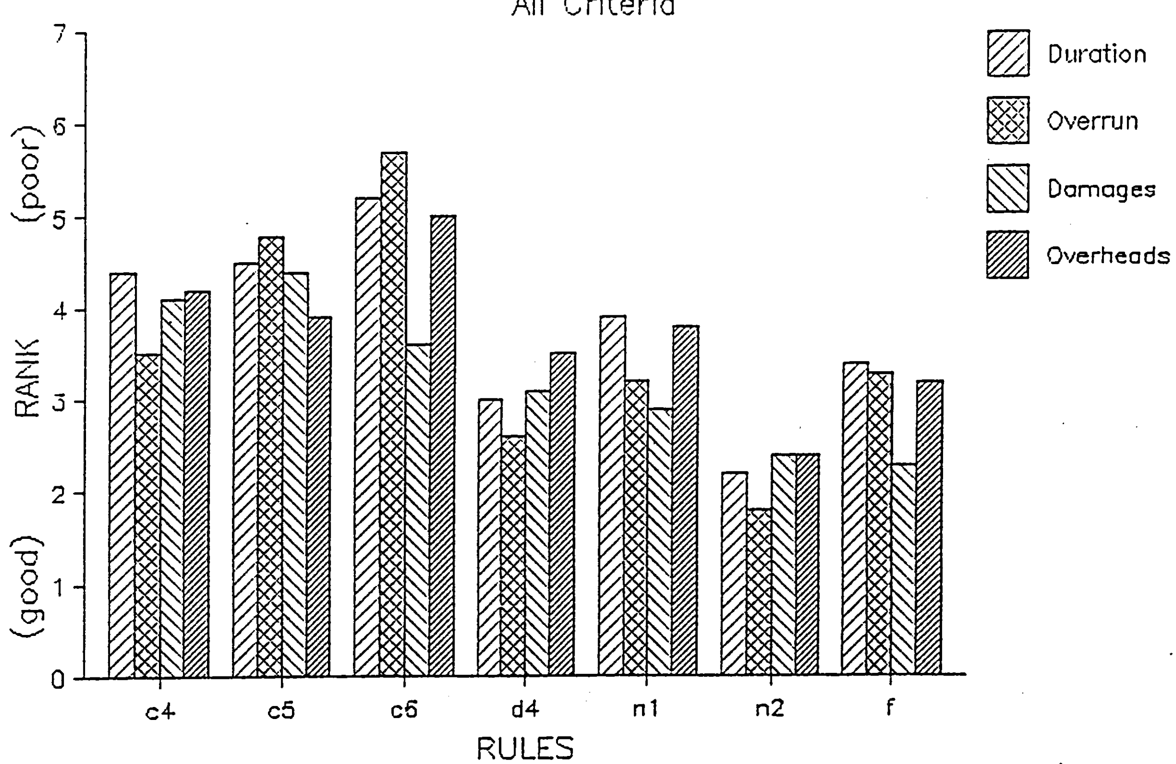


Figure 33. AVERAGE RANKING ACHIEVED BY EACH RULE FOR EACH CRITERION, AFTER SECOND TRIAL

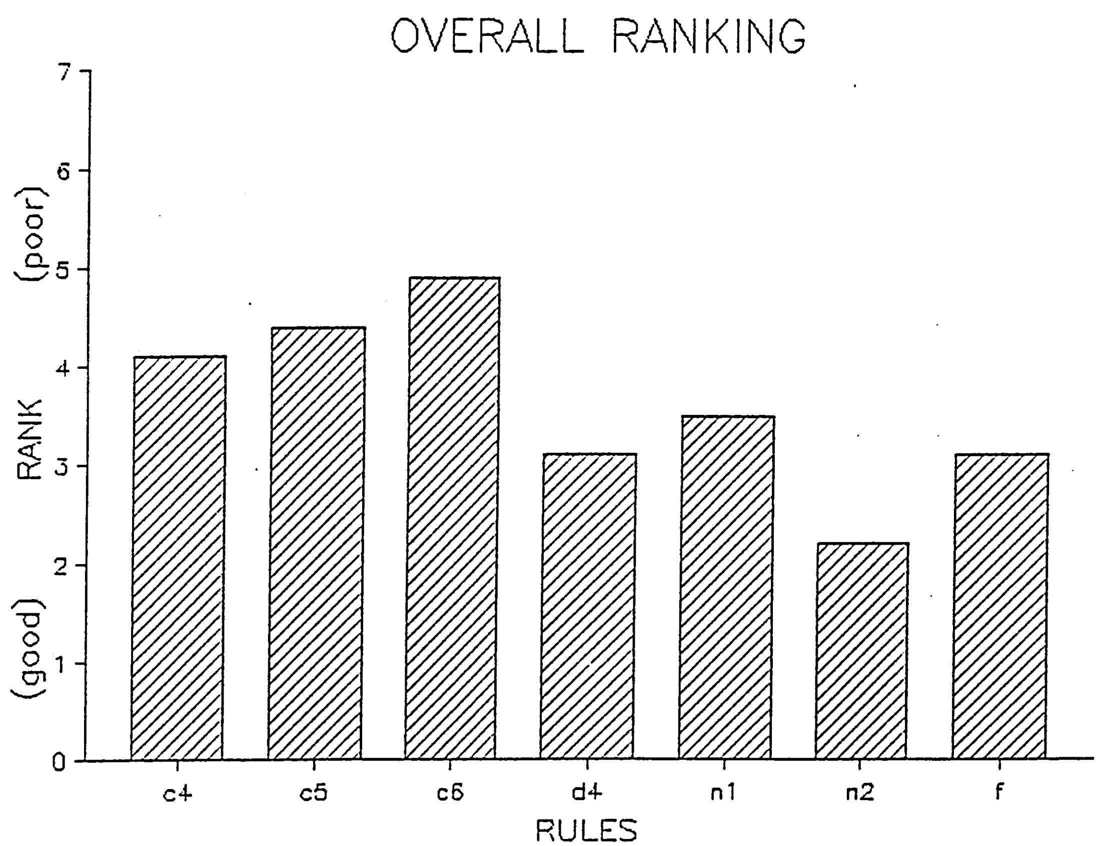


Figure 34. OVERALL RULE RANKINGS FOR ALL RULES AFTER SECOND TRIAL

DURATION

RULE	Mean	SD	95% Conf Lmts	(min)	(max)
c4	103.4	11.3	+/- 6.0	97.4	109.4
c5	99.9	6	+/- 3.2	96.7	103.1
c6	107	14.4	+/- 7.7	99.3	114.7
d4	95.7	5.7	+/- 3.0	92.7	98.7
n1	99.4	3.9	+/- 2.1	97.3	101.5
n2	93.4	5	+/- 2.7	90.7	96.1
f	97.7	6.2	+/- 3.3	94.4	101

OVERRUN

RULE	Mean	SD	95% Conf Lmts	(min)	(max)
c4	131.8	138	+/- 73.5	58.3	205.3
c5	130.3	86.2	+/- 45.9	84.4	176.2
c6	198.2	128	+/- 68.2	130	266.4
d4	60.1	59.4	+/- 31.6	28.5	91.7
n1	63.5	56.7	+/- 30.2	33.3	93.7
n2	38.1	37.2	+/- 19.8	18.3	57.9
f	75.5	57.2	+/- 30.5	45	106

DAMAGES

RULE	Mean	SD	95% Conf Lmts	(min)	(max)
c4	180.3	155.6	+/- 82.9	97.4	263.2
c5	125.2	61.6	+/- 32.8	92.4	158
c6	139.1	119.5	+/- 63.6	75.5	202.7
d4	72.3	68.7	+/- 36.6	35.7	108.9
n1	63.5	48.8	+/- 26.0	37.5	89.5
n2	53.8	48.8	+/- 26.0	27.8	79.8
f	63.5	52.8	+/- 28.1	35.4	91.6

OVERHEADS

RULE	Mean	SD	95% Conf Lmts	(min)	(max)
c4	104.1	10.4	+/- 5.5	98.6	109.6
c5	100.1	6.5	+/- 3.5	96.6	103.6
c6	106.6	13.4	+/- 7.1	99.5	113.7
d4	96.2	6.6	+/- 3.5	92.7	99.7
n1	98.8	5.4	+/- 2.9	95.9	101.7
n2	93.1	6.7	+/- 3.6	89.5	96.7
f	97.5	6.7	+/- 3.6	93.9	101.1

Tables 4(a) - (d). MEAN RATINGS AND DISPERSIONS EVALUATED FOR EACH CRITERION (2ND TRIAL)

	c5	c6	d4	n1	n2	f	TOTALS (+)	TOTALS (-)
f							1	1
n2						+	5	0
n1					–		0	2
d4				+			3	0
c6			–		–	–	0	3
c5					–		0	1
c4			–		–		0	2

Duration

	c5	c6	d4	n1	n2	f	TOTALS (+)	TOTALS (-)
f							2	1
n2						+	4	0
n1							2	0
d4							2	0
c6			–	–	–	–	0	4
c5			–	–	–	–	0	4
c4					–		0	1

Overrun

	c5	c6	d4	n1	n2	f	TOTALS (+)	TOTALS (-)
f							3	0
n2							3	0
n1							3	0
d4							2	0
c6				–	–	–	0	3
c5			–	–	–	–	0	4
c4			–	–	–	–	0	4

Damages

	c5	c6	d4	n1	n2	f	TOTALS (+)	TOTALS (-)
f							2	0
n2							4	0
n1					–		1	1
d4							2	0
c6			–	–	–	–	0	4
c5					–		0	1
c4			–		–	–	0	3

Overheads

<u>Example</u>; c6 [–] (column n2) = c6 performed significantly worse than n2.

Figure 35. SIGNIFICANT DIFFERENCES BETWEEN RULES ACCORDING TO EACH CRITERION

(AFTER SECOND TRIAL)

	(correlation coefficient) r
OVERRUN	.80
DAMAGES	.70
OVERHEADS	.88

Figure 36. CORRELATION OF CRITERIA WITH DURATION AFTER SECOND TRIAL.

9.5 INDIVIDUAL RESULTS SUMMARY (SECOND TRIAL)

RULE: 'c4' DESCRIPTION: Critical activities first, then earliest start first.

OVERALL RANKING: 4.1 SIGNIFICANT DIFFERENCES: 0,10

REMARKS: A poor performance, significantly so in comparison with 'd4' which differed only in being bound to assign higher priorities to critical activities. Did significantly worse than 'n2' on all criteria.

RULE: 'c5' DESCRIPTION: Critical activities first, then contract float first.

OVERALL RANKING: 4.4 SIGNIFICANT DIFFERENCES: 0,10

REMARKS: Again worse than 'n2' on all criteria. Furthermore, and on the target criteria, damages, worse than all the rules except 'c4' and 'c6'. This result provides very strong evidence that targetting 'secondary' criteria such as damages and overheads, rather than the primary criterion of duration, is counter-productive except possibly in certain extreme circumstances [SEE '9.6 GENERAL FINDINGS (SECOND TRIAL)'].

RULE: 'c6' DESCRIPTION: Critical activities first, then greatest damages first.

OVERALL RANKING: 4.9 SIGNIFICANT DIFFERENCES: 0,14

REMARKS: Worst result of all, and worst by all measures except damages - on which it was second worst. Again no evidence of a superior performance on damages compared to that achieved on other criteria. The variance found in the results seemed very considerable on all criteria.

RULE: 'd4' DESCRIPTION: Activities utilising most critical resource first, then earliest start first.

OVERALL RANKING: 3.1 SIGNIFICANT DIFFERENCES: 9,0

REMARKS: A relatively simple rule that exceeded expectations by matching the ranking of SPJ's own, more sophisticated 'f' rule. Furthermore the difference between this and 'n2' was not found to be significant at the 95% level on any criterion.

RULE: 'n1' DESCRIPTION: 'Newrule', comparing all activities which utilise the same resource and which overlap at earliest times.

OVERALL RANKING: 3.5 SIGNIFICANT DIFFERENCES: 6,3

REMARKS: A disappointing performance which by comparison with 'n2' clearly illustrates the adverse effect of not attempting to anticipate the actual resourcing problems that manifest themselves in the course of levelling.

RULE: 'n2' DESCRIPTION: 'Newrule', comparing all activities which utilise the same resource.

OVERALL RANKING: 2.2 SIGNIFICANT DIFFERENCES: 16,0

REMARKS: The mean results for this rule were better than all others, on all criteria. In the case of 'c4','c5' and 'c6', this superiority was significant on every criterion.

RULE: 'f' DESCRIPTION: SPJ's own rule (least total float first).

OVERALL RANKING: 3.1 SIGNIFICANT DIFFERENCES: 8,2

REMARKS: Significantly surpassed by 'n2' on three criteria, there was no indication of a superior consistency in its results that might have compensated for its poor showing. It's apparent edge over 'n2' on damages suggested by its ranking in this field, is not significant but does illustrate the independence in the behaviour of this criterion.

9.6 GENERAL FINDINGS (SECOND TRIAL)

The results of the second trial bore out the conclusions drawn from the first.

The supremacy of 'n2' over 'f', despite the latter's inherent advantage, is conclusive with regard to the difference between the two in the quality of their decision-making.

The argument that the attention of a rule should primarily be focused on duration minimisation, even when another activity criterion is considered to be of greater importance, is given more weight by the significant superiority of other rules ('n1','n2','f') over 'c5' and 'c6' on their target criterion of damages. This finding must be qualified by reference to conclusion 4, which is neither confirmed or rejected by the results [SEE '8.4 EARLY CONCLUSIONS'].

The rule that success by the criterion of duration will on average be followed by success on all other criteria held true despite the fact that the correlations measured between duration and other criteria fell considerably from the levels computed after the first trial. This seems to have been a consequence of testing a smaller number of rules, of a generally higher standard of performance. This provided less pairings (112 pairings for each criterion against 276 previously), over much smaller ranges. Against the background of a reduced range the same degree of digression from a linear relationship amongst a lesser number of pairings would reduce the reported correlation.

The damages correlation also appears misleadingly low because any reduction achieved in the duration, below that at which the damages clause comes into effect, can elicit no further reduction in the damages incurred, as of course, it would already stand at zero. This effect is more pronounced in the second trial because of the proportionately greater number of occasions (24% compared to 9% previously) on which this more efficacious group of rules have managed to successfully level all the projects within their completion dates.

The failure of 'c4' set against the success of 'd4' confirms that the criticality of an activity should not automatically qualify it for a priority higher than that accorded to non-critical activities. From the first trial it was known that the effect of differentiating between resources, the function of 'd4's primary module, was negligible. Therefore the success of 'd4' relative to 'c4' must be attributed to the relatively unhindered action of module 4 enjoyed by one but not by the other, as 'c4' is bound by its primary module to assign higher priorities to critical activities. The success of 'd4', coupled with the simplicity of its rationale, recommends module 4 (earliest start first) as the rule of thumb proposed after the first trial. [SEE '9.1 THE NEED FOR FURTHER TESTING'].

9.7 TESTING USING ACTUAL PROJECT DATA

The limitations on the number, resource content, and size of the artificial projects that made up each workload used in the trials, were such that the range of levelling problems tackled by each rule remained relatively narrow. The diversity of contracts that constitute the workloads of real building firms poses resourcing problems, greater both in number and complexity, than any that had been simulated using artificial projects. Crucially, there existed a strong possibility that the increase in the complexity of the problem would be accompanied by a deterioration in the performance of all the rules, with the possible exception of 'f'. It was anticipated that as the contracts increased in duration and number of activities, the transformation of the schedule associated with levelling would become correspondingly more comprehensive, invalidating a greater number of the 'decisions' taken by the rules. The rate at which this deterioration occurred would determine the point at which 'n2' lost its supremacy over 'f', and consequently the limits of its practical usefulness.

The trials had also been limited in scope to the initial scheduling of a fixed set of activities. It was now necessary to consider the place of multi-project scheduling using decision rules in the context of the broader requirements of a planning system, and with particular respect to the following;

(i) the speed and convenience of the technique's operation;

(ii) the progressing of the project plan;

(iii) the handling of variations to contracts;

(iv) the ease of identification of troublespots and bottlenecks;

(v) its relation to complementary solutions to resourcing problems (additional manpower, overtime, re-assignment of labour, etc.).

Only by applying the rules to an actual workload taken from the real world could such evaluations be made.

To this purpose detailed documentation relating to a period of the company's operations in early 1988 was secured from one of the participating firms. 'N2', as the clearly best all round performer, was retained, whilst 'f' was also retained so as to provide a standard against which to continue the assessment of 'n2'.

10 A TRIAL USING ACTUAL PROJECT DATA

10.1 THE WORKLOAD

The workload that was to be the subject of the simulation was that of a participating firm operating in the Sheffield locality, covering the period 18th Jan 1988 to 11th April 1988. The work comprised five major contracts, of which two were close to completion at 18/1/88, and a number of smaller miscellaneous jobs that took place over this period. The start of the study coincided with the commencement of one of the major contracts. Initially the firm's workforce consisted of four labourers, four joiners, and two bricklayers.

The Major Contracts:-

NAME: 'Mexboro'

CONTRACT SUM: 105,753.50

CONTRACT CONDITIONS: JCT, Intermediate Contract, latest rev

COMMENCEMENT: 26/10/87 ORIG. CONTRACT PERIOD: 22 weeks

DAMAGES: 430 per week

VARIATIONS RECEIVED DURING STUDY: 18

DESCRIPTION: Extensive refurbishment of 5 houses including stripping out, complete re-roofing, renewal of all services, new finishings and fittings, and provision of DPC and timber treatment as required.

- - - - - - - - - - - - - - - -

NAME: 'Masboro'

CONTRACT SUM: 70,184.02

CONTRACT CONDITIONS: JCT, Minor Bldg Works 1980, latest rev

COMMENCEMENT: 18/1/88 ORIG. CONTRACT PERIOD: 17 weeks

DAMAGES: 100 per week

VARIATIONS RECEIVED DURING STUDY: 21

DESCRIPTION: Alterations to, and an extension within an existing factory building to form upgraded office accomodation. Also re-roofing, rendering and ancillary work to exterior of adjacent three storey building. The work, which was divided into three phases, was due to start at the time of the first update.

- - - - - - - - - - - - - - - -

NAME: 'Cranworth'

CONTRACT SUM: 109,754.02

CONTRACT CONDITIONS: JCT, Minor Bldg Works 1980, latest rev

COMMENCEMENT: 23/11/87   ORIG. CONTRACT PERIOD: 23 weeks

DAMAGES: 200 per week

VARIATIONS RECEIVED DURING STUDY: 17

DESCRIPTION: General upgrading of existing single storey building consisting of offices, consulting rooms, etc., enclosing a central quadrangle.

- - - - - - - - - - - - - - - -

The other two contracts completed during the first weeks of the study were:-

'Ellis St' - A refurbishment contract for one house that experienced three variations during the period of study;

'Woodsets' - A new doctor's surgery for which there were two variations.

New Work - The seven small jobs introduced during the period reviewed, accounted for about 16% of all work completed.

10.2 PRODUCING THE PROGRAMMES

Contract drawings, incentive information, and the contractor's own manually produced programmes were the sources of information for the precedence diagrams produced for each contract. Virtually all the activities to be undertaken by the firm's workforce were covered by bonus targets built up from items taken from the estimate. The estimates were themselves derived from a database developed on an earlier research project (WESTGATE,S.E.:86).

Wherever possible activities from the contractor's own programme which had been amalgamations of bonus targets, were divided into their constituent targets again, to bring about a one-to-one correspondence between bonus targets and activities. This had the effect of breaking the resource linkages that are implicit in 'multitarget' activities. These are undesirable in that they do not allow the assignment of different gangs to the different targets that make up the activity, thereby placing a constraint on the scheduling of labour which fails to reflect the contractor's actual range of options. The increased number of small activities multiplied the number of possible levelling alternatives, and therefore allowed the rules greater flexibility in the search for the best solution. It also aided progress reporting and the evaluation of productivity by the direct correspondence between programmed activities and the items appearing on the timesheets. The resulting programme for one of the contracts is shown in Figure 37.

10.3 UPDATING THE SCHEDULE

The schedule was brought up to date at weekly intervals for the first four weeks, followed by two further updates at monthly intervals. Including the first, this represented a total of seven updates against which to test the rules. The progress was based on an analysis of the timesheets, and variations were entered at the time management became aware of them. The labour content of the variations was extracted from the contractor's own valuation. Any extensions of time granted were taken from the correspondence between contractor and architect.

Between each update the schedule was levelled using both 'newrule', and 'f'. The status of the contracts, and the action indicated by the rule giving the shortest overall duration, were observed and noted before proceeding to the next update.

As this exercise was conducted sometime after the period in which the work took place, management did not have the schedules upon which to base their actions. Hence it was not possible to be conclusive about what the consequences would have been, had they actually followed the course indicated by them.

10.3.1 The Charts

Update Charts

Figures 38 to 44 show the schedule and the resource histograms of the three principle trades as they appeared at each update. Between each update, Tables 5(a - f) and Tables 6(a - f) indicate the variations received, and the major changes in priority as calculated by 'newrule'.

Masboro St: AT 18 JAN 1988, BEFORE LEVELLING
Task Gantt

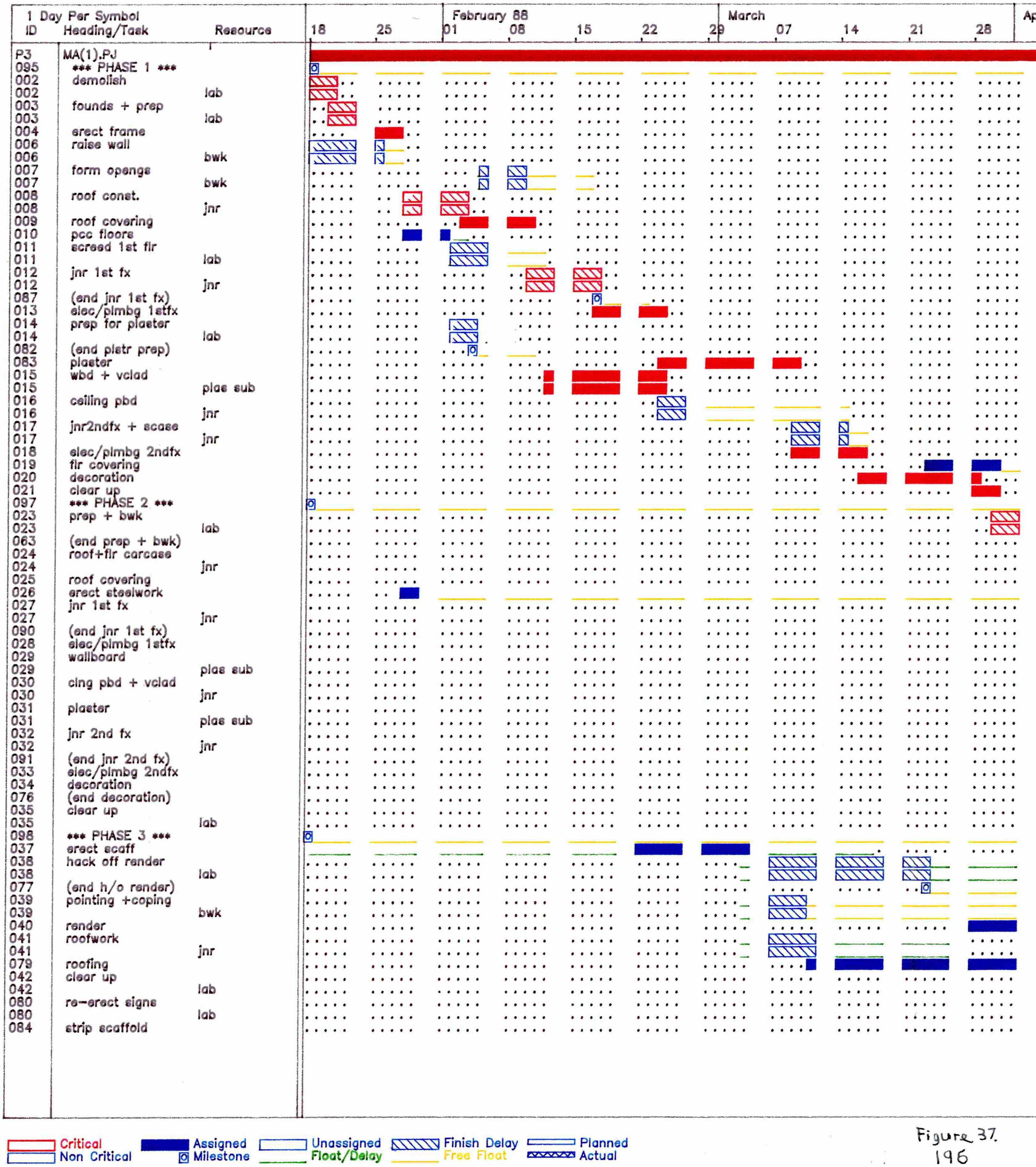
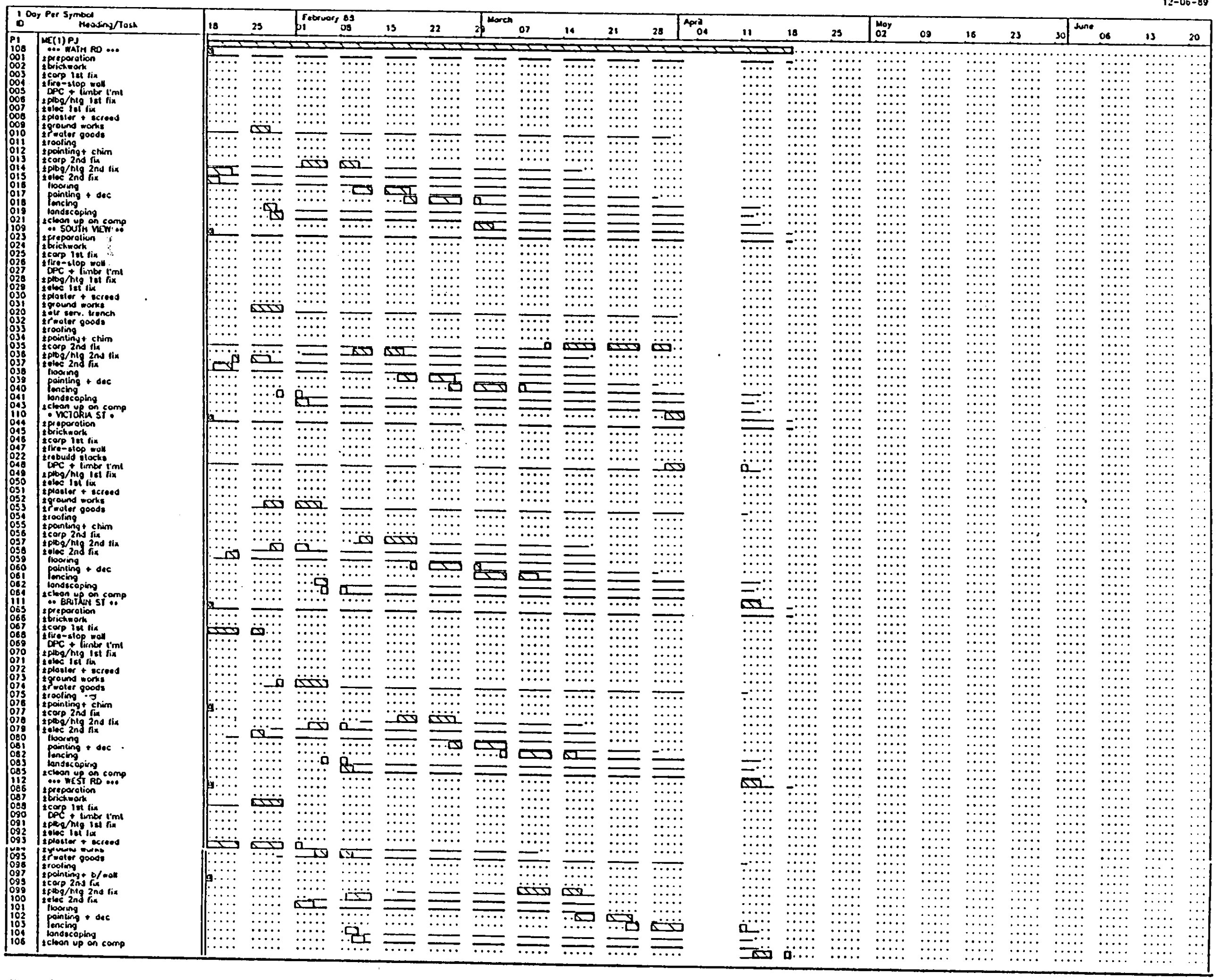


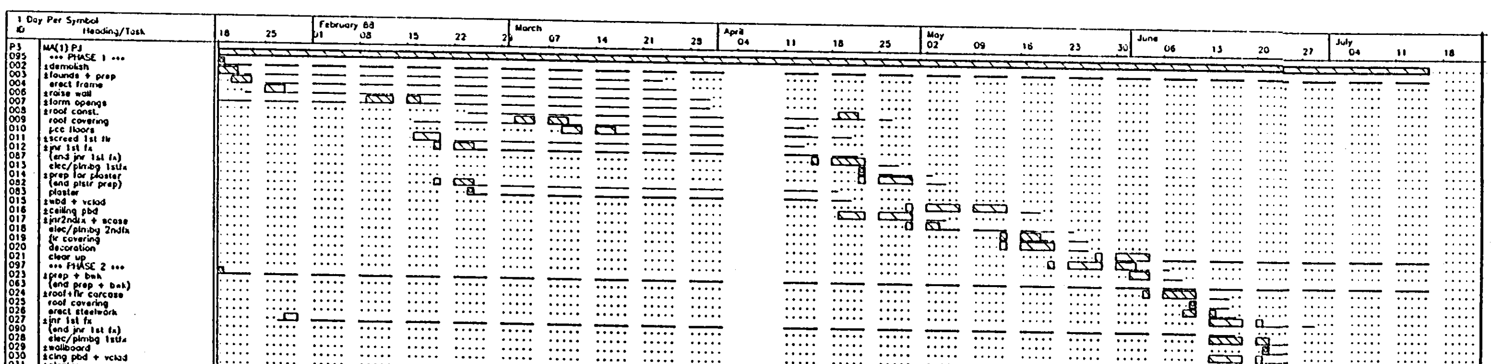
Figure 37.

Mexboro
Task Gantt

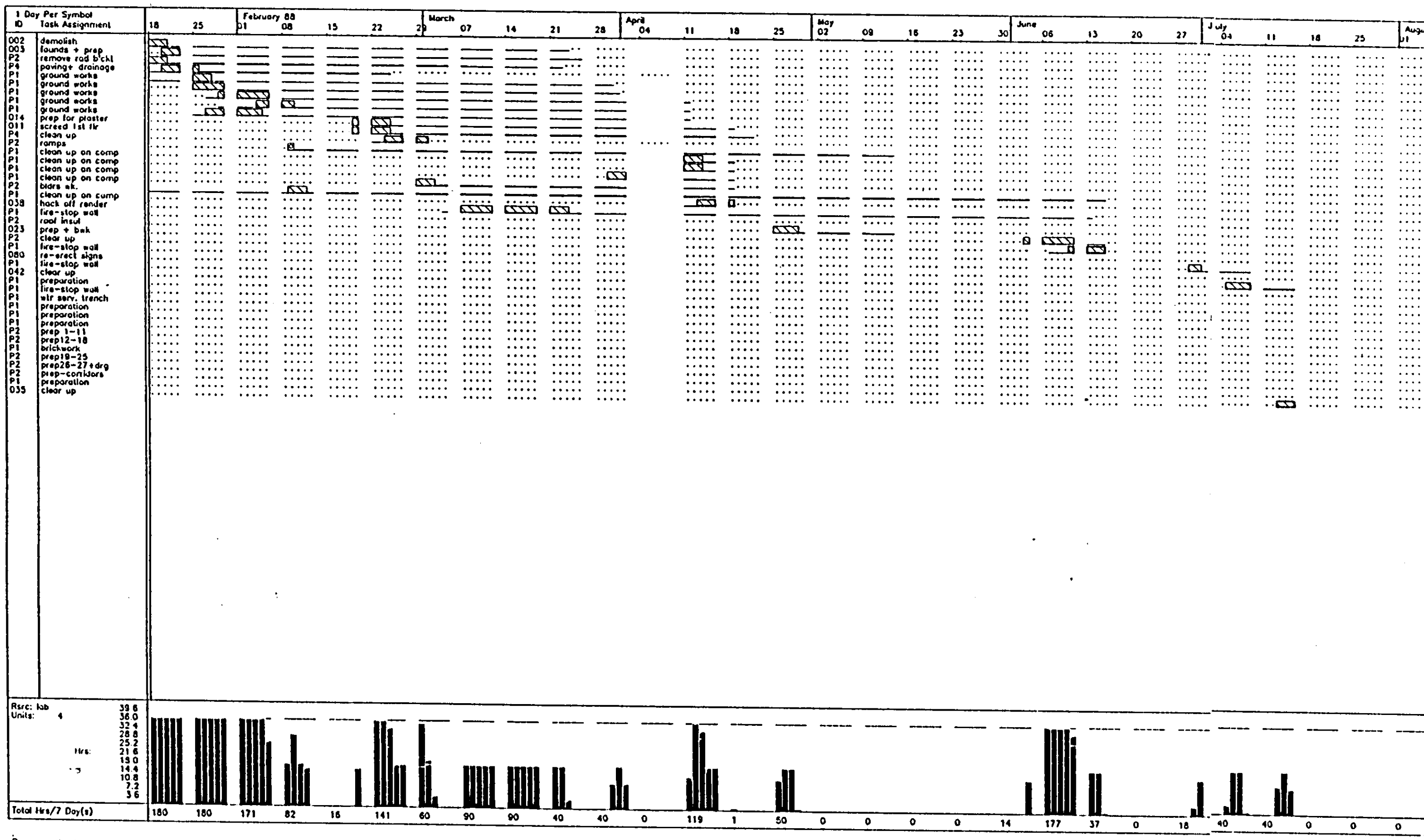
Project: ME(1) PJ
12-06-89



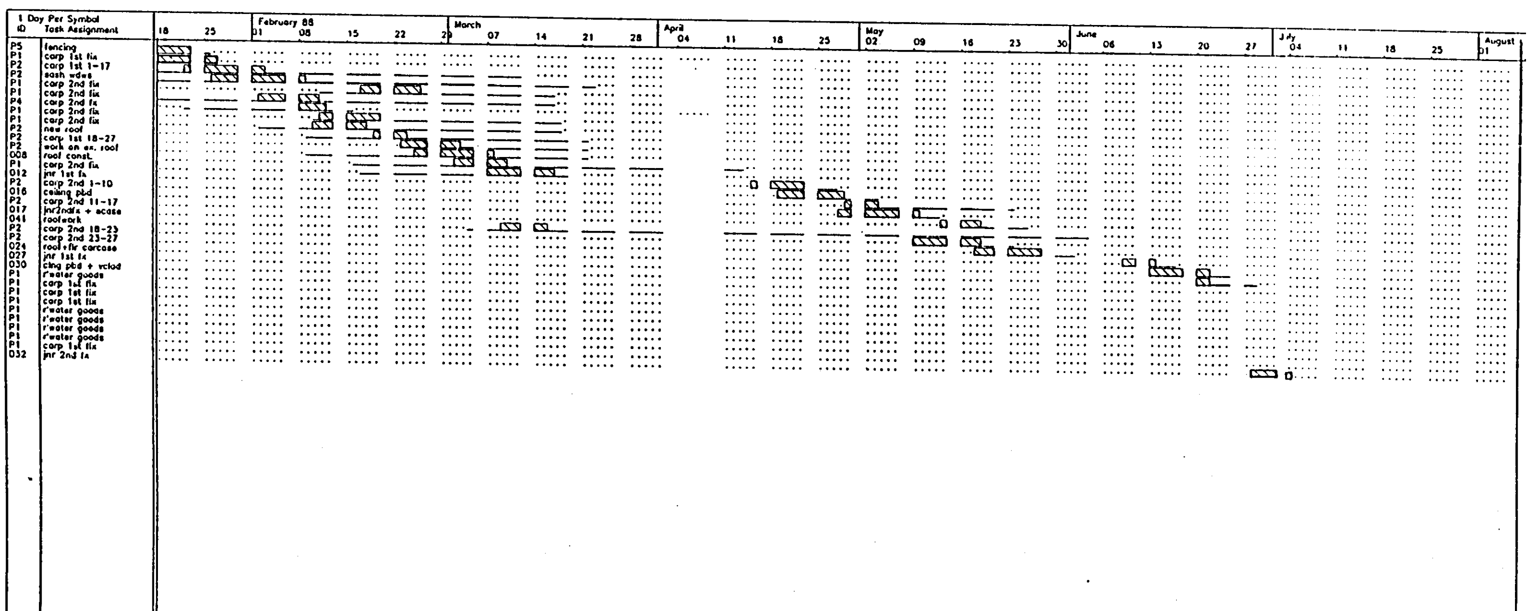
Masboro St., Bar Refrigeration
Task Gantt



Resource Gantt



Resource Gantt



VARIATIONS 18-1-88 - 25-1-88

	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	VAR'N HRS
MEXBORO	fire-stop wall	42		11	29	15	Completed/Crit.	29
"	brickwork	87	TARGET 2	95	54	15	Scheduled/Crit.	-29
MASBORO	conc. floor	1		81	60	5	Scheduled	60
"	jnr`1st fx	12	TARGET 4	62	61	10	Scheduled	-32
"	deeper founds	22		99	138	5	Scheduled	138
"	hack off render	38	TARGET 3/	54	236	5	Scheduled	16
CRANWORTH	int. bwk 9-17	12	TARGET 11	12	140	5	Completed/Crit.	-43
"	carp 1st 1-17	20	TARGET 9A	93	181	10	Interrupted	48
"	bwk repairs	23		64	14	15	Scheduled	14
"	carp 1st 18-27	26	TARGET 9B	76	154	10	Scheduled	48

MAJOR PRIORITY CHANGES (>10) 18-1-88 - 25-1-88

	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	PRI. CHANGE
MEXBORO	clean up on com	21		74	40	5	Scheduled	18
"	carp 2nd fix	35	TARGET 6	87	104	10	Scheduled	11
"	elec 2nd fix	58		59	15	20	Scheduled	-20
CRANWORTH	sash wdws	13	TARGET 19	79	156	10	Scheduled	-11
ELLIS ST	carp 2nd fx	3		96	64	10	Scheduled	14

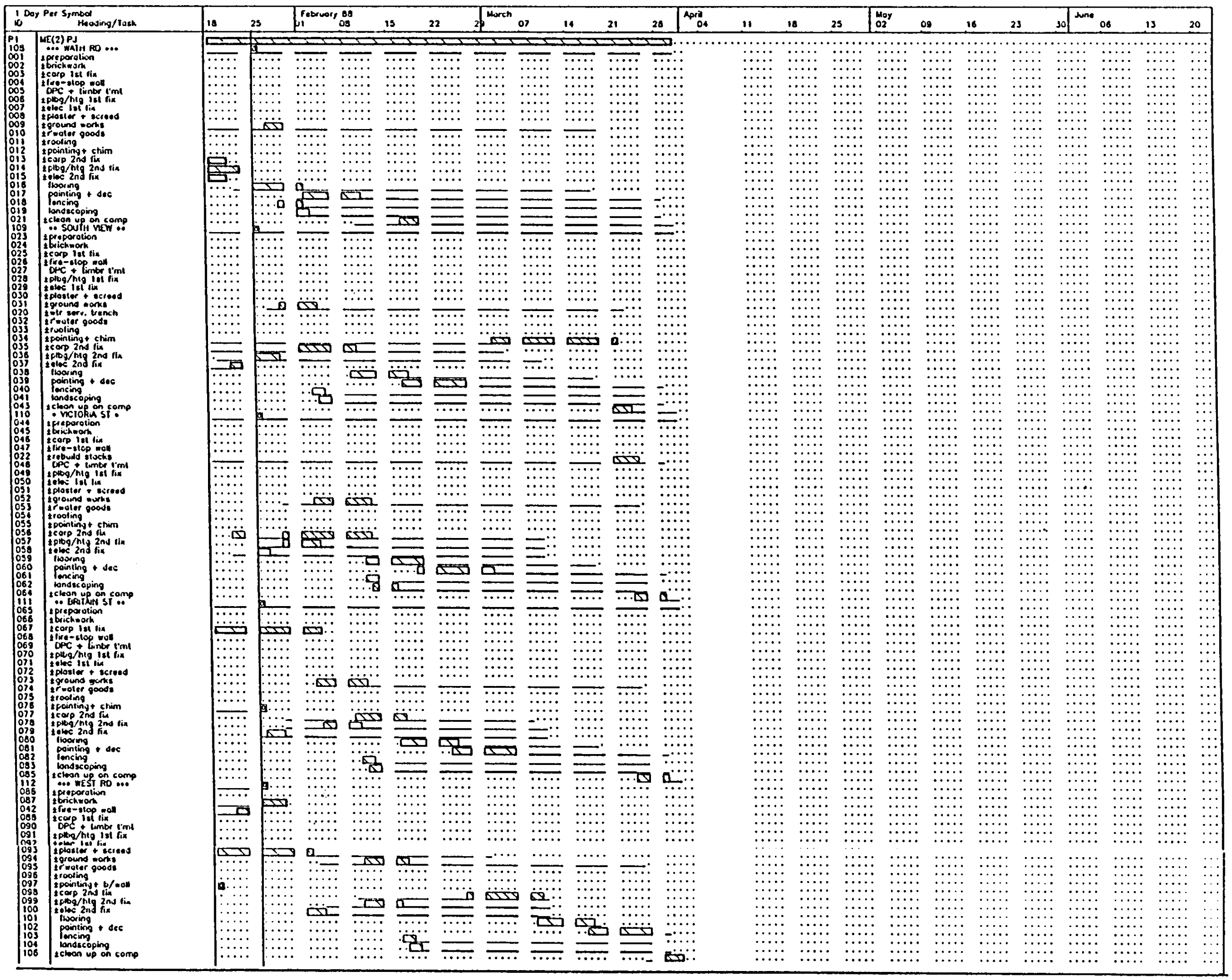
TRADES:-

'5'	LABOURER
'10'	JOINER
'15'	BRICKLAYER
> '15'	OTHER TRADES

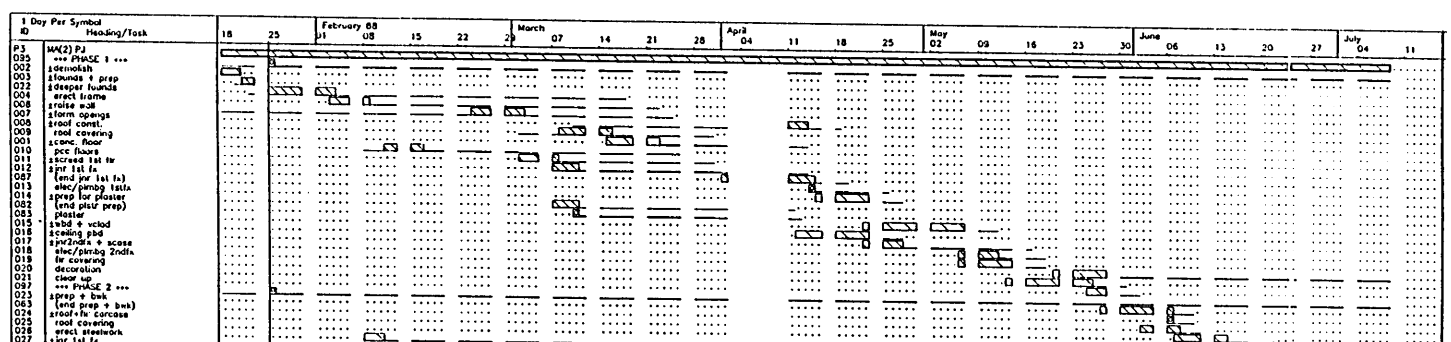
Tables 5(a), 6(a). VARIATIONS, AND CHANGES IN PRIORITY > 10% AS CALCULATED BY NEWRULE, BETWEEN UPDATES 1 & 2

Hexboro
Task Gantt

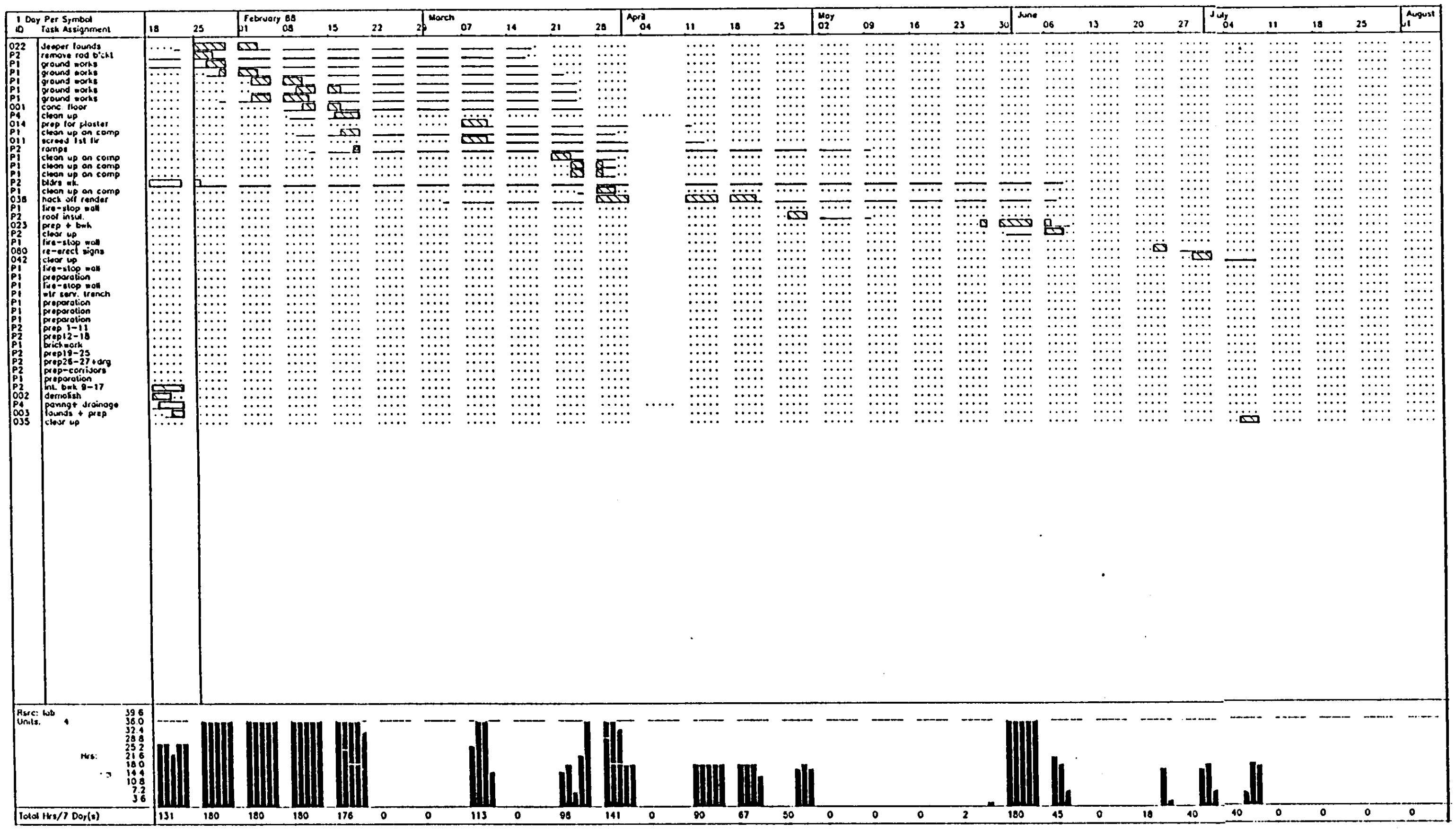
Project: ME(2) PJ
12-06-89



Masboro St, Bar Refrigeration
Task Gantt



Resource Contt



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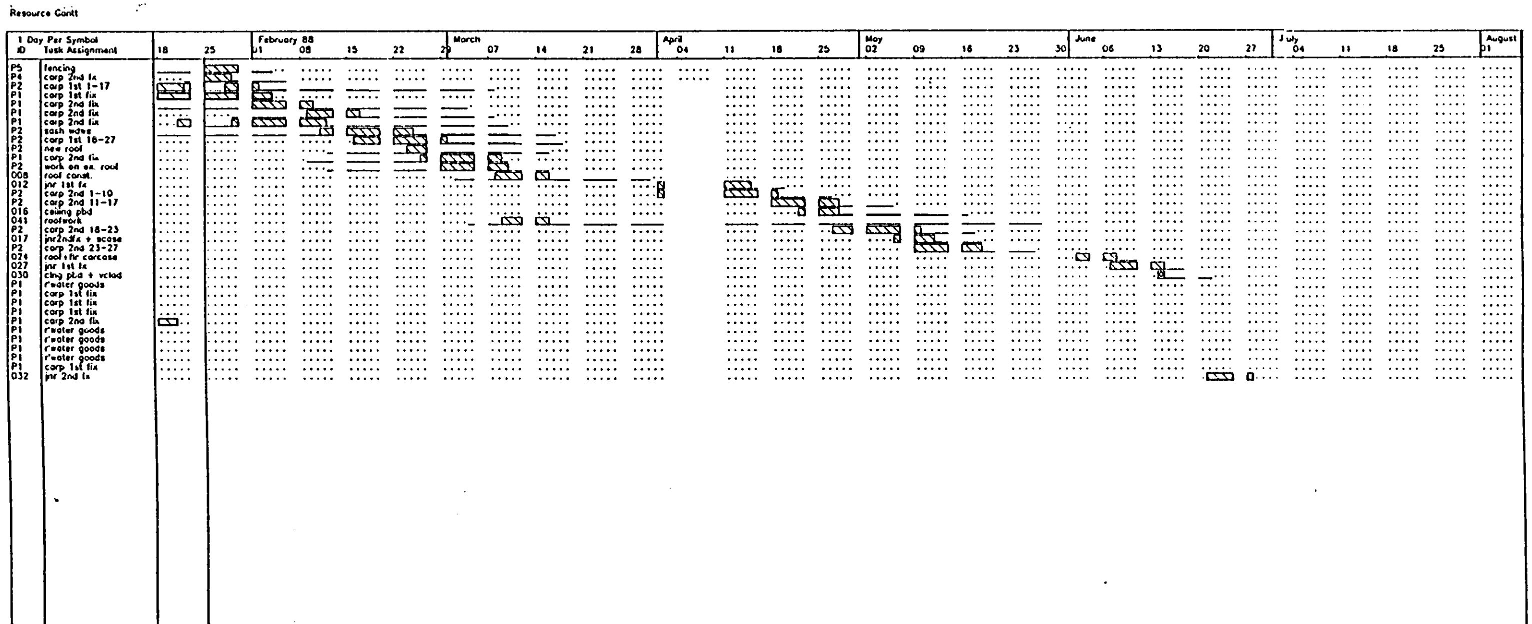


VARIATIONS 25-1-88 - 1-2-88

	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	VAR'N HRS
MASBORO	roof const.	8	TARGET 3	73	117	10	Scheduled	32
"	roofwork	41	TARGET 3/	56	117	10	Scheduled	29
"	remove wall bea	43		67	142	5	Scheduled	142
CRANWORTH	carp 1st 1-17	20	TARGET 9A	93	186	10	Interrupted	5
WOODSET	Sclean up+extras	3		88	45	15	Interrupted/Cri	45

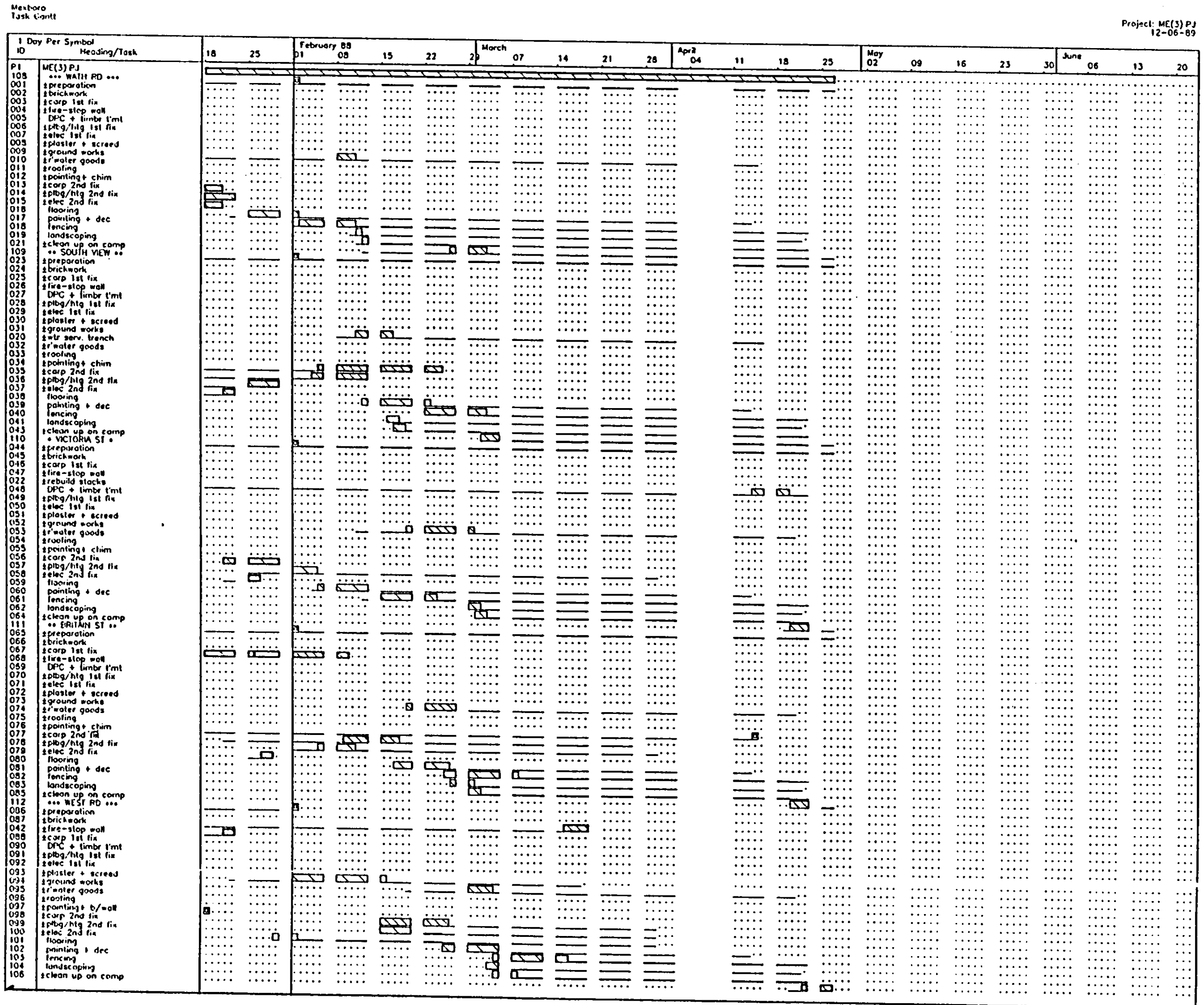
MAJOR PRIORITY CHANGES (>10) 25-1-88 - 1-2-88

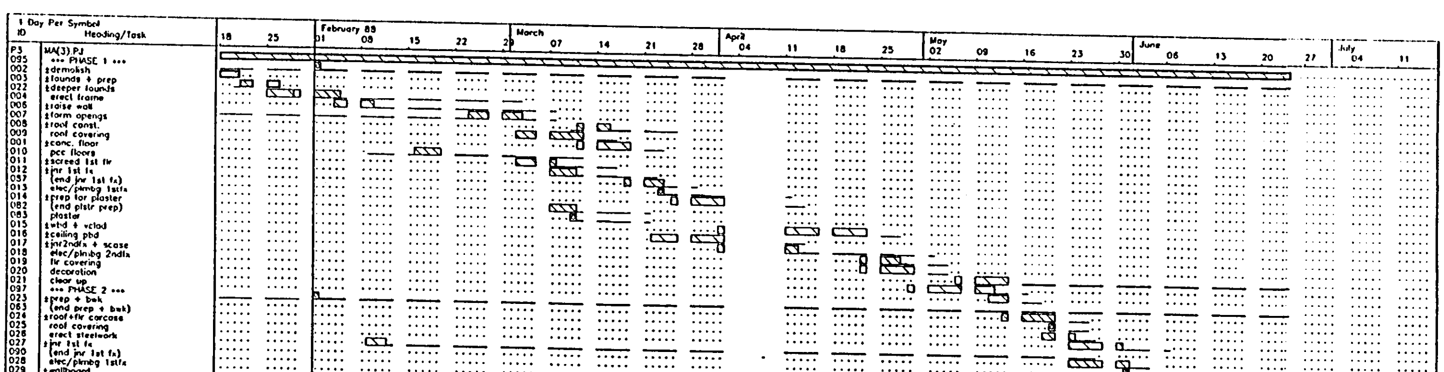
	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	PRI. CHANGE
MEXBORO	elec 2nd fix	100		59	15	20	Interrupted	-40

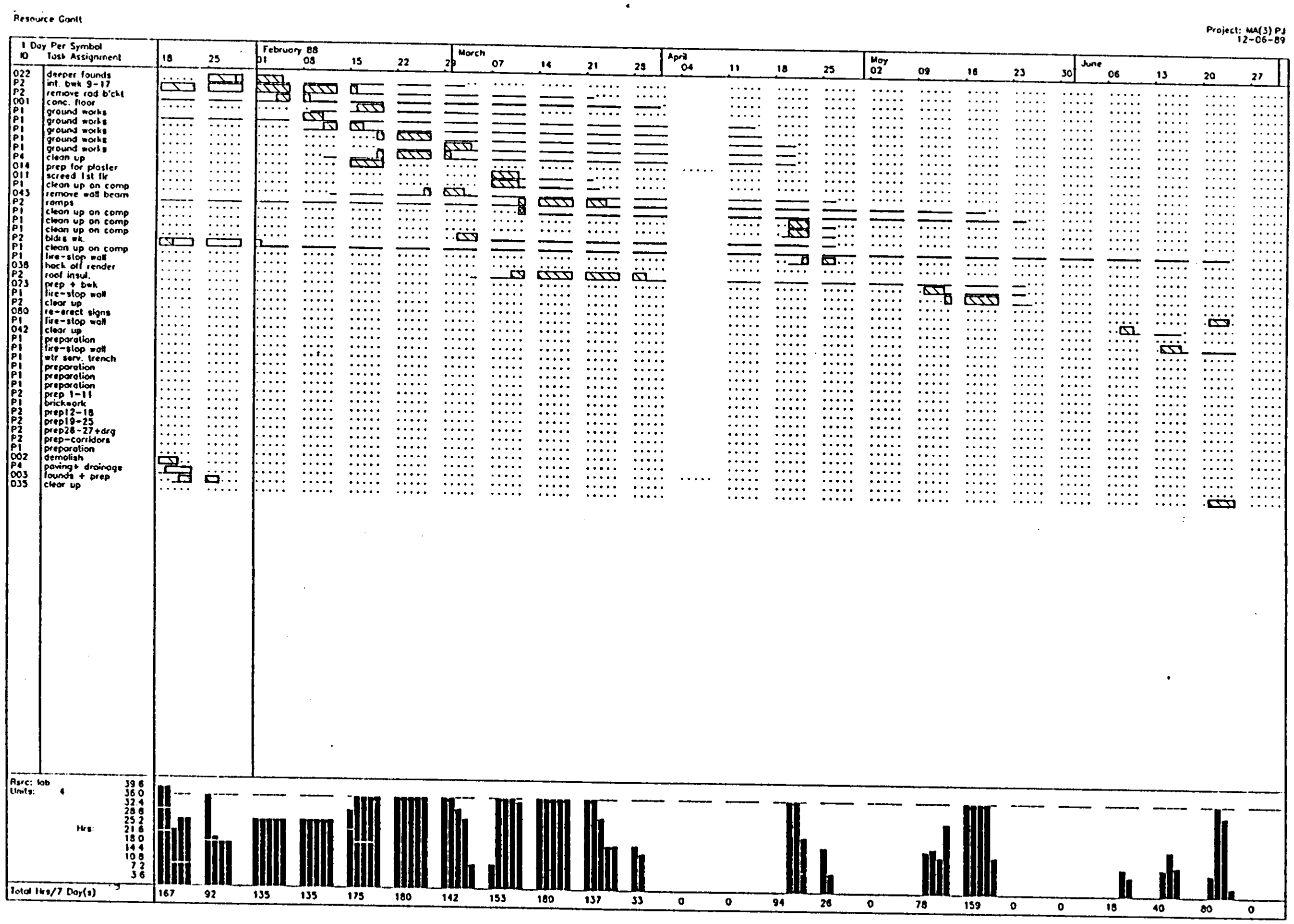
TRADES:-

'5'	LABOURER
'10'	JOINER
'15'	BRICKLAYER
> '15'	OTHER TRADES

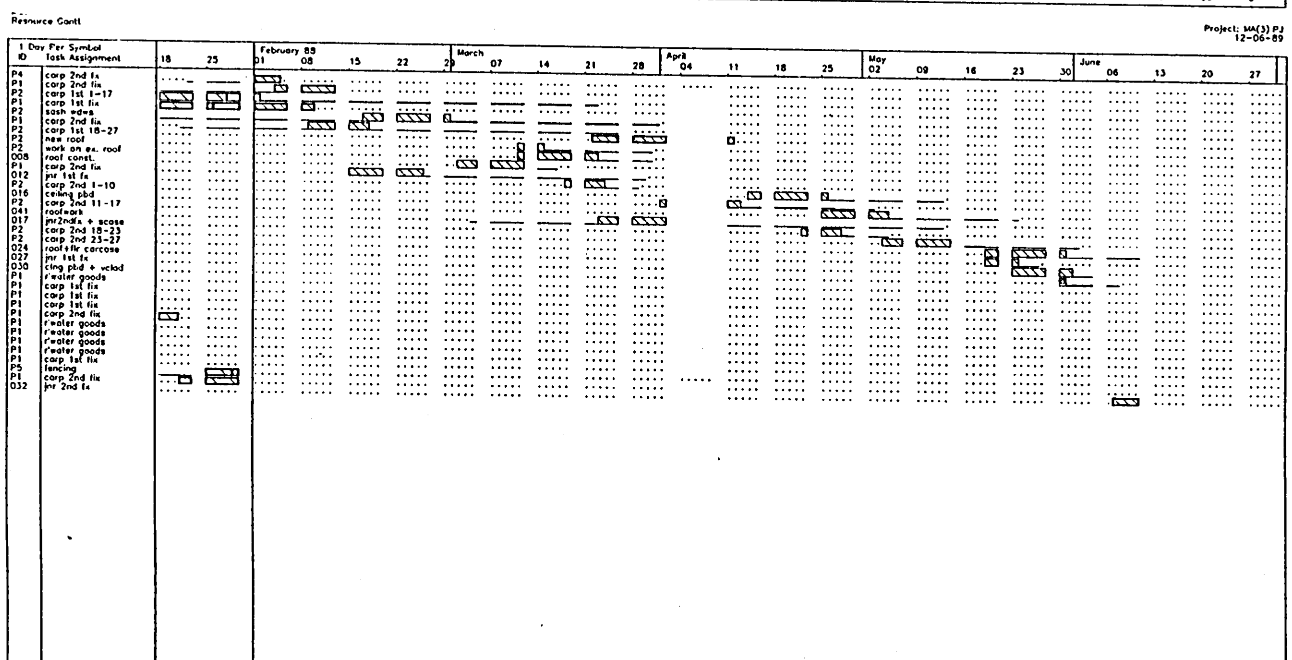
Tables 5(b), 6(b). VARIATIONS, AND CHANGES IN PRIORITY > 10% AS CALCULATED BY NEWRULE, BETWEEN UPDATES 2 & 3


Mexboro
Task Gantt
Project: ME(3) PJ
12-06-89
1 Day Per Symbol
ID
Heading/Task
February 89
March
April
May
June
ME(3) PJ
*** WATH RD ***
** SOUTH VIEW **
* VICTORIA ST *
** BRITAIN ST **
*** WEST RD ***


Mexboro St., Bar Refrigeration
Task Gantt
1 Day Per Symbol
ID
Heading/Task
February 89
March
April
May
June
July
MA(3) PJ
*** PHASE 1 ***
*** PHASE 2 ***



Resource Gantt
Project: MA(3) PJ
12-06-89
1 Day Per Symbol
ID Task Assignment
18 25
February 88
01 08 15 22 29
March
07 14 21 28
April
04 11 18 25
May
02 09 16 23 30
June
06 13 20 27
022 deeper founds
P2 int. bwk 9-17
P2 remove rad b'ckt
001 conc. floor
P1 ground works
P1 ground works
P1 ground works
P1 ground works
P1 ground works
P4 clean up
014 prep for plaster
011 screed 1st flr
P1 clean up on comp
043 remove wall beam
P2 ramps
P1 clean up on comp
P1 clean up on comp
P1 clean up on comp
P2 bldrs wk.
P1 clean up on comp
P1 fire-stop wall
038 hack off render
P2 roof insul.
023 prep + bwk
P1 fire-stop wall
P2 clear up
080 re-erect signs
P1 fire-stop wall
042 clear up
P1 preparation
P1 fire-stop wall
P1 wtr serv. trench
P1 preparation
P1 preparation
P1 preparation
P2 prep 1-11
P1 brickwork
P2 prep12-18
P2 prep19-25
P2 prep28-27+drg
P2 prep-corridors
P1 preparation
002 demolish
P4 paving+ drainage
003 founds + prep
035 clear up
Rsrc: lab
Units: 4
Hrs:
39 6
36 0
32 4
28 8
25 2
21 6
18 0
14 4
10 8
7 2
3 6
Total Hrs/7 Day(s)
167 92 135 135 175 180 142 153 180 137 33 0 0 94 26 0 78 159 0 0 18 40 80 0



Resource Gantt
Project: MA(3) PJ
12-06-89
1 Day Per Symbol
ID Task Assignment
18 25
February 88
01 08 15 22 29
March
07 14 21 28
April
04 11 18 25
May
02 09 16 23 30
June
06 13 20 27
P4 carp 2nd fx
P1 carp 2nd fix
P2 carp 1st 1-17
P1 carp 1st fix
P2 sash wdws
P1 carp 2nd fix
P2 carp 1st 18-27
P2 new roof
P2 work on ex. roof
008 roof const.
P1 carp 2nd fix
012 jnr 1st fx
P2 carp 2nd 1-10
016 ceiling pbd
P2 carp 2nd 11-17
041 roofwork
017 jnr2ndfx + scase
P2 carp 2nd 18-23
P2 carp 2nd 23-27
024 roof+flr carcase
027 jnr 1st fx
030 clng pbd + vclad
P1 r'water goods
P1 carp 1st fix
P1 carp 1st fix
P1 carp 1st fix
P1 carp 2nd fix
P1 r'water goods
P1 r'water goods
P1 r'water goods
P1 r'water goods
P1 carp 1st fix
P5 fencing
P1 carp 2nd fix
032 jnr 2nd fx

VARIATIONS 1-2-88 - 8-2-88

Task Name		ID	Task Desc	Pri	Hrs	Trade	Status	VAR'N HRS
MEXBORO	replace joist	63		88	7	10	Scheduled	7
"	brickwork	87	TARGET 2	95	59	15	Scheduled/Crit.	5
MASBORO	replace asb sht	44		70	4	10	Scheduled	4
CRANWORTH	carp 1st 18-27	26	TARGET 9B	85	160	10	Interrupted	6
ELLIS ST	lintol	9		13	27	15	Completed/Crit.	27
"	pack up walls	10		10	27	15	Completed/Crit.	27
WOODSET	extra + snaggin	4		7	27	10	Completed/Crit.	27

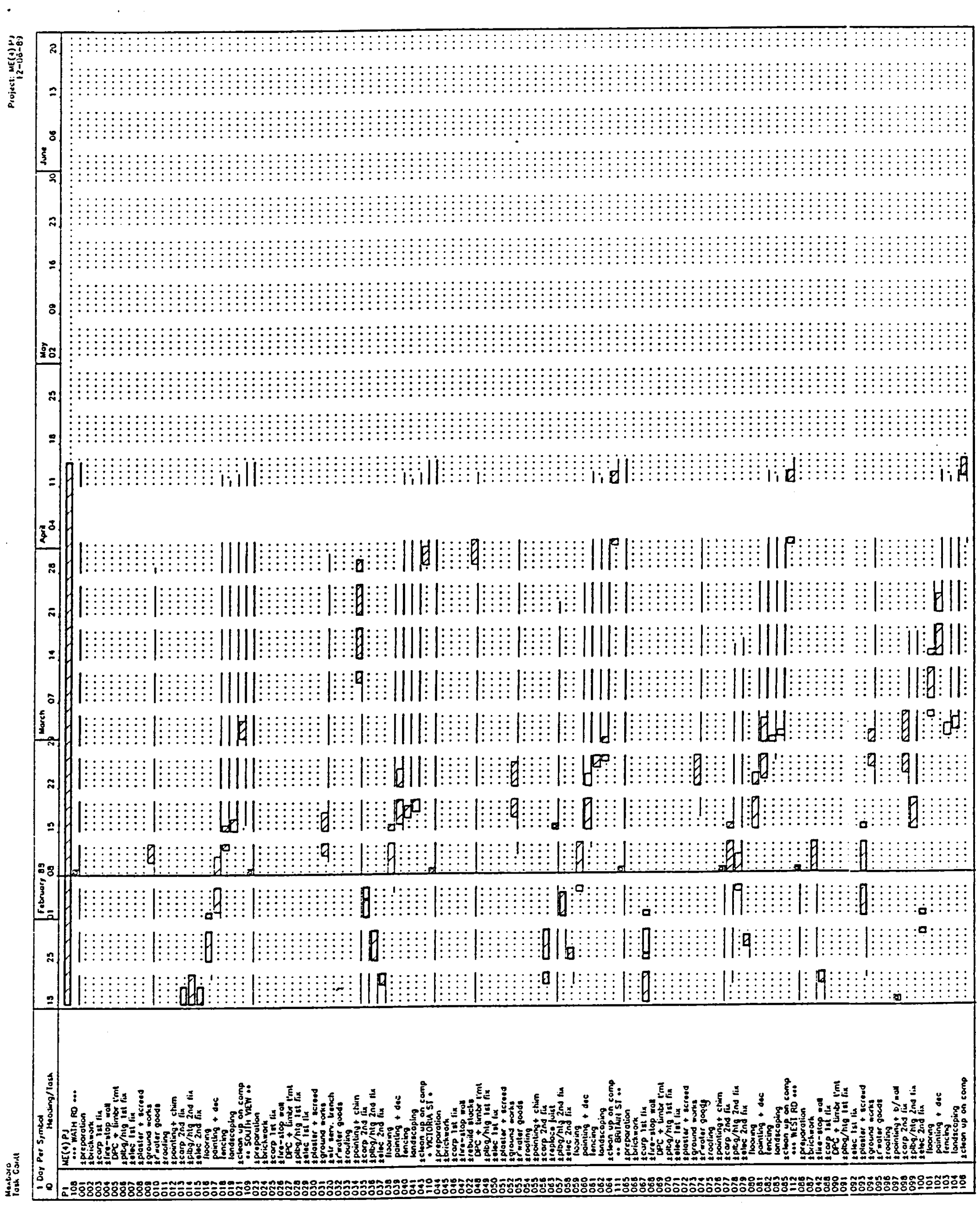
MAJOR PRIORITY CHANGES (>10) 1-2-88 - 8-2-88

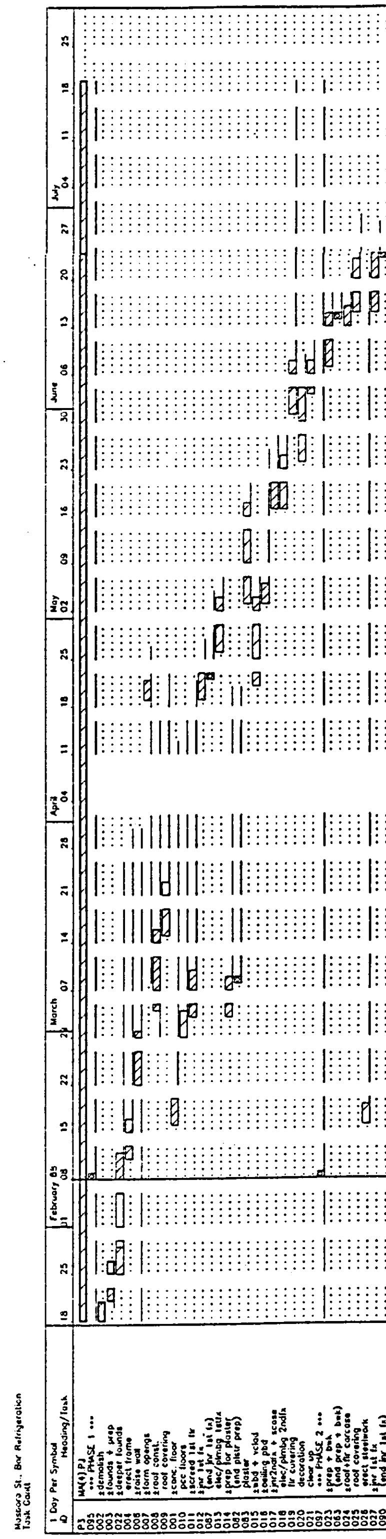
Task Name		ID	Task Desc	Pri	Hrs	Trade	Status	PRI. CHANGE
MEXBORO	carp 2nd fix	98	TARGET 6	83	136	10	Scheduled	13
MASBORO	hack off render	38	TARGET 3/	65	236	5	Interrupted	15
"	roofwork	41	TARGET 3/	67	117	10	Scheduled	11

TRADES:-

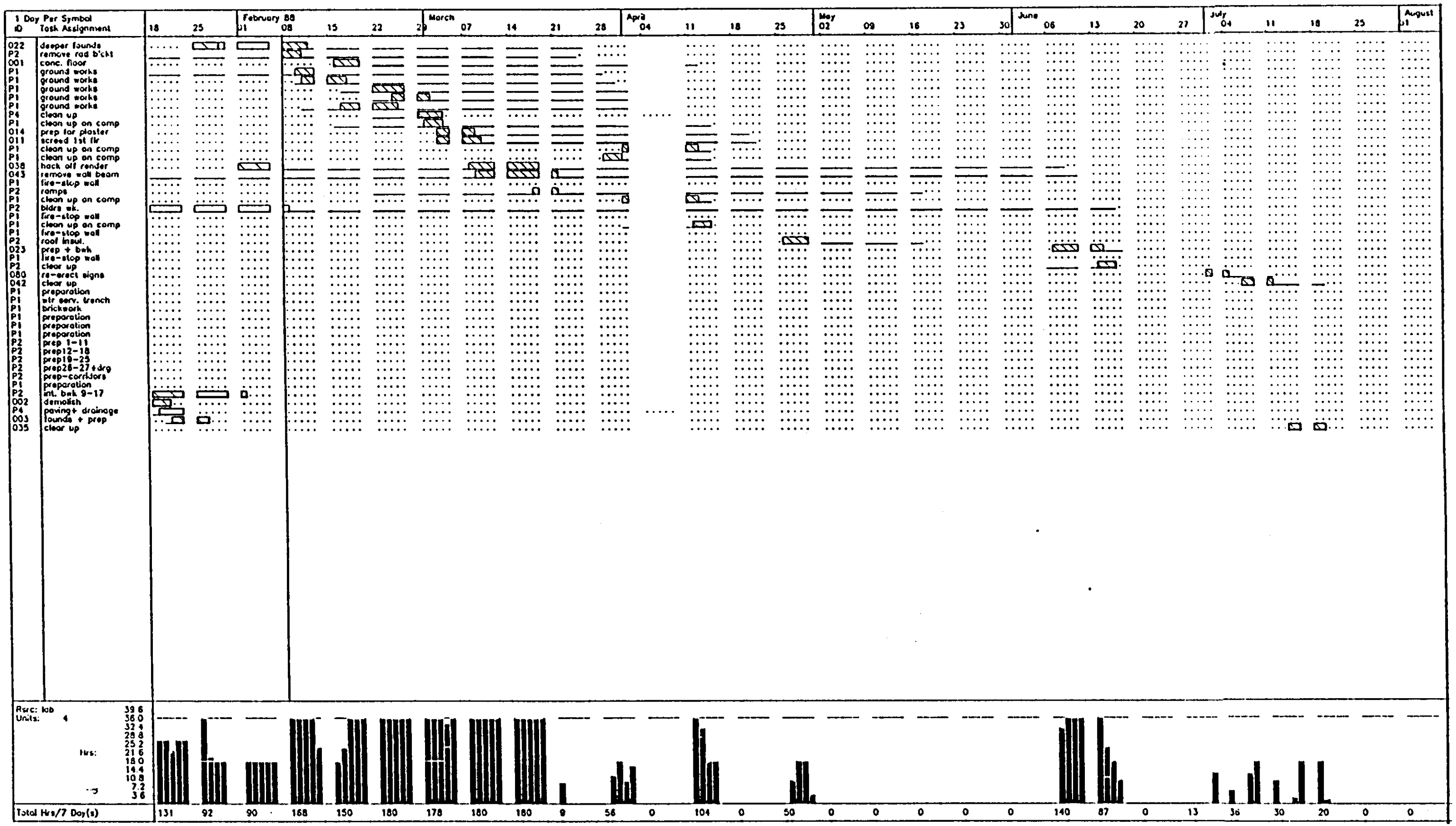
'5'	LABOURER
'10'	JOINER
'15'	BRICKLAYER
> '15'	OTHER TRADES

Tables 5(c), 6(c). VARIATIONS, AND CHANGES IN PRIORITY > 10% AS CALCULATED BY NEWRULE, BETWEEN UPDATES 3 & 4

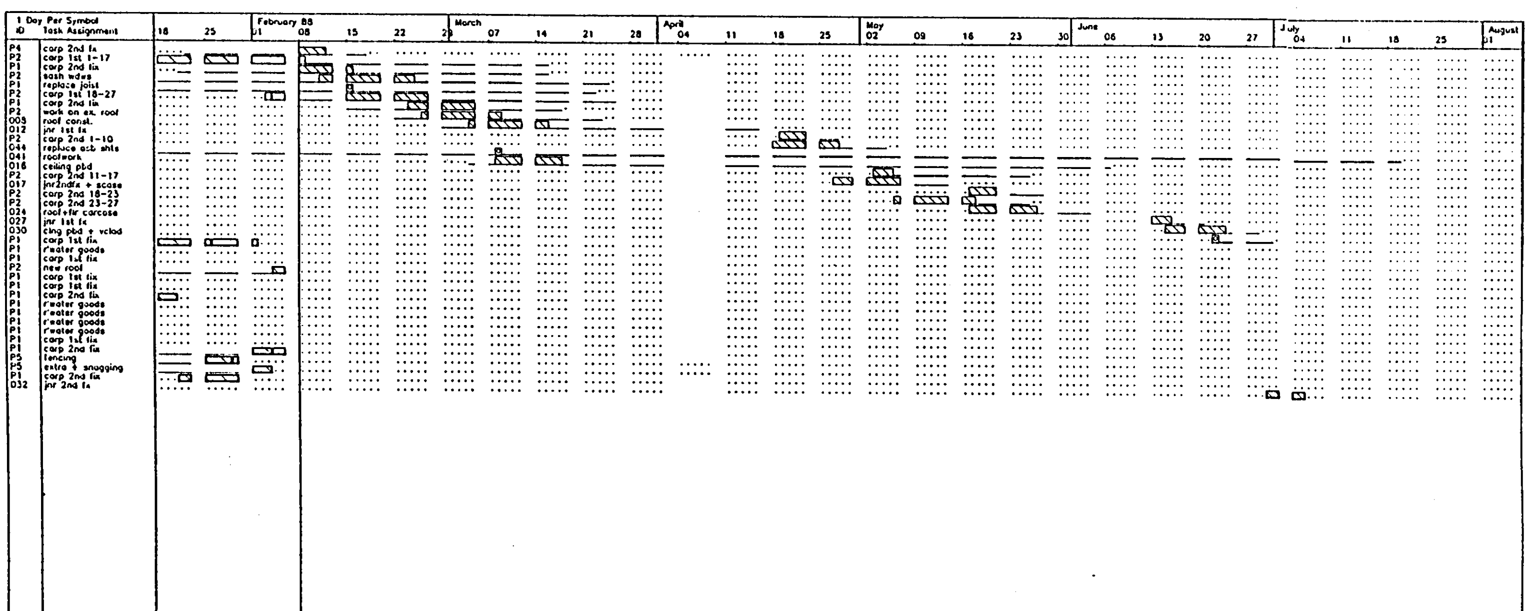




Resource Contt



Resource Contt



VARIATIONS 8-2-88 - 15-2-88

	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	VAR'N HRS
MEXBORO	add. drainage	84		84	6	5	Scheduled	6
"	repoint passage	89		67	29	15	Completed/Crit.	29
"	replace gutters	105		45	5	10	Completed/Crit.	5
"	extra joinery	107		43	9	10	Completed/Crit.	9
MASBORO	form opengs	7	TARGET 5	77	47	15	Scheduled	6
CRANWORTH	bldrs wk.	25		54	207	5	Interrupted	167
"	carp 2nd 23-27	36	TARGET 16	60	143	10	Scheduled	18
OTHER	Shaw's patio d'	5		5	18	10	Completed/Crit.	-64

MAJOR PRIORITY CHANGES (>10) 8-2-88 - 15-2-88

	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	PRI. CHANGE
MASBORO	raise wall	6	TARGET 2	99	95	15	Scheduled	11
CRANWORTH	carp 2nd 11-17	40	TARGET 14	76	125	10	Scheduled	14

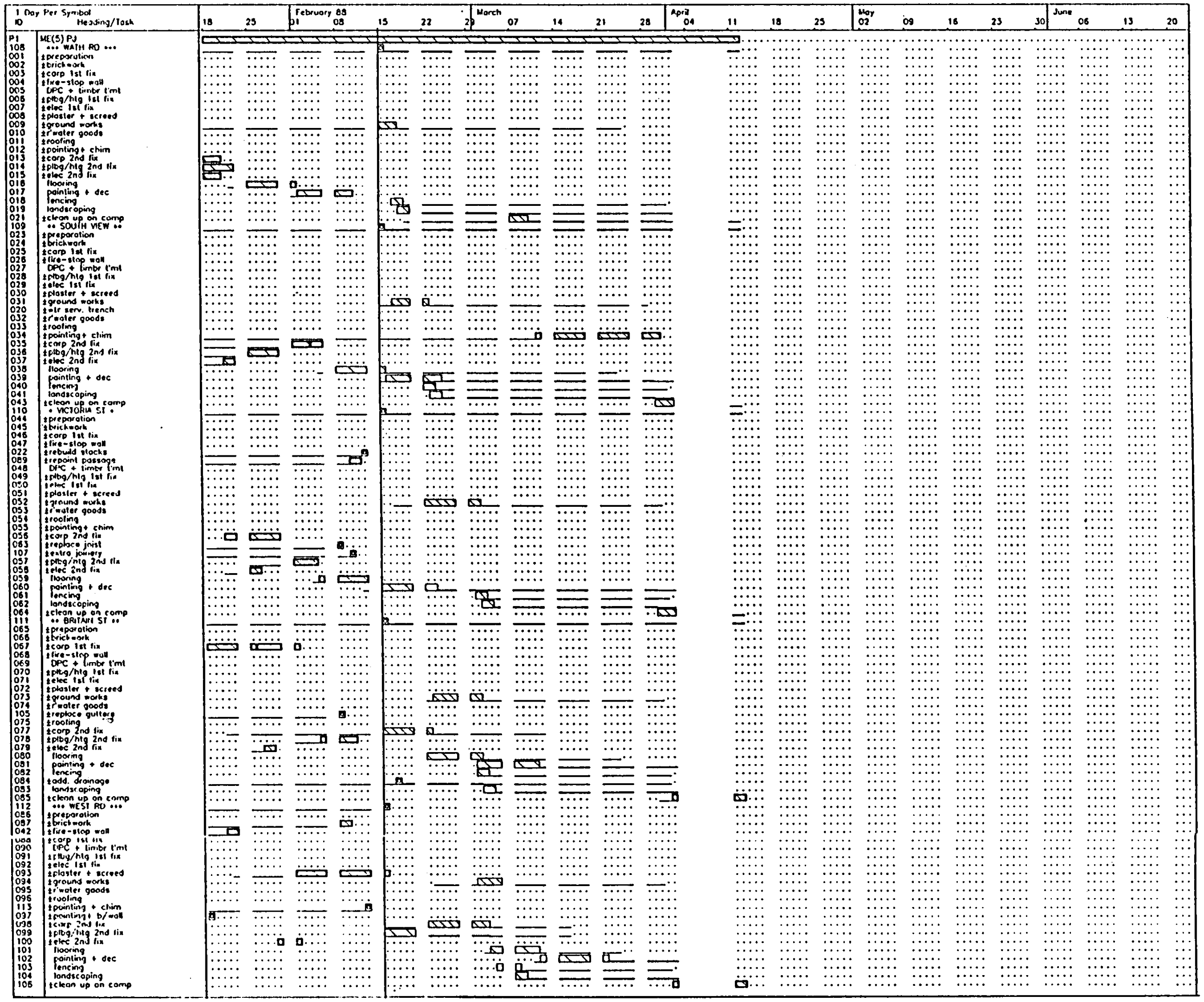
TRADES:-

'5'	LABOURER
'10'	JOINER
'15'	BRICKLAYER
> '15'	OTHER TRADES

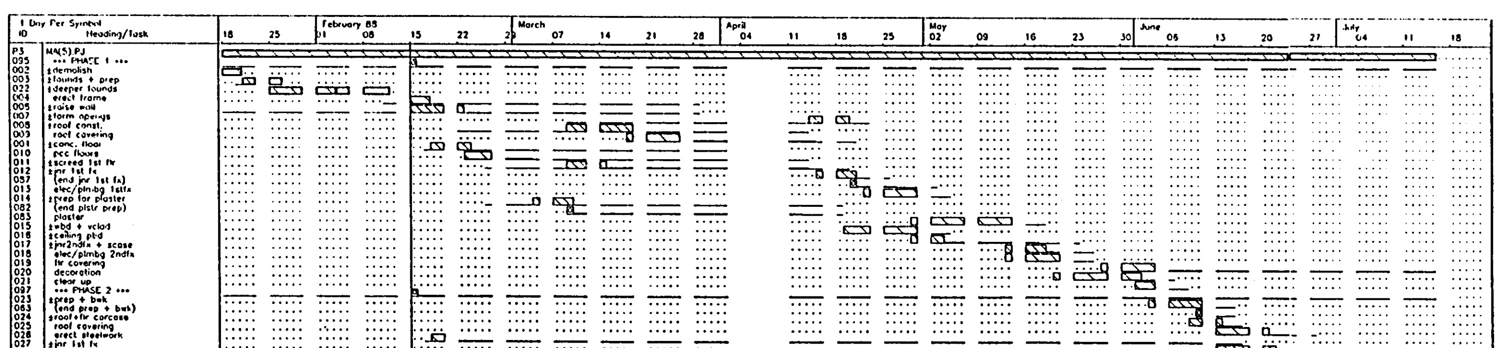
Tables 5(d), 6(d). VARIATIONS, AND CHANGES IN PRIORITY > 10% AS CALCULATED BY NEWRULE, BETWEEN UPDATES 4 & 5

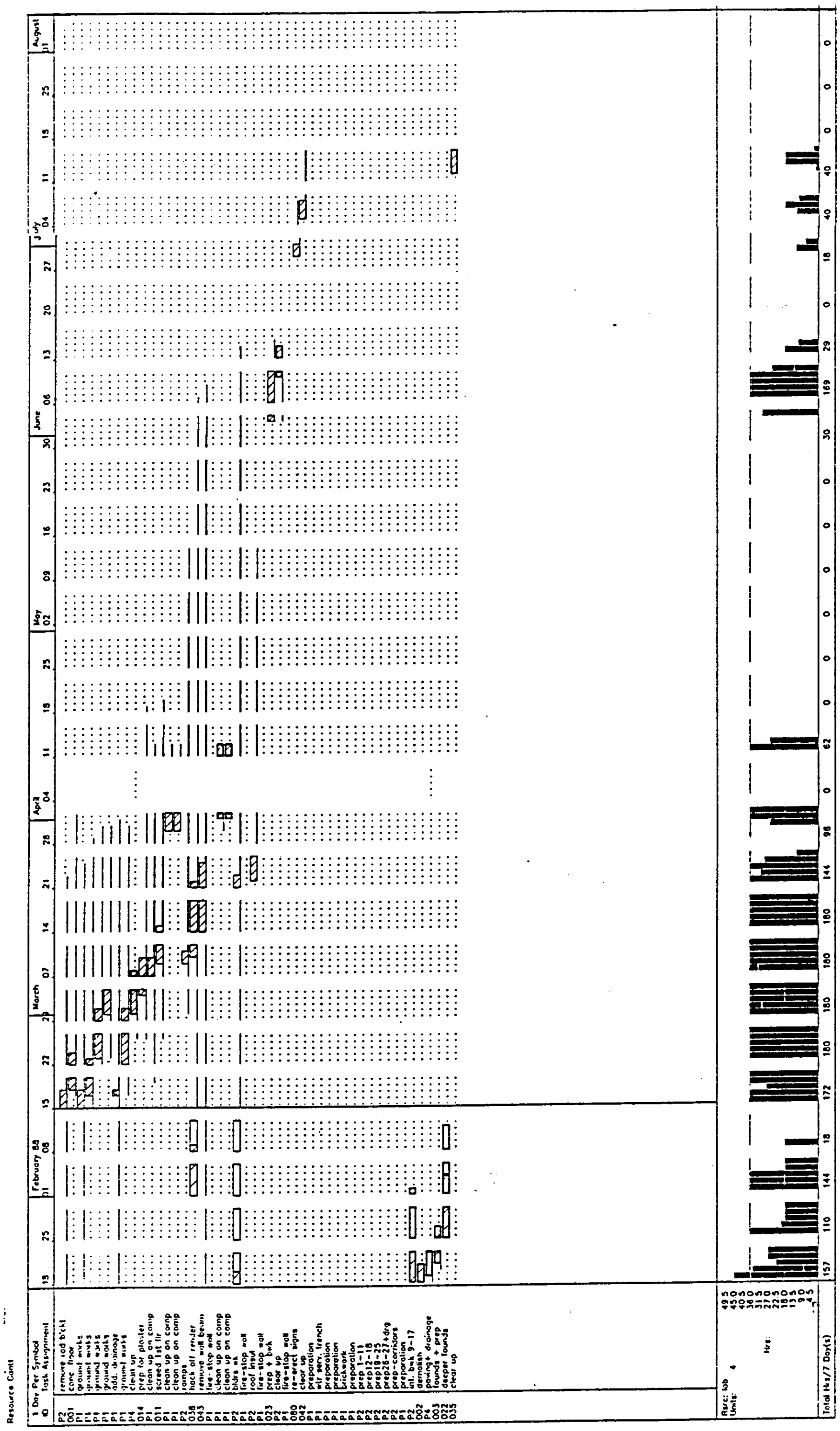
Mexboro
Task Gantt

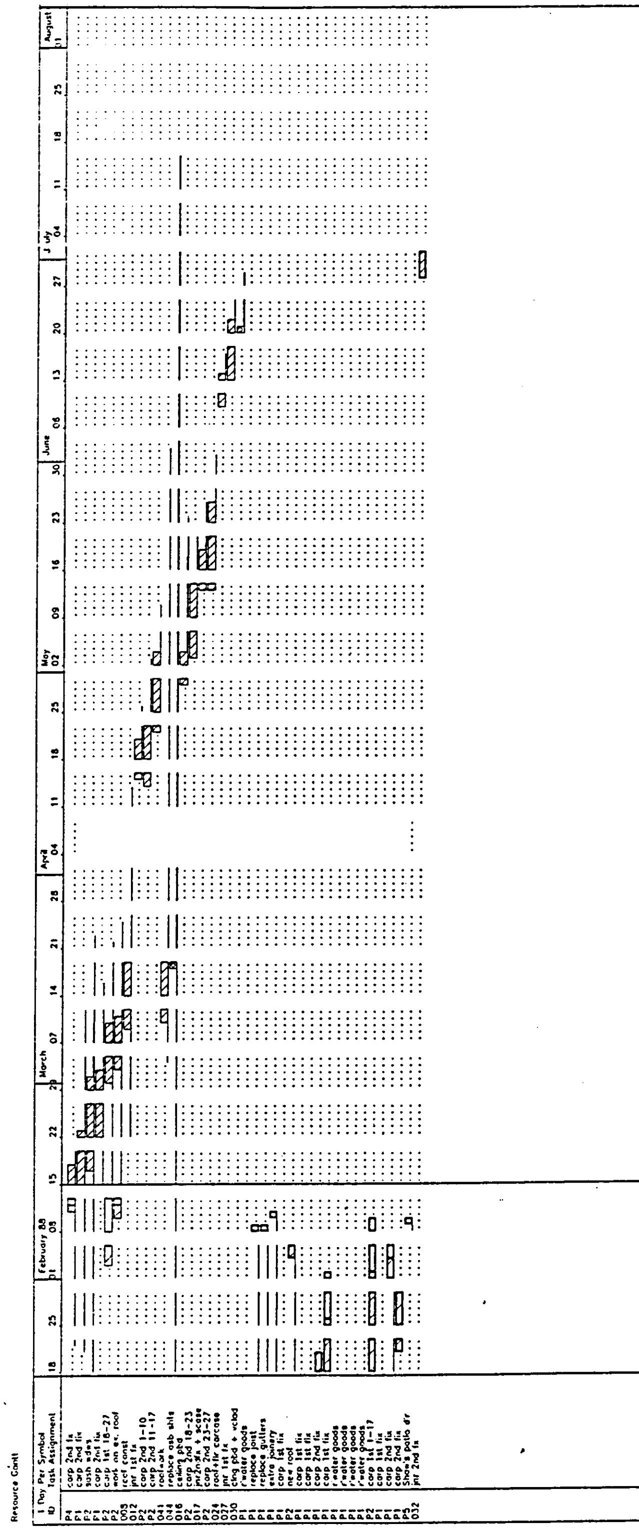
Project: ME(5) PJ
11-06-89



Mexboro St., Bar Refrigeration
Task Gantt







VARIATIONS 15-2-88 - 14-3-88

	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	VAR'N HRS
MEXBORO	ground works	31	TARGET 4	96	80	5	Scheduled/Crit.	16
"	pointing+ chim	34	TARGET 7	14	224	15	Completed/Crit.	-8
"	ground works	73	TARGET 4	95	102	15	Interrupted/Cri	12
"	plaster + scree	93		99	103	25	Interrupted/Cri	8
"	hang h/w doors	114		57	9	10	Completed/Crit.	9
"	chim. + pointin	115		67	9	15	Completed/Crit.	9
"	demolish wc	116		82	40	5	Scheduled	40
"	demolish wc	117		86	18	5	Scheduled	18
MASBORO	erect scaff	37		85	9	10	Interrupted	9
"	pointing +copin	39	TARGET 3/	3	27	15	Scheduled	-32
"	remove wall bea	43		22	150	5	Completed/Crit.	8
"	block up opning	45		20	13	5	Completed/Crit.	13
CRANWORTH	carp 2nd 1-10	30	TARGET 13	4	122	10	Completed/Crit.	2
"	carp 2nd 18-23	33	TARGET 15	89	136	10	Interrupted/Cri	2
"	carp 2nd 23-27	36	TARGET 16	80	145	10	Interrupted/Cri	2
"	carp 2nd 11-17	40	TARGET 14	92	127	10	Interrupted/Cri	2
ELLIS ST	brick up f'plac	11		16	9	5	Completed/Crit.	9
OTHER	joinery	7		11	58	10	Completed/Crit.	58
"	labouring	8		10	55	5	Completed/Crit.	55
"	MERTHYR MOT BAY	9		8	144	5	Completed/Crit.	144
"	YT SHARROW fenc	10		9	18	10	Completed/Crit.	18

MAJOR PRIORITY CHANGES (>10) 15-2-88 - 14-3-88

	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	PRI. CHANGE
MEXBORO	rebuild stacks	22		81	58	15	Interrupted	11
"	clean up on com	85		76	40	5	Scheduled	18
MASBORO	roof const.	8	TARGET 3	99	117	10	Scheduled	16
"	screed 1st flr	11	TARGET 10	90	59	5	Scheduled	17
"	prep for plaste	14	TARGET 7	94	54	5	Scheduled	17
"	roof+flr carcas	24	TARGET 2/	78	41	10	Interrupted	20
"	jnr 1st fx	27	TARGET 2/	69	104	10	Scheduled	14
"	clng pbd + vcla	30	TARGET 2/	75	8	10	Scheduled	22
"	clear up	42		60	40	5	Scheduled	18
"	re-erect signs	80		62	18	5	Scheduled	18
CRANWORTH	bwk repairs	23		99	14	15	Scheduled/Crit.	18
"	bldrs wk.	25		68	207	5	Interrupted	14

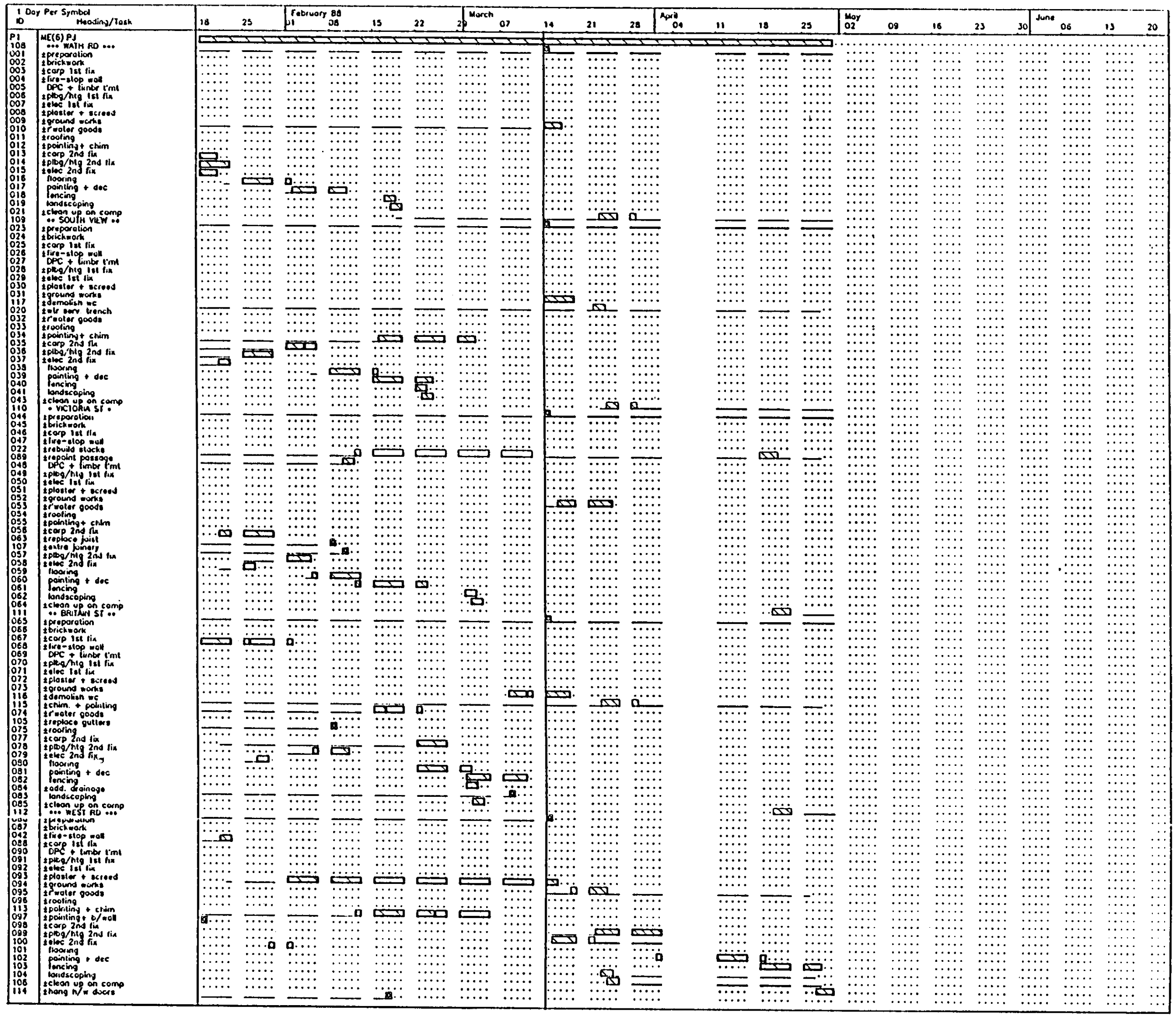
TRADES:-

'5'	LABOURER
'10'	JOINER
'15'	BRICKLAYER
> '15'	OTHER TRADES

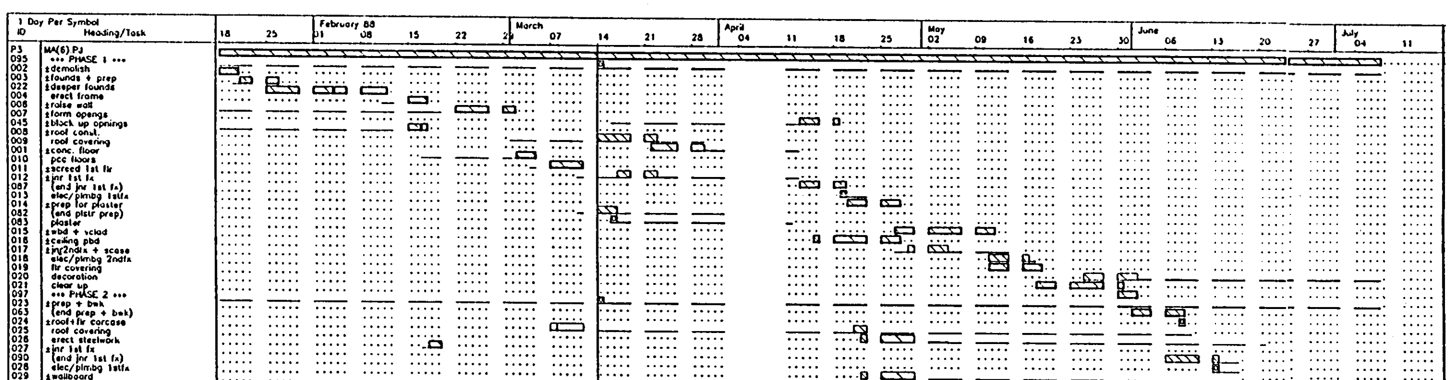
Tables 5(e), 6(e). VARIATIONS, AND CHANGES IN PRIORITY > 10% AS CALCULATED BY NEWRULE, BETWEEN UPDATES 5 & 6

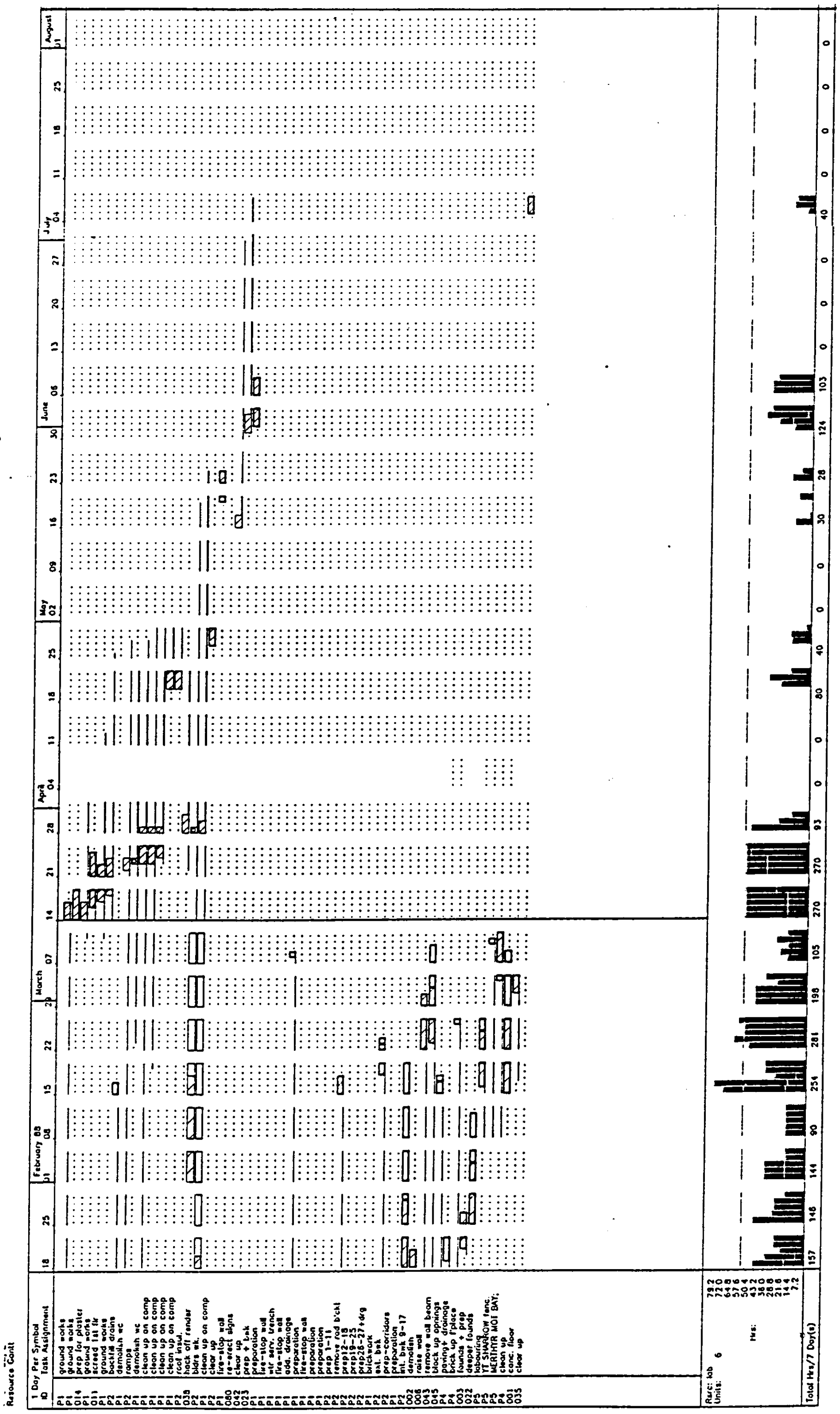
Mexboro
Task Gantt

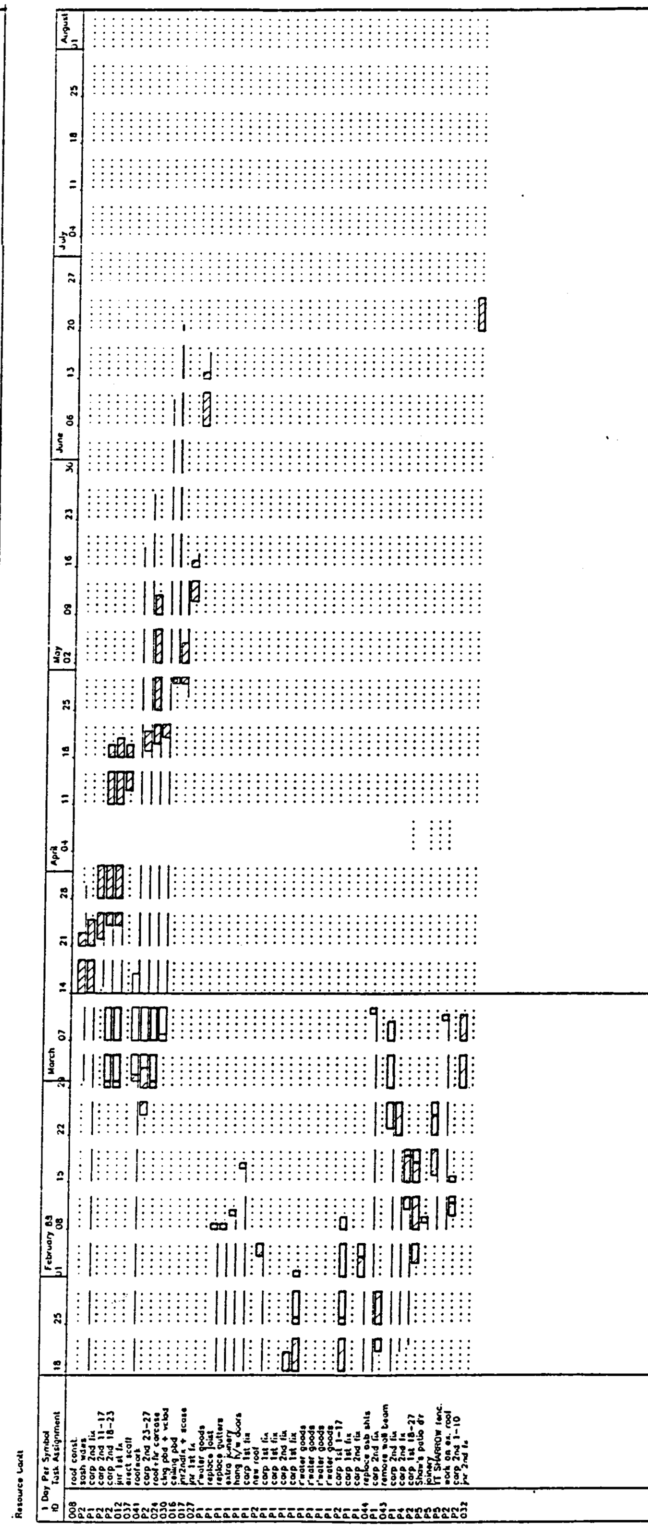
Project: ME(6) PJ
12-06-89



Mexboro St., Bar Refrigeration
Task Gantt







VARIATIONS 14-3-88 - 11-4-88

	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	VAR'N HRS
MEXBORO	ground works	9	TARGET 4	0	45	5	Completed/Crit.	5
"	ground works	31	TARGET 4	0	74	15	Completed/Crit.	-6
MASBORO	jnr 1st fx	12	TARGET 4	88	70	10	Scheduled/Crit.	9
"	prep for plaste	14	TARGET 7	97	63	5	In Progress/Cri	9
"	wbd + vclad	15	TARGET 8	83	208	10	Scheduled/Crit.	136
"	prep + bwk	23	TARGET 2/	69	211	5	Scheduled/Crit.	24
"	roof+flr carcas	24	TARGET 2/	0	74	10	Completed/Crit.	33
"	jnr 1st fx	27	TARGET 2/	74	112	10	Scheduled	8
"	replace windows	46		85	44	10	Scheduled	44
"	clad ext stack	47		89	14	15	Scheduled	14
CRANWORTH	sash wdws	13	TARGET 19	0	172	10	Completed/Crit.	16
"	carp 2nd 1-10	30	TARGET 13	0	123	10	Completed/Crit.	1
"	carp 2nd 18-23	33	TARGET 15	0	137	10	Completed/Crit.	1
"	carp 2nd 23-27	36	TARGET 16	94	149	10	Interrupted	4
"	carp 2nd 11-17	40	TARGET 14	0	128	10	Completed/Crit.	1
OTHER	ELLIS ST snaggi	11		0	355	5	Completed/Crit.	355
"	drainage	13		0	72	5	Completed/Crit.	72
"	rebuild pier	14		0	36	15	Completed/Crit.	36
"	ALBANY refurb	15		89	50	5	Scheduled/Crit.	50
"	MOT BAY	16		95	72	5	Scheduled	72

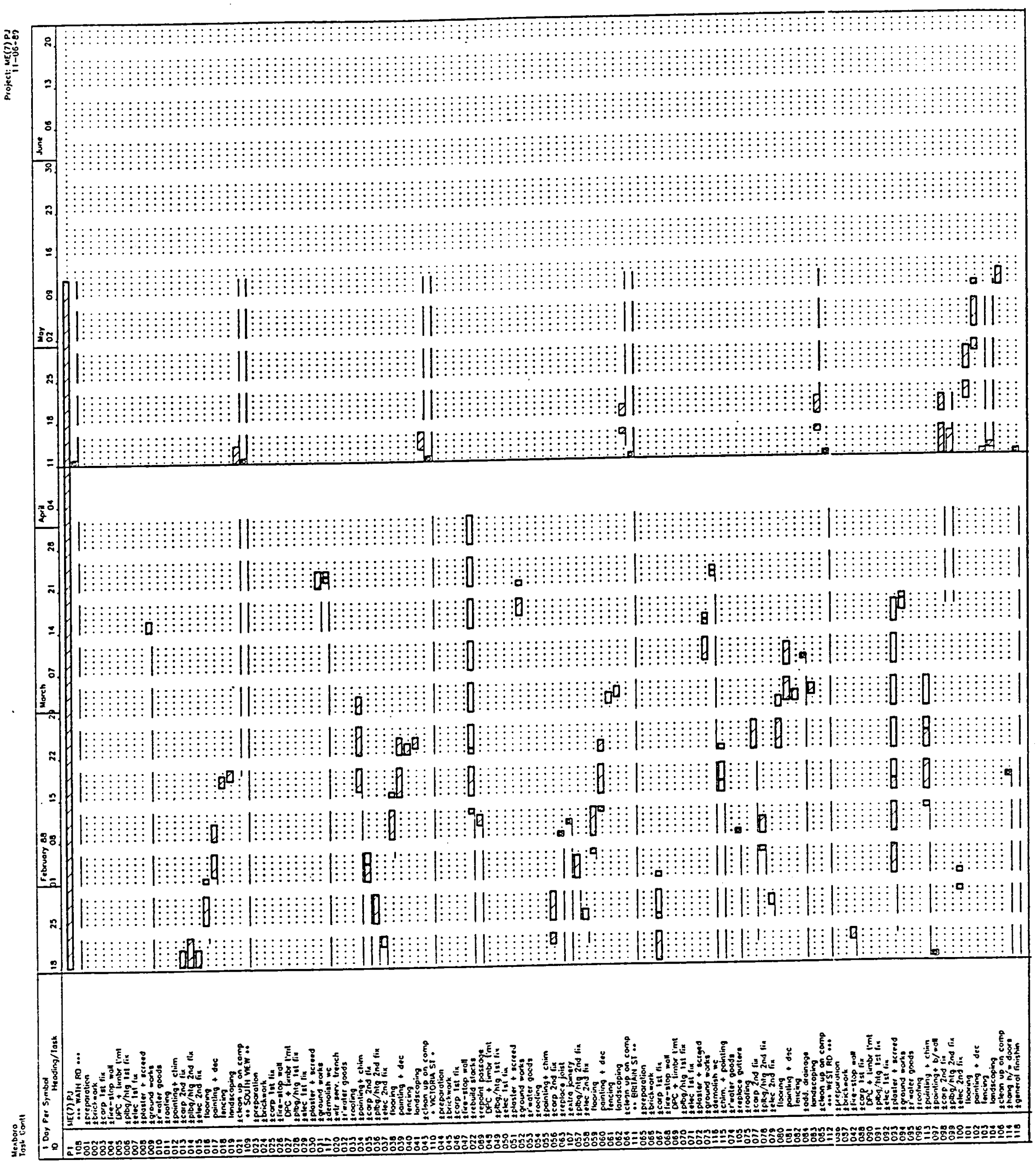
MAJOR PRIORITY CHANGES (>10) 14-3-88 - 11-4-88

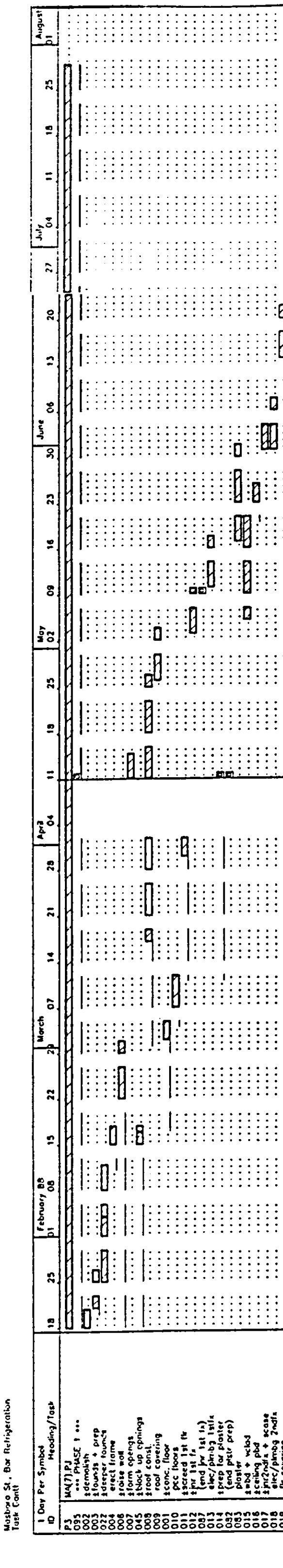
	Task Name	ID	Task Desc	Pri	Hrs	Trade	Status	PRI. CHANGE
MEXBORO	clean up on com	64		85	40	5	Scheduled	11
"	clean up on com	85		87	40	5	Scheduled	11
MASBORO	form opengs	7	TARGET 5	95	47	15	Scheduled/Crit.	11
"	prep + bwk	23	TARGET 2/	69	211	5	Scheduled/Crit.	11
CRANWORTH	remove air vent	8		92	40	15	Scheduled	15
"	bldrs wk.	25		80	207	5	Interrupted	12
"	roof insul.	27	TARGET 20	91	50	5	In Progress	19
"	carp 2nd 23-27	36	TARGET 16	94	149	10	Interrupted	14

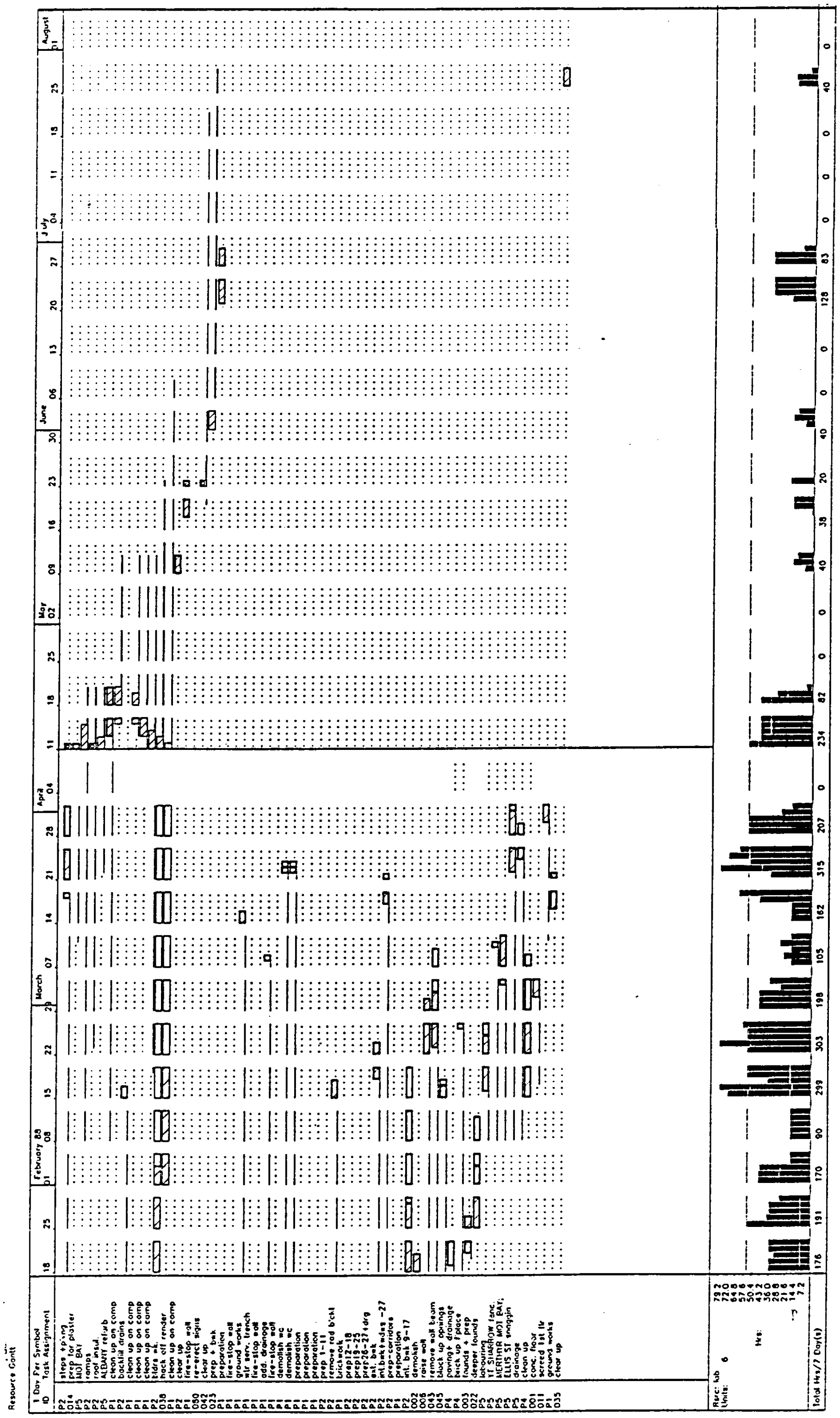
TRADES:-

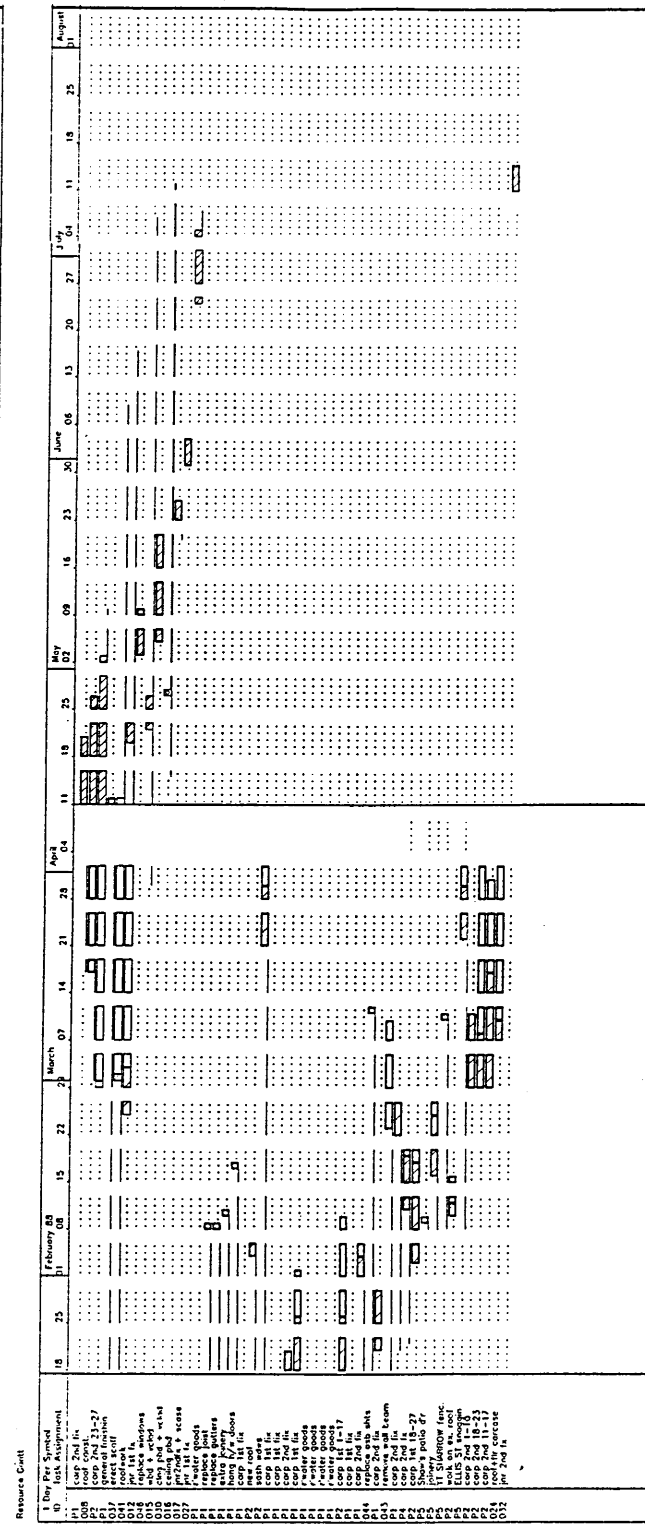
'5'	LABOURER
'10'	JOINER
'15'	BRICKLAYER
> '15'	OTHER TRADES

Tables 5(f), 6(f). VARIATIONS, AND CHANGES IN PRIORITY > 10% AS CALCULATED BY NEWRULE, BETWEEN UPDATES 6 & 7









Summary Charts

A number of indicators were monitored throughout the period of study. These are represented on the following charts;

Figure 45: 'DURATIONS - AT EARLIEST DATES':- This chart shows the duration of each major contract, taking 18/1/88 as a datum, with the schedule at its earliest dates.

Figure 46: 'OVERSCHEDULED HOURS':- For each of the three main trades, this chart indicates the number of manhours that cannot be accommodated within the schedule without extending the critical path. This represents the position after 'smoothing' of the schedule.

Figure 47: 'DURATIONS - AFTER LEVELLING BY 'NEWRULE'':- These represent the durations of all the contracts (datum = 18/1/88) after levelling using 'newrule'.

Figure 48: 'DURATIONS - AFTER LEVELLING BY 'F'':- These represent the durations of all the contracts (datum = 18/1/88) after levelling using 'f'.

Figure 49: 'COMBINED DURATIONS':- This shows the total of all the durations at earliest times, after levelling using 'newrule', and after levelling by 'f'.

Figure 50: 'DIFFERENCE BETWEEN 'NEWRULE' AND 'F'':- The difference between the total durations of 'newrule' and 'f'.

Figure 51: 'FORECAST OVERRUN':- This represents the projected overrun of the contract completion dates, as predicted by whichever rule produced the best result, after having made allowance for any extensions of time granted to date.

Figure 52: 'AVERAGE CONTRACT PRIORITY':- This shows the average of the activity priorities calculated for each contract by 'newrule'.

Figure 53: 'PERCENTAGE OF PLANNED ACTIVITIES PROGRESSED':- This indicates for each contract what percentage of those activities that the last update's levelled schedule recommended should have been progressed, actually was progressed by the contractor. It serves as a rough indication of how closely actual progress followed that planned.

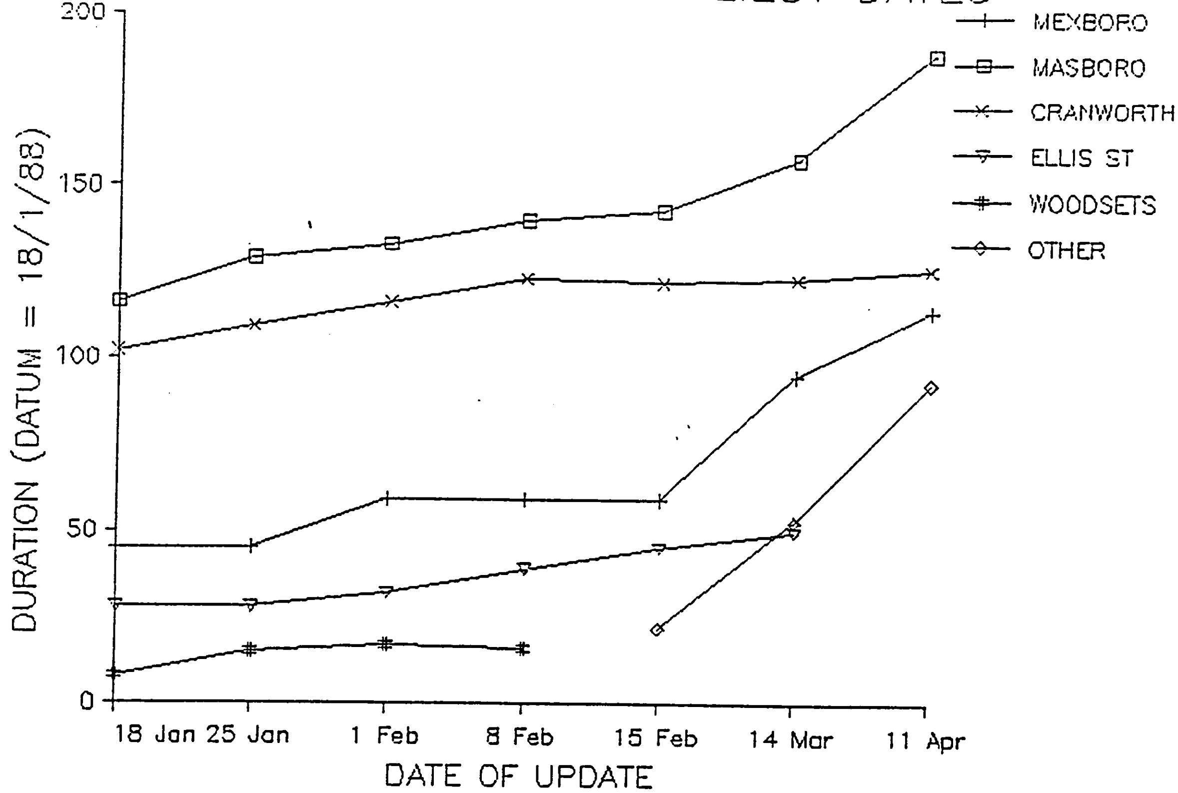


Figure 45. DURATIONS - AT EARLIEST DATES

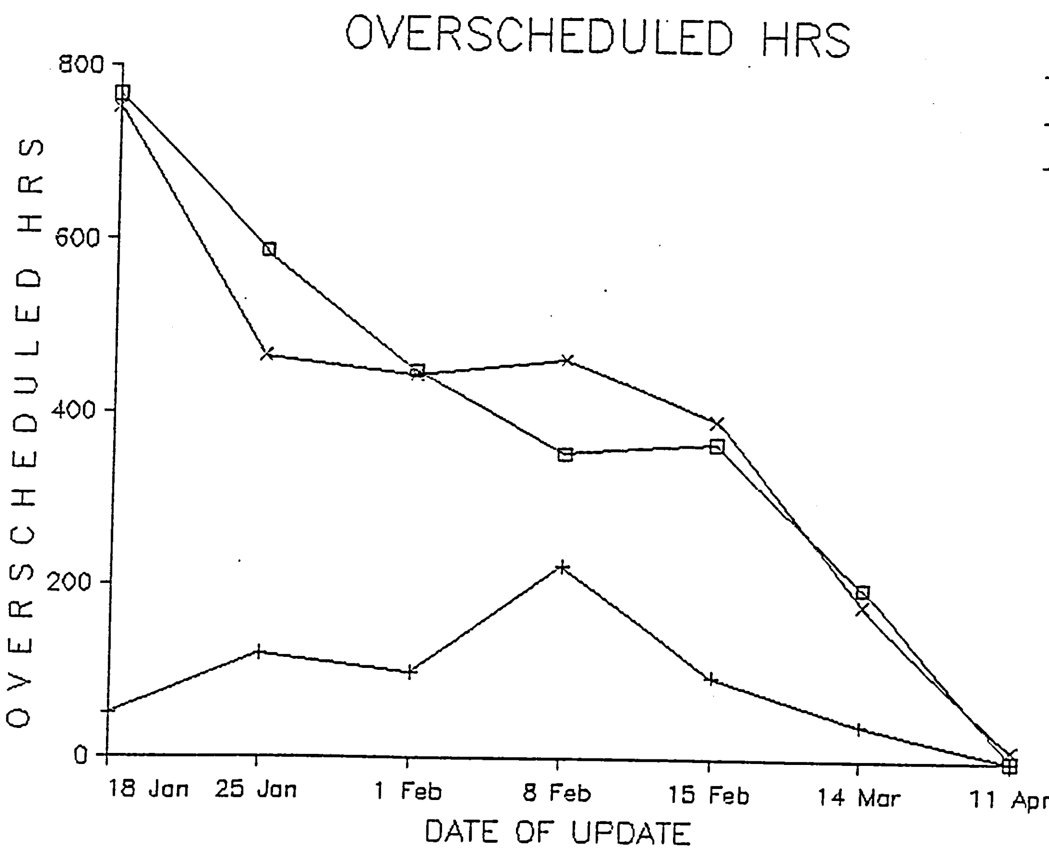


Figure 46. OVERSCHEDULED HOURS

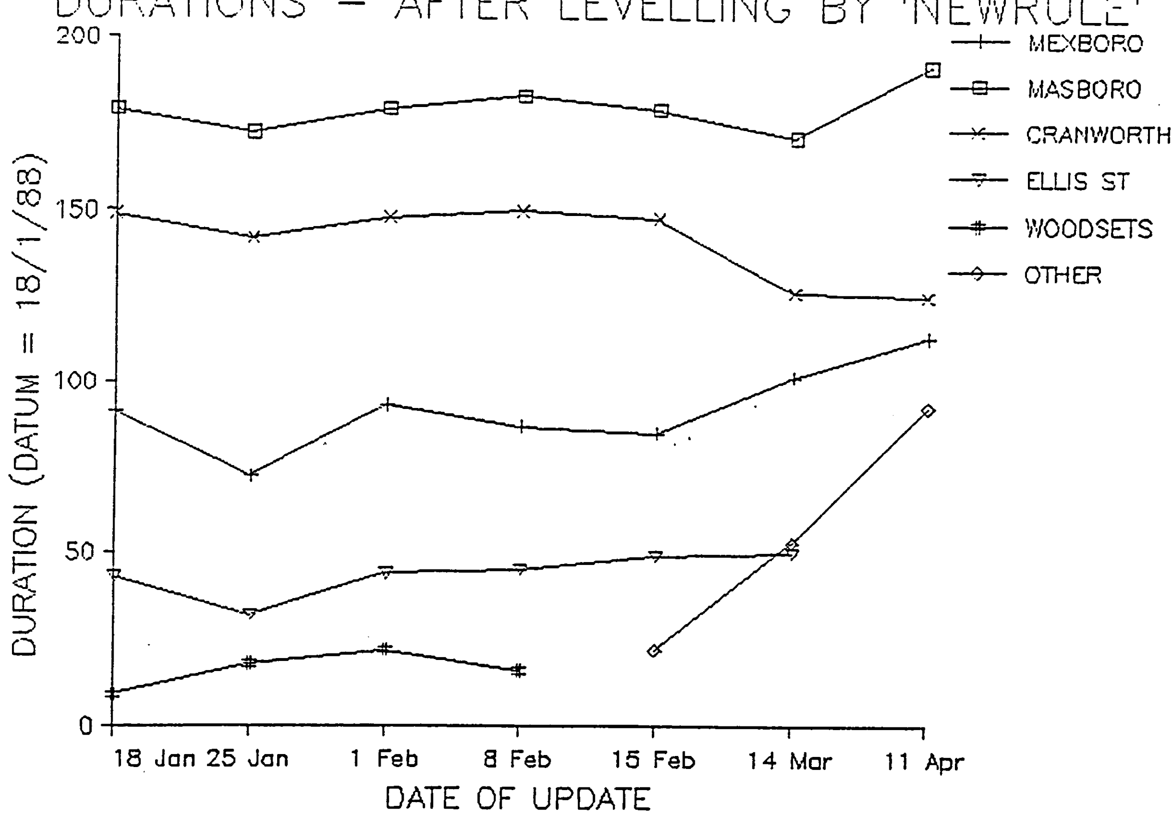


Figure 47. DURATIONS - AFTER LEVELLING BY 'NEWRULE'

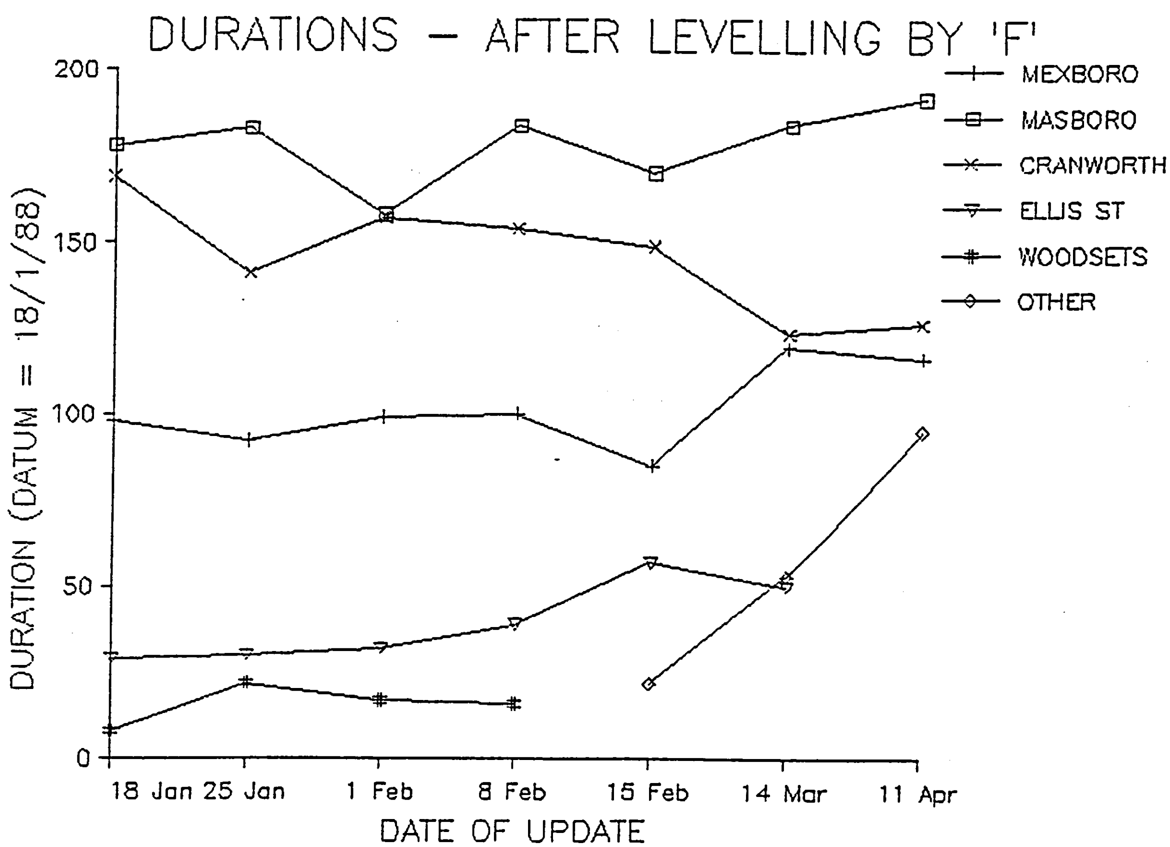


Figure 48. DURATIONS - AFTER LEVELLING BY 'F'

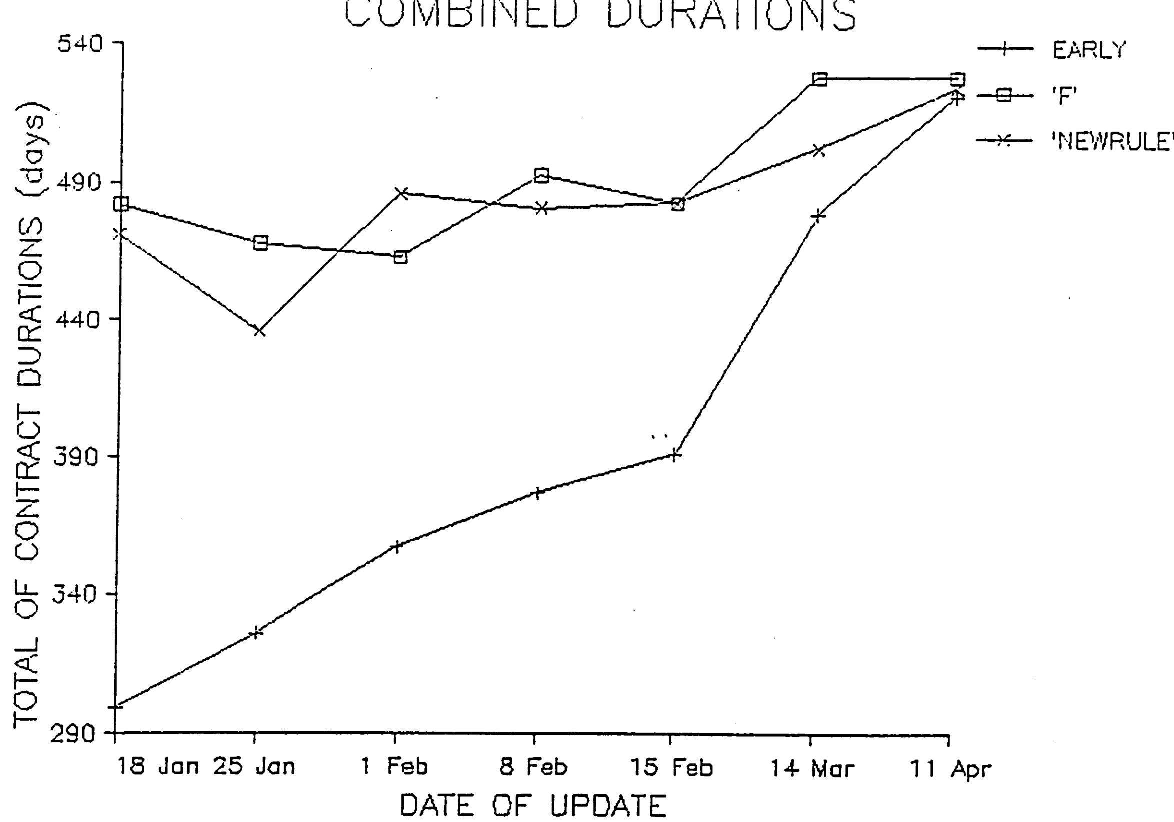


Figure 49. COMBINED DURATIONS

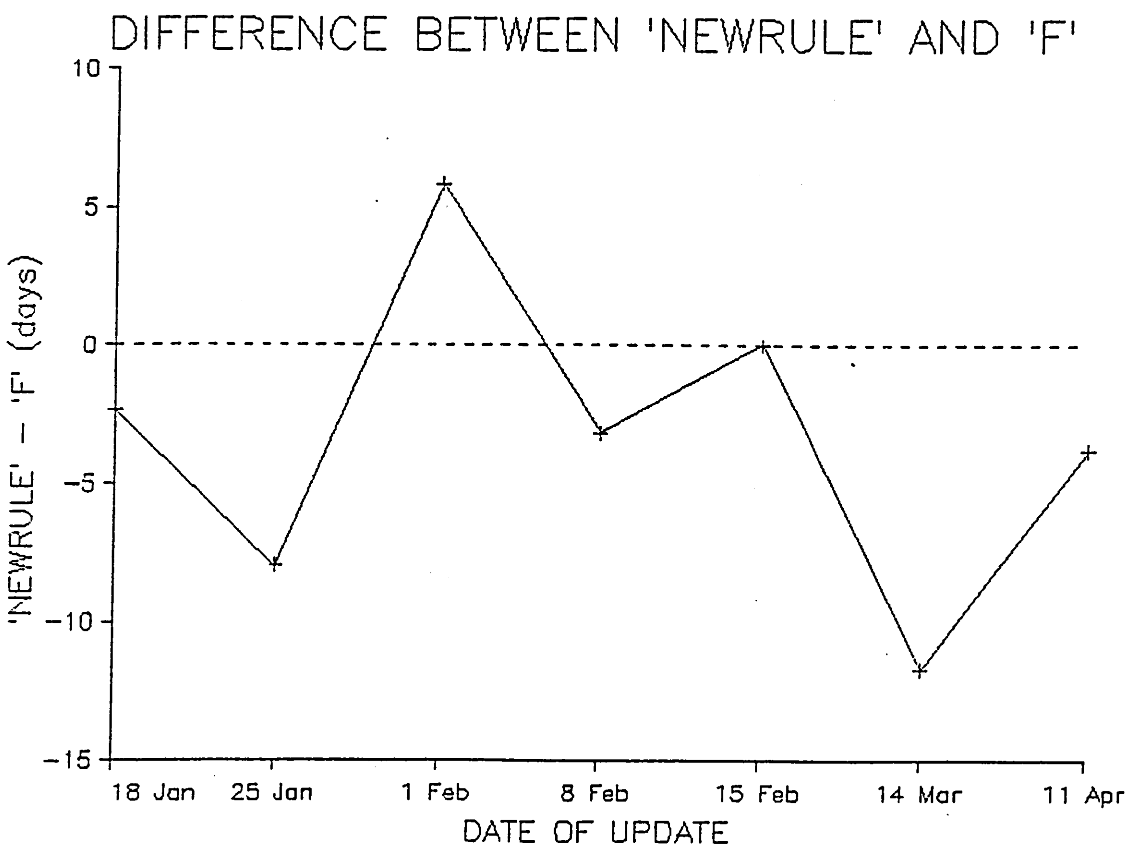


Figure 50. DIFFERENCE BETWEEN 'NEWRULE' AND 'F'

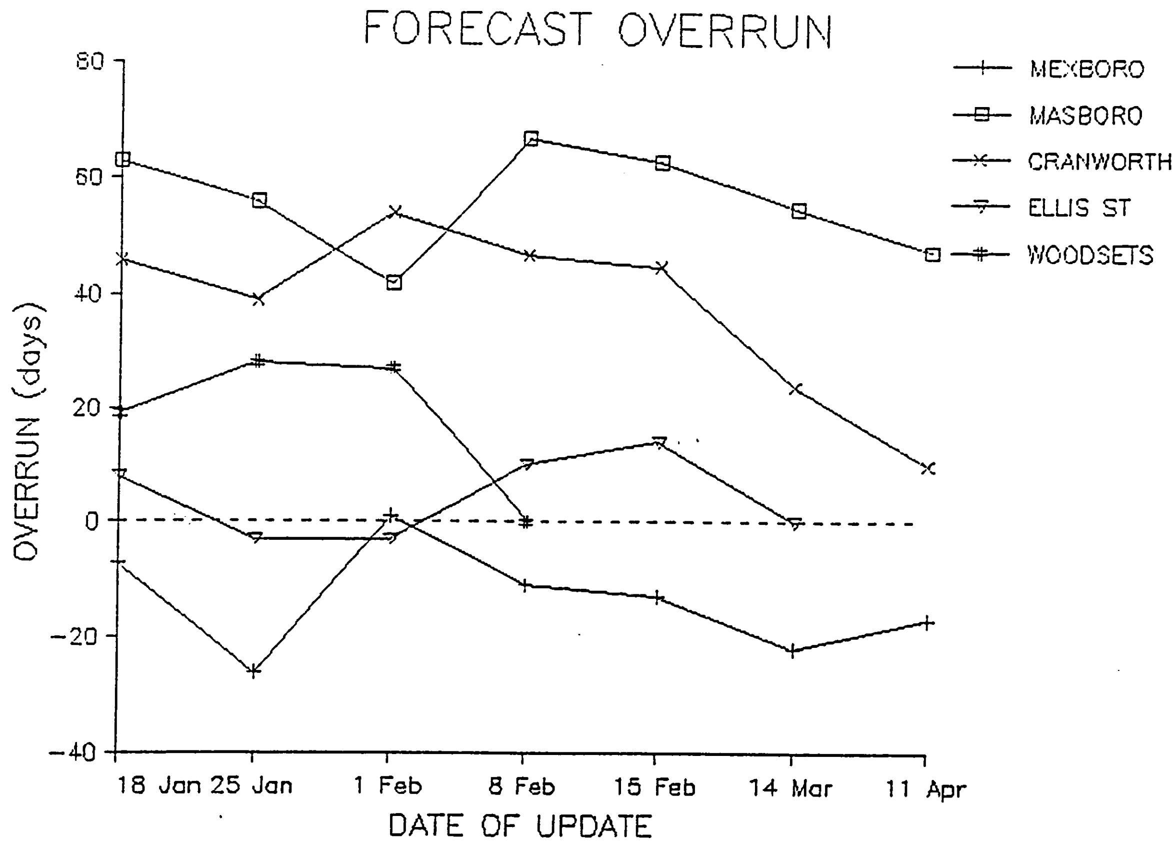


Figure 51. FORECAST OVERRUN

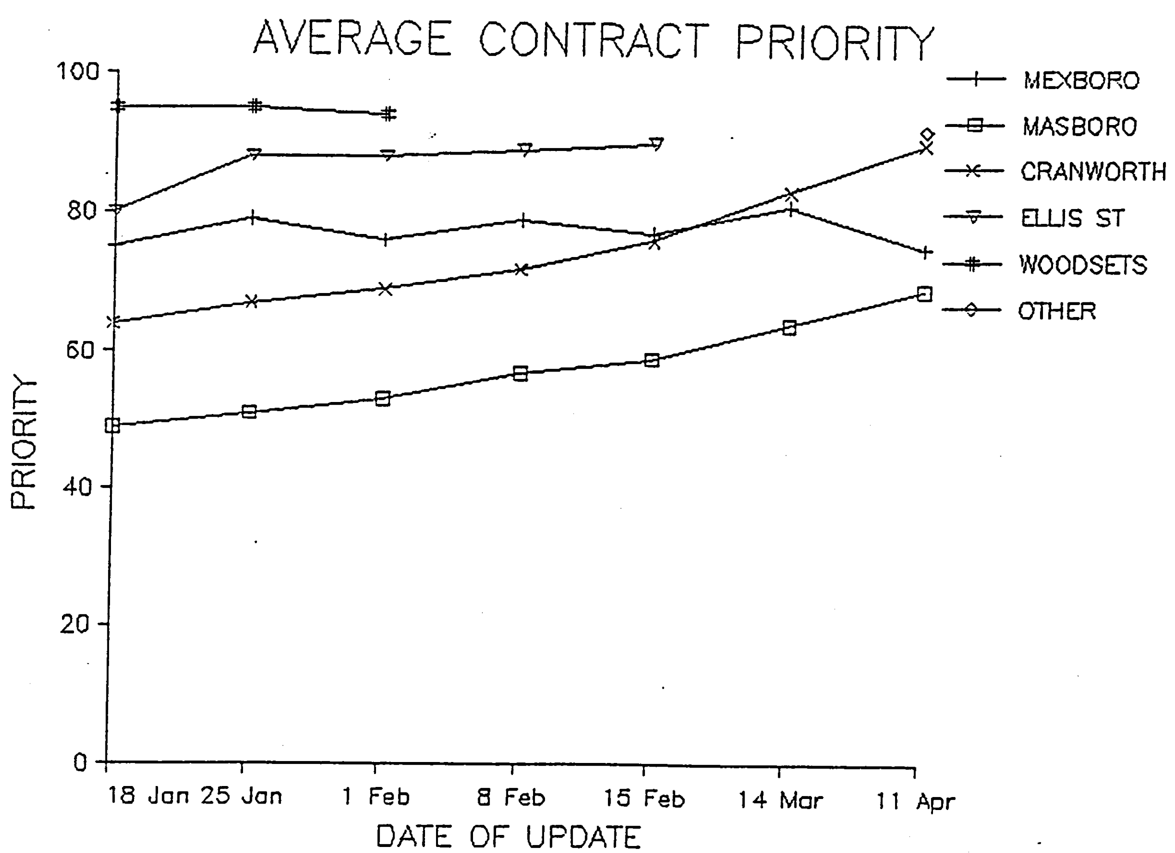


Figure 52. AVERAGE CONTRACT PRIORITY

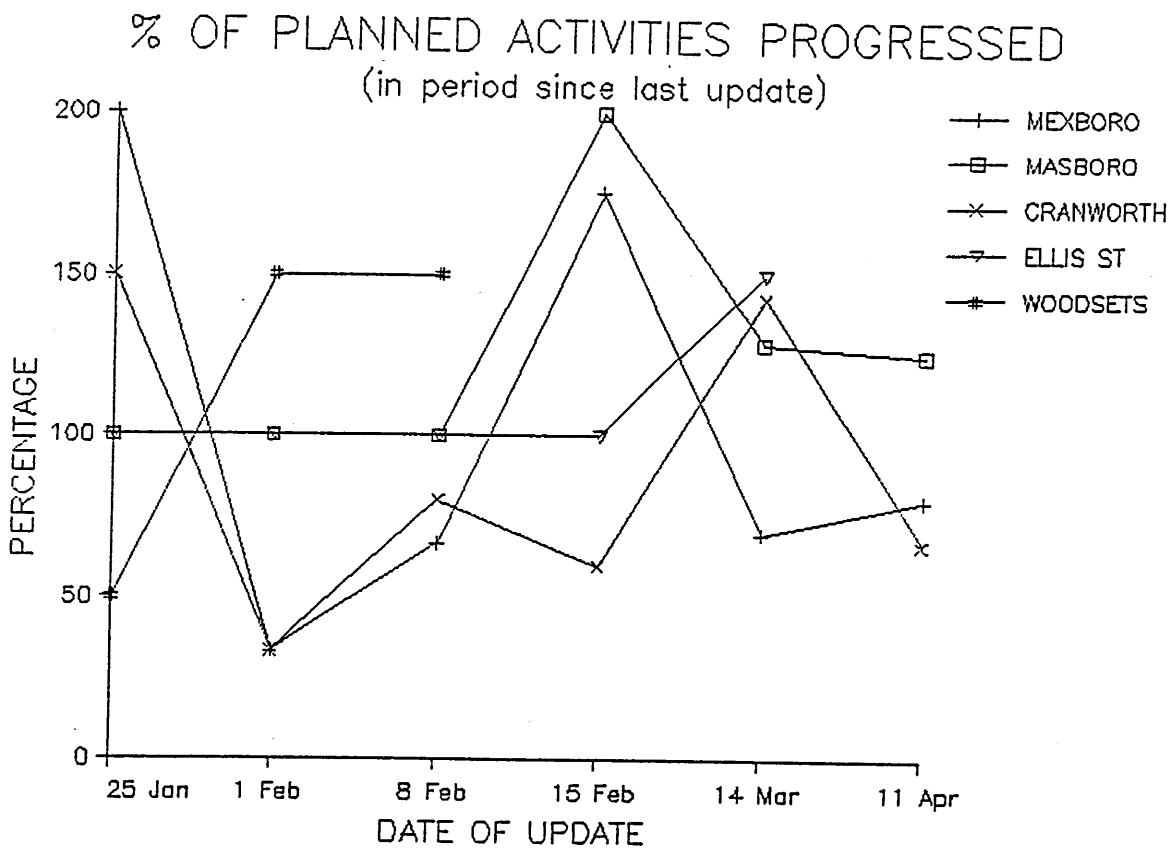


Figure 53. PERCENTAGE OF PLANNED ACTIVITIES PROGRESSED

10.4 THE CHANGING SCHEDULE

SCHEDULE AT START OF SIMULATION (UPDATE 1, 18/1/88): By 18/1/88 both Mexboro and Cranworth have experienced a number of variations, although only Mexboro has been granted an extension of time. The bricklayers and joiners each have approximately eighteen manweeks more work than they can accommodate before extending the critical paths of one or more projects [Fig. 46]. The result of levelling is thirteen weeks of continuous work for the bricklayers. The continuity of work for the labourers is disrupted by the delay of preceding brickwork activities. This was an instance of the over-extension of one category of labour causing the under-utilisation of another. Only Mexboro is scheduled for completion within its contract completion period, and Masboro, is scheduled to overrun by nine weeks [Fig. 51].

Clearly the employment of more bricklayers and joiners would have reduced these trades' overscheduled hours. The delays of brickwork and joinery might then have been of the same order of magnitude as those of the labourers. This continued to be the case for the next two months.

THE FIRST MONTH (UPDATES 2,3,4 and 5, 25/1/88 - 15/2/88): In the first week major variations occurred on the new contract, Masboro, the immediate effect of which was to halt work on the foundations. Whilst awaiting instructions over the next two weeks, the men were not reassigned to work of a high priority (as perceived by newrule) as this would have involved their temporary transfer to other contracts. Nonetheless, the best ever correlation between actual and planned progress, and the reassignment of a major 'brickwork' item to the labourers, resulted in a substantial net drop in overschediuled hours [Figs. 53, 46]. Consequently there were reductions in a all but one of the contracts' levelled durations [Figs. 47, 49].

Over the next three weeks variations to brickwork items impeded the reduction in the backlog of the bricklayers overscheduled hours, whilst reassignment and the execution of unscheduled work such as clearing up items ensured that the labourers did not run short of work. Thus by 8/2/88 the continuity of work previously projected for joinery has been disrupted by delays of preceding brickwork activities caused by levelling.

Both Woodsets and Ellis St were handed over after their contract completion dates. Damages were not sought in either case as the large volume of variations that arose in the closing weeks of each was held to account for the delays. As these contracts came to an end, new work was undertaken. Such work comprised small jobs involving mainly labourers and joiners, and therefore did not add to the workload of the most over-extended operatives, the bricklayers.

THE SECOND MONTH (UPDATE 6, 14/3/88): During the following month two more labourers were taken on. The additional manpower they represented was taken up almost entirely by new work commenced during the month and so had little impact on the progress of the three main contracts. In the same period a joiner went absent and was not replaced for two weeks, slowing progress. The granting of a further four week extension to Mexboro may have signalled (correctly) to management that this was not their most pressing problem as there was a net migration of labour away from this contract elsewhere during this middle month. This resulted in an extension to the forecast completion date that contrasted with the improvements in the programmes of the other two main contracts [Figs. 47, 48].

THE FINAL MONTH (UPDATE 7, 11/4/88): Although work ceased altogether on Masboro for a week, the operatives were reassigned and the workforce as a whole worked through the Easter holiday. The beneficial effect on progress this had was eliminated by the failure to progress certain critical activities on both Mexboro and Masboro, which the schedule at the beginning of the month indicated should have been attended to. New work, and the reassignment of a subcontractor item to the joiners workload ensured that men were not left idle. Masboro and Cranworth received extensions of time of two weeks each, whilst Mexboro received a further extension of one week.

However only Mexboro is scheduled to meet its new completion date, despite the negligible effect of levelling arising from the much reduced number of overscheduled hours

[Figs. 46, 51]. The resource histograms at the close of the simulation indicate a serious shortfall of work for the labourers in the very near future, and the exhaustion of all remaining brickwork in less than two weeks. In this situation an increase in the assignments of men to activities would reduce contract durations whilst maintaining continuity of work in the short term. However there is a pressing need for further work.

FINAL CONTRACT COMPLETIONS: Cranworth gained, and Mexboro lost time, but both achieved completion by their extended completion dates. Further extensions of time amounting to six weeks allowed Masboro also to meet its completion date.

10. 5 PERFORMANCE OF NEWRULE AND 'F'

'Newrule' Was Superior To 'F'.

On only one occasion did 'newrule' perform worse than 'f'. The results do not indicate whether or not 'newrule' declines in performance relative to 'f' as the complexity of the schedule increases. However 'newrule' was still able to compete successfully, at levelling the schedules of the first two updates which were the most complex of the trial.

There is also some evidence from a comparison of Figure 47 and Figure 48 that newrule is more consistent in its distribution of levelling delay between the contracts from one week to the next, although it is not possible to be conclusive about this.

Both Rules Performed Well.

On only two occasions (UPDATES 2, 3) did they both fail to achieve 100% utilisation of the most overscheduled resource 'bricklayers' over the initial period during which overscheduling was a problem. A close examination of the circumstances at each time reveals this to have been unavoidable in both cases.

Without a full analysis of all the levelling possibilities, it is not possible to determine what proportion of the underscheduling of 'lab' and 'jnr' must be accepted as the unavoidable result of delaying preceding 'bwk' activities, and what proportion should be ascribed to poor decision making by the rules in trying to solve these trades own resourcing problems. The greater number of available labourers and joiners meant a greater number of possible solutions, and therefore presented more complex challenges to the rules than did 'bwk', which, with only two men to draw on, could usually not allow the scheduling of more than one activity at a time.

10.6 PRIORITY DISTRIBUTION WITH NEWRULE

Priorities Of Remaining Activities Increase.

As activities were completed, the priorities of the activities remaining usually increased as Tables 6 (a - f) demonstrate. This occurred for two reasons.

1) Newrule assigns priorities to completed activities, as well as to those still scheduled, from a fixed range of possible values (1 - 99). The rule ensures that the nominal

priorities of completed activities are always lower than those of scheduled activities, and during levelling they are effectively ignored. As the number of scheduled activities remaining declines in proportion to the total reviewed by newrule, the upper section of the priority range that they occupy becomes smaller and consequently as a group their priorities are generally higher than before.

2) Large increments in activity priorities will also tend to appear when the completion of one activity brings the start date(s) of its immediate successor(s) suddenly very much closer to the current date. In view of the importance to newrule of an activity's relative position in the schedule, this places the successor(s) in a much better position to compete for priority.

A Contract's Average Priority Is Not Meaningful.

The principal determinant of the relative magnitude of the contracts' average priorities is the contract's remaining duration, for the reason that activities starting later will, by newrule's logic, always lose out to those starting earlier, all other things being equal. This is because newrule compares pairs of activities which are not yet in conflict with each other at their earliest start dates. If two such activities subsequently do come into conflict it can only be because the early activity has already suffered appreciable delay from the levelling of preceding activities. It will therefore probably have lost more of its float than its competitor, which makes it less able to sustain further delay, and consequently more deserving of the higher priority. Thus contracts with a greater proportion of their activities starting later will generally have lower priorities, which subsequently tend to increase as progress is made, and new contracts are introduced to the schedule.

It is clear therefore that a contract's average priority cannot be taken as a rule of thumb measure of each contract's entitlement to resources for the purpose of the day to day management of the firm's workload. Masboro, for example, a contract enjoying very little float on any of its activities, is the contract least able to sustain delay, and yet is of lowest average priority throughout the period monitored [Fig. 52].

10.7 IMPROVEMENTS IN MANAGEMENT INFORMATION DERIVED FROM RULE-BASED LEVELLING

The application of a decision rule to a multiproject schedule offered new and improved project information, as well as providing additional facilities:-

1. PROJECTED COMPLETION DATES: For each of the contracts the completion dates predicted by the rules were much closer to the handover dates actually achieved than those indicated by the schedule at earliest start dates, or those calculated by levelling the individual programmes in isolation. An early knowledge of the risk of overrun on a contract would have allowed management either to manually adjust priorities so as to reorganise the schedule to meet contract completion dates, to seek additional labour in good time, or to expand overtime.

2. PROJECTED LABOUR DEMAND: The number of weeks of unbroken work for each trade is a readily understood measure of resource demand that can be immediately derived from an inspection of the levelled histograms. At the pre-tender stage this would indicate both when and what type of work was needed to maintain continuity of work for the trades. It would also signal to management whether or not a difference between labour supply and demand was sufficiently long term in nature to merit the hiring or dismissal of labour.

3. A LOGICALLY PLANNED SCHEDULE OF LABOUR: The application of a decision rule allows management to consult the resulting labour schedule with regard to the short term movement of labour in the knowledge that the long term implications for the schedule have been considered. This would be of considerable benefit to a system of weekly meetings and day to day decision making, which otherwise can only imperfectly take account of the long term perspective.

4. THE FACILITY TO ALLOW FOR CHANGES TO THE SCHEDULE: Multiproject levelling gives the planner the flexibility to reorganise the entire schedule to make allowance either for the variations and progress pertaining to one of its constituent contracts, or for the entry of an entirely new contract. This presents the opportunity to optimise the deployment of a shared workforce as each revision occurs.

5. **THE DICTATION OF PRIORITY:** The system of activity priorities allows the user to manipulate the levelling procedure by entering his own assessment of an activity's priority wherever he disagrees with 'newrule''s verdict. Thus it is possible to take heed of circumstances of the activity or project other than those analysed by the rule.

10.8 THE DEPLOYMENT OF LABOUR, 18/1 - 11/4

Although work continued through the Easter break, and despite a mid-term increase in manpower from four to six labourers, only Cranworth made greater progress (194 hrs) over the period reviewed, than had been scheduled at 18/1/88, and all contracts suffered delay beyond the completion dates projected at this date. An analysis of how the operatives spent their time over this period helps to explain this [SEE Fig. 54, Table 7].

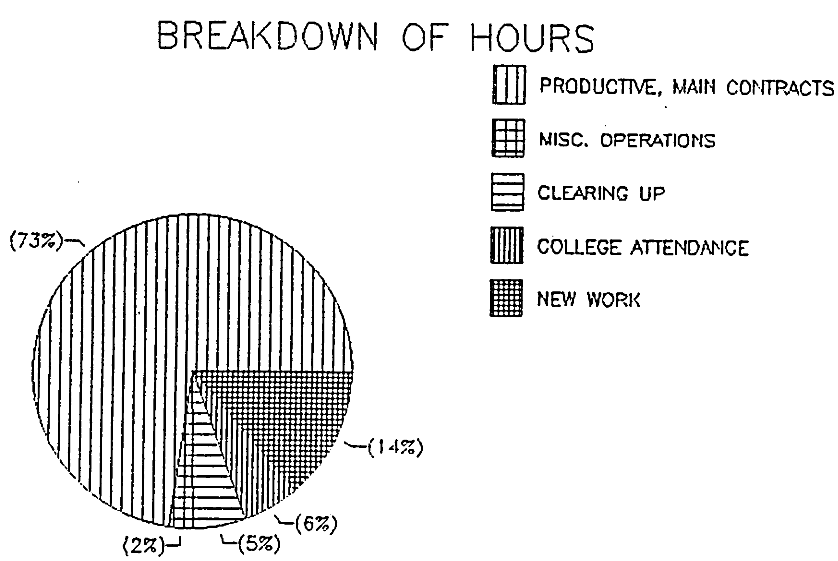


Figure 54. BREAKDOWN OF LABOUR UTILISATION

REVIEW OF ACTIVITIES COMPLETED BY
FIRM'S EMPLOYEES 18-1-88 - 11-4-88
ON FIVE MAIN CONTRACTS

CONTRACT	ME	MA	CR	EL	WO	TOTAL
NO. OF ACTIVITIES SCHED.	17	8	11	3	2	41
NO OF SCHED ACTS COMPLETED	12	5	11	3	1	32
UNCOMPLETED ACTIVITIES	5	3	0	0	1	9
NO. OF MANHRS SCHED.	1553	691	1078	197	120	3639
VALUE HRS COMP.(INC VARNS)	1368	683	1308	260	192	3811
VARIATIONS	194	398	36	63	72	763
UNCOMPLETED SCHED. HRS	379	406	(194)	0	0	591
ACTUAL HOURS COMPLETED	1012	867	820	203	89	2991
ACT - EST DIFFERENCE (HRS)	(356)	184	(488)	(57)	(103)	(820)
ACT - EST DIFFERENCE (%)	(26%)	27%	(37%)	(22%)	(54%)	(22%)
AVE. START DELAY (DAYS)	10	(8)	(12)	(2)	7	(2 ave)
AVE. FINISH DELAY (DAYS)	12	(1)	(7)	4	7	2 ave
ACTIVITIES EXEC BY GREATER NO OF MEN THAN ASSIGNED	0	0	2	0	0	2
ACTIVITIES EXEC BY LESS NO OF MEN THAN ASSIGNED	5	0	5	2	0	12
ACTIVITIES, TRADE CHANGED	3	1	3	0	0	7

Table 7. ANALYSIS OF FIRM'S PERFORMANCE
OVER PERIOD OF UPDATES

Of the 5580 manhours that the operatives were actually available for work, only 73% were expended on activities directly contributing to the value of the five main contracts, about one fifth of which represented variations received after 18/1/88. Of the remaining hours, 'Other' work, ie jobs not scheduled at 18/1/88 but contributing to company turnover, accounted for 14%, and college days absorbed another 6%. The 5% of manhours described as 'clearing up' in the timesheets were in addition to the allowance already made for such work in the targets that formed the basis for the programmes. The remaining 2% represented time spent on miscellaneous items that had not been accounted for in the estimate.

The completion of activities in considerably less time (-22%) than their estimated hours, resulted in a saving of hours greater than the extra work introduced through variations. However, the manpower released early in this way, and the joiner and labourer manpower shown as unscheduled in the later weeks of the 18/1/88 schedule were entirely taken up by additional items and could not be redeployed on the main contracts to make up time lost through variations. Thus despite the higher productivity achieved, the value of the work completed on the main contracts (including work on variations) in terms of estimated manhours (3811) was only marginally greater than that scheduled at 18/1/88 (3639).

10.9 THE EFFECTS OF DEVIATIONS FROM THE SCHEDULE

The simulation revealed five distinct categories of deviation from the original schedule that had influenced the rate of progress of the five main contracts;

(i) Variations;

(ii) New Work:- The demands of 'Other' work, of which the contractor was not aware at 18/1/88, and which did not therefore appear in the original schedule;

(iii) Trade Changes:- Work executed by a different trade than that originally scheduled;

(iv) Assignment Changes:- Work carried out by a different number of men than originally scheduled;

(v) Actual/Estimate Variance:- The difference between the actual and the estimated manhours.

To isolate the effect of each category of change from those of the others, the schedule was returned to the position at 18/1/88 and each set of changes was re-introduced, en bloc, one at a time, in the above order. Between each step the schedule was re-calculated at its earliest times and re-levelled using both 'f' and 'Newrule'. The changes in the combined durations illustrated in Figure 55 may be taken as a good approximation of the likely effect of each type of divergence. This is qualified by the recognition that this method allows the rules a foreknowledge of the changes which may permit them to schedule more efficiently than would have been possible at the actual time of their occurrence. The final pair of bars represents the difference between the durations projected at the final update (which take account of actual progress), and those projected by the schedule at update 1 after all the aforementioned changes had been entered.

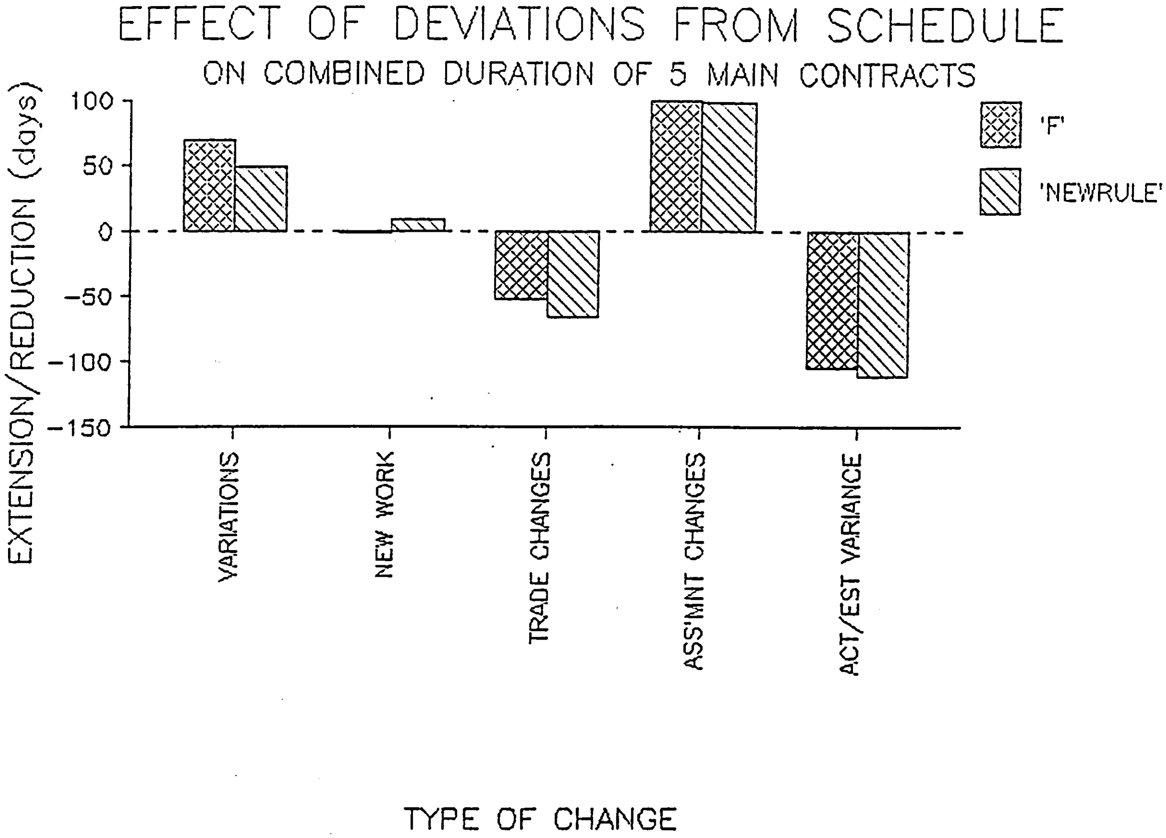


Figure 55. IMPACT ON SCHEDULE OF DIVERGENCE FROM PLAN

Variations

Over half the additional hours introduced by variations related to Masboro. However because this contract's activities are typically lacking in float, newrule distributed the greater part of the additional levelling delay to other contracts, particularily Mexboro and Ellis St. Although most of the variations concerned joinery, the principle cause of levelling delay is still a shortage of bricklayers, for whom the period of work continuity was extended by a further 2 weeks as a result of its own variations.

New Work

Although there was as much new work as there were variations, its impact on the contract durations was negligible. This was for two reasons.

Firstly, whereas in reality most of the new work was executed as early as possible, both rules elected to delay this work rather than the activities of the main contracts. Secondly, these jobs were composed, in the main, of labourer items. At the time of their introduction to the schedule there was a projected shortage of work for the labourers, and therefore most of this new demand could be absorbed into the schedule without serious delay.

Trade Changes

Four former bricklayer items were carried out by labourers, and three labourer items were carried out by bricklayers. This represents a net swing of 251 manhours from the over-extended bricklayers to the under-utilised labourers, and brought about reductions in durations across the board.

Assignment Changes

Nearly half the scheduled activities completed during the period reviewed were carried out by a different number of men than that scheduled at 18/1/88. Almost invariably this represented a reduction in the manpower assigned, from two men to only one.

(Often progress on the activity would be suspended altogether whilst the labour was engaged elsewhere.

However, interruption of this sort could not be entered into the schedule and so was not part of the delay measured.)

Although manpower reduction, like the trade changes, was plainly an effort to maintain some level of progress on all the contracts during a period of labour shortage, the resulting extensions in activity durations did more to set back the anticipated completion dates than any other single cause.

This occurred despite an apparent superiority in the productivity achieved by men working alone over those working in pairs, suggested by the difference found between them in the savings they were able to achieve on their targets [Table 8].

	COMPLETED BY;	
	1 MAN	2 MEN
NO. OF ACTIVITIES	24	28
ESTIMATED MANHOURS	1686	1693
ACTUAL HRS - EST. HRS (%)	(33)	(11)

Table 8. COMPARISON OF SAVINGS ON TARGETS ACHIEVED BY 1 MAN AND 2 MAN GANGS

Actual/Estimate Variance

The savings on the estimated manhours were very unevenly distributed amongst the activities. Masboro showed increases on the estimated hours for all but one of its activities, whereas Cranworth's activities were completed in 37% less time than estimated. The overall result was a total reduction in the contracts' levelled durations of over 14 weeks, despite the fact that only Cranworth and Woodsets showed a shortening of their critical paths as a consequence of this variance.

Other Causes

Amongst the many factors that may have contributed to the further delay that occurred, are the following, known to have been present;

(i) Changes in the availability of labour caused by working through a holiday period, college attendance, employee absence, etc.;

(ii) Digression from the sequence of work advised by the rules;

(iii) Lack of foreknowledge of events such as variations and new work;

(iv) Interruption of activities by the reassignment of labour;

(v) Daily fluctuations in the labour working on an activity.

10.10 A FINAL TRIAL

10.10.1 Modification Of The Projects To Reduce Projected Contract Overrun

Both rules had pursued the single objective of minimising the extension to the 'critical path' which thus far had been taken to be the longest distance between the start of the first activity and the completion of the last. Figure 51 demonstrates that this approach had led to the simultaneous scheduling of significant underrun of one contract (Mexboro), and severe overrun of others. It seemed probable that a transferral of labour from Mexboro to these other contracts might achieve a reduction in total overrun at the expense of total duration.

In order to effect this using the rules, it was necessary to somehow communicate to them the differences between the contracts in the closeness of each to its contract completion date. This had to be done without disrupting the basic logic of the rules. Therefore a dummy activity, corresponding to the contract completion date, was entered into each programme at its earliest start dates, with the result that all of a contracts' activity floats immediately increased by as much as the difference between the old critical path duration and the contract period. Where the contract period was less than the critical path at earliest start, there was effectively no change to the programme.

All the revised updated schedules were relevelled using both rules. This time 'newrule' gave the best result on every update [Fig. 56]. As anticipated, in terms of total duration the results were worse on average than before [Fig. 57]. However on every occasion but one the redistribution of levelling delay achieved a reduction in total contract overrun from its previous level [Fig. 58].

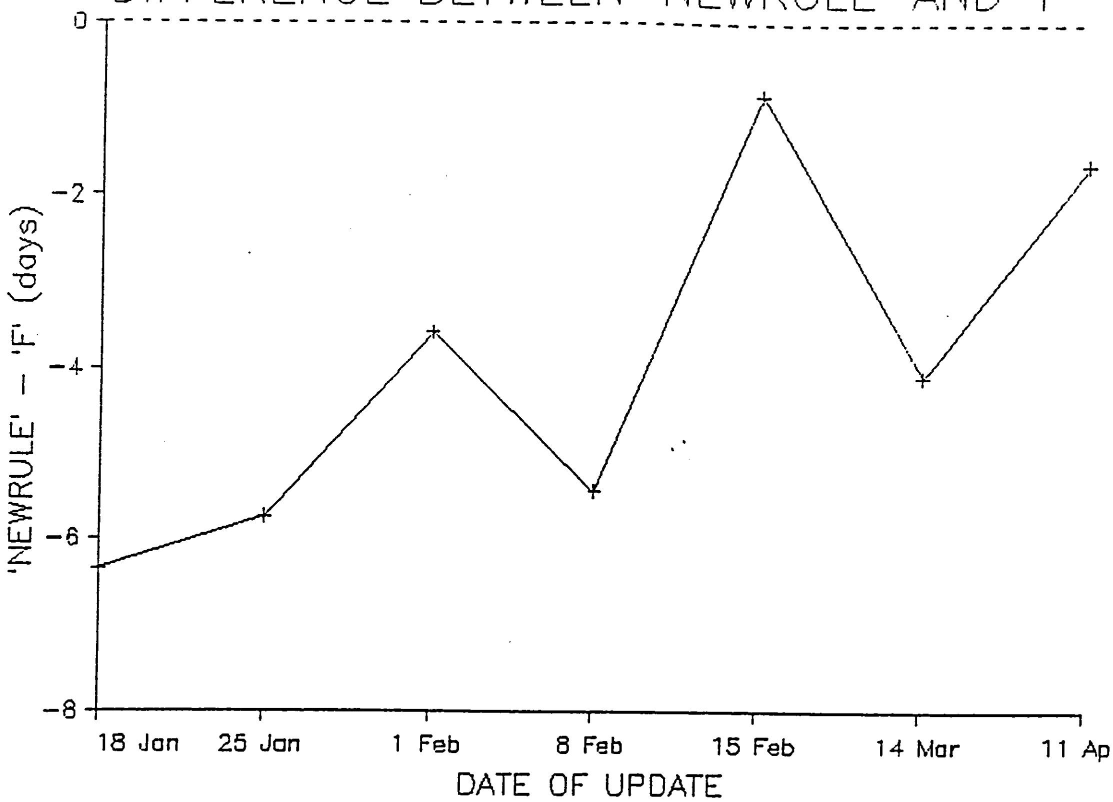


Figure 56. DIFFERENCE BETWEEN 'NEWRULE' AND 'F' FOLLOWING RE-LEVELLING OF MODIFIED SCHEDULE

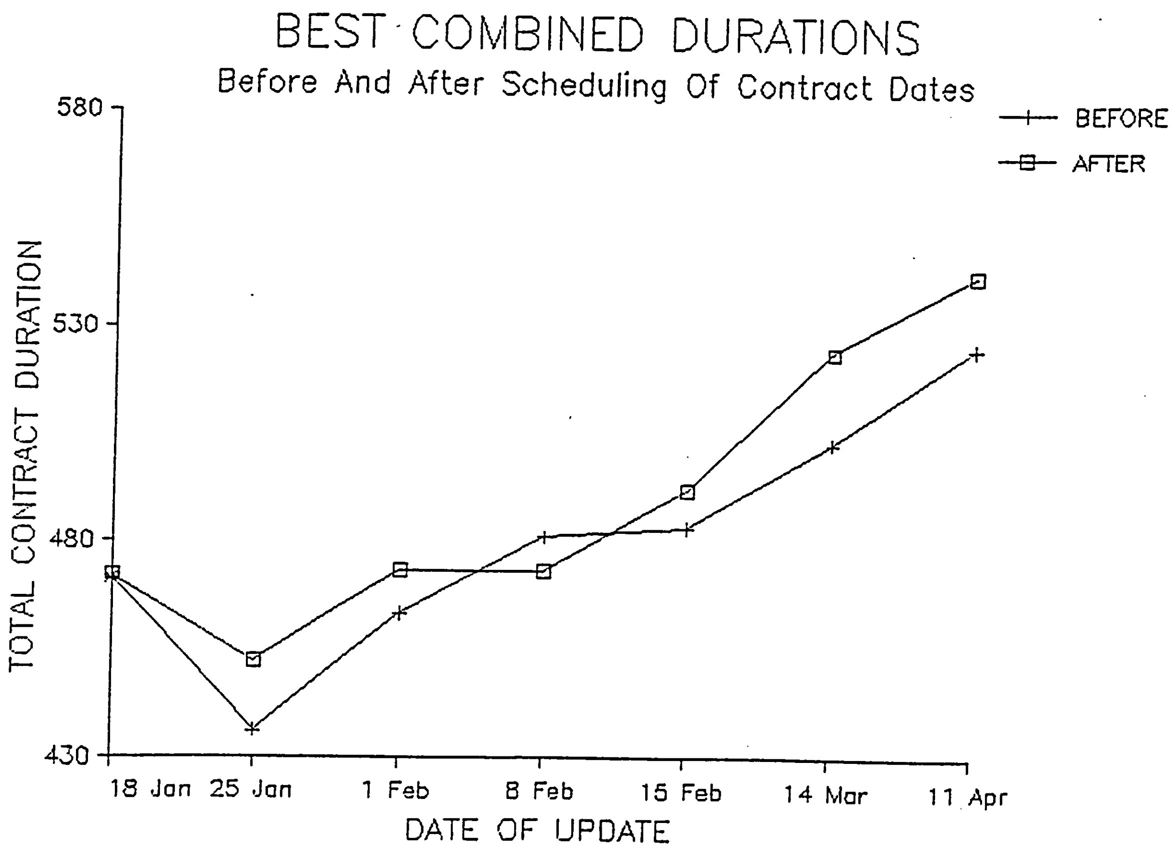


Figure 57. COMPARISON OF COMBINED DURATIONS BEFORE AND AFTER MODIFICATION OF SCHEDULE

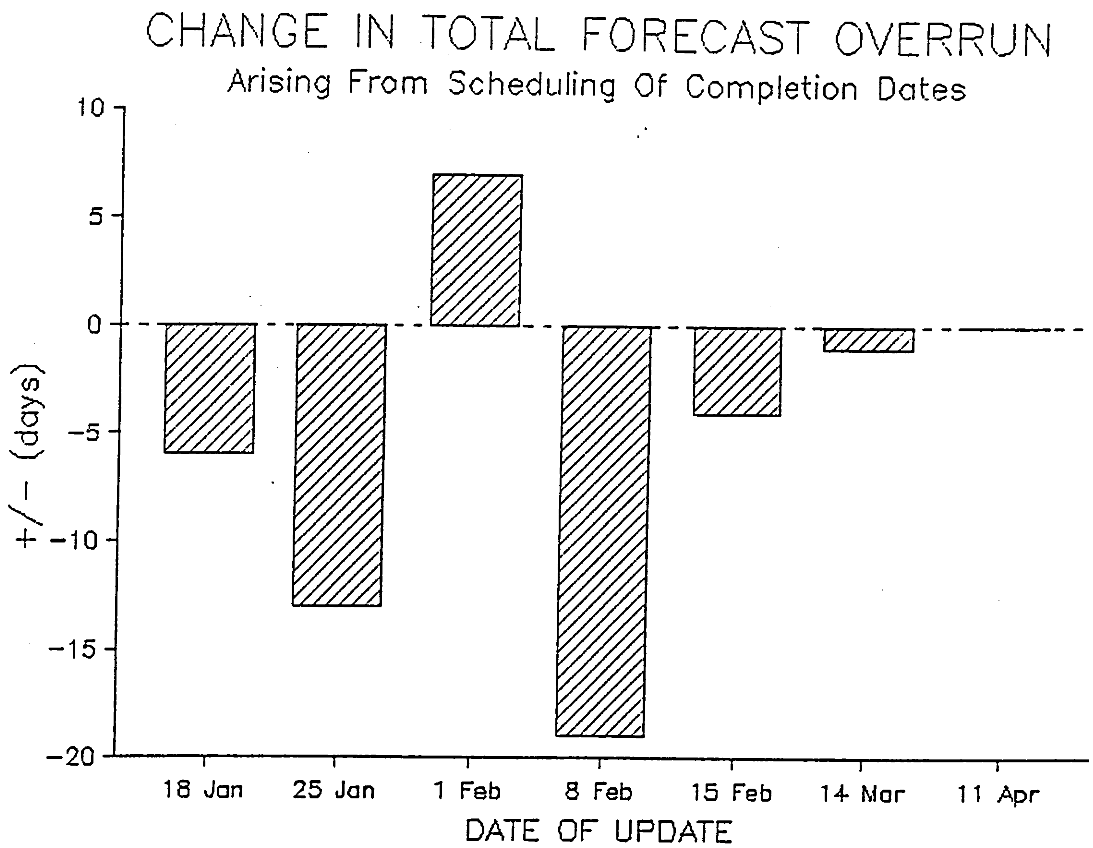


Figure 58. CHANGES TO FORECAST OVERRUN

11 MATERIALS TRANSPORTATION AND HANDLING

11.1 PROCUREMENT OF MATERIALS

11.1.1 Suppliers

There was a preference for using builders merchants rather than manufacturers as the suppliers of materials, although this varied considerably in degree between the firms. Finished items (e.g. kitchen units), and large orders, such as for bricks and blocks, were commonly sought from manufacturers. Small orders, and those required at short notice, were typically supplied by a merchant. Familiarity with the practices of local merchants, and their convenience to management and operatives alike were cited by managers as the main reasons for their firms' dependence on this source.

11.1.2 Delivery And Collection

All the firms expressed an interest in having as many materials delivered as possible as it was rare for an additional charge to be made for delivery. In reality all the firms were involved to some extent in materials collection, as Figure 59 illustrates.

The immediacy of the need for an item usually dictated whether or not it was collected, as supplier delivery was generally slower. Unordered materials, and late orders made up this category.

For only one firm was the responsibility for materials collection wholly devolved to certain individuals. The

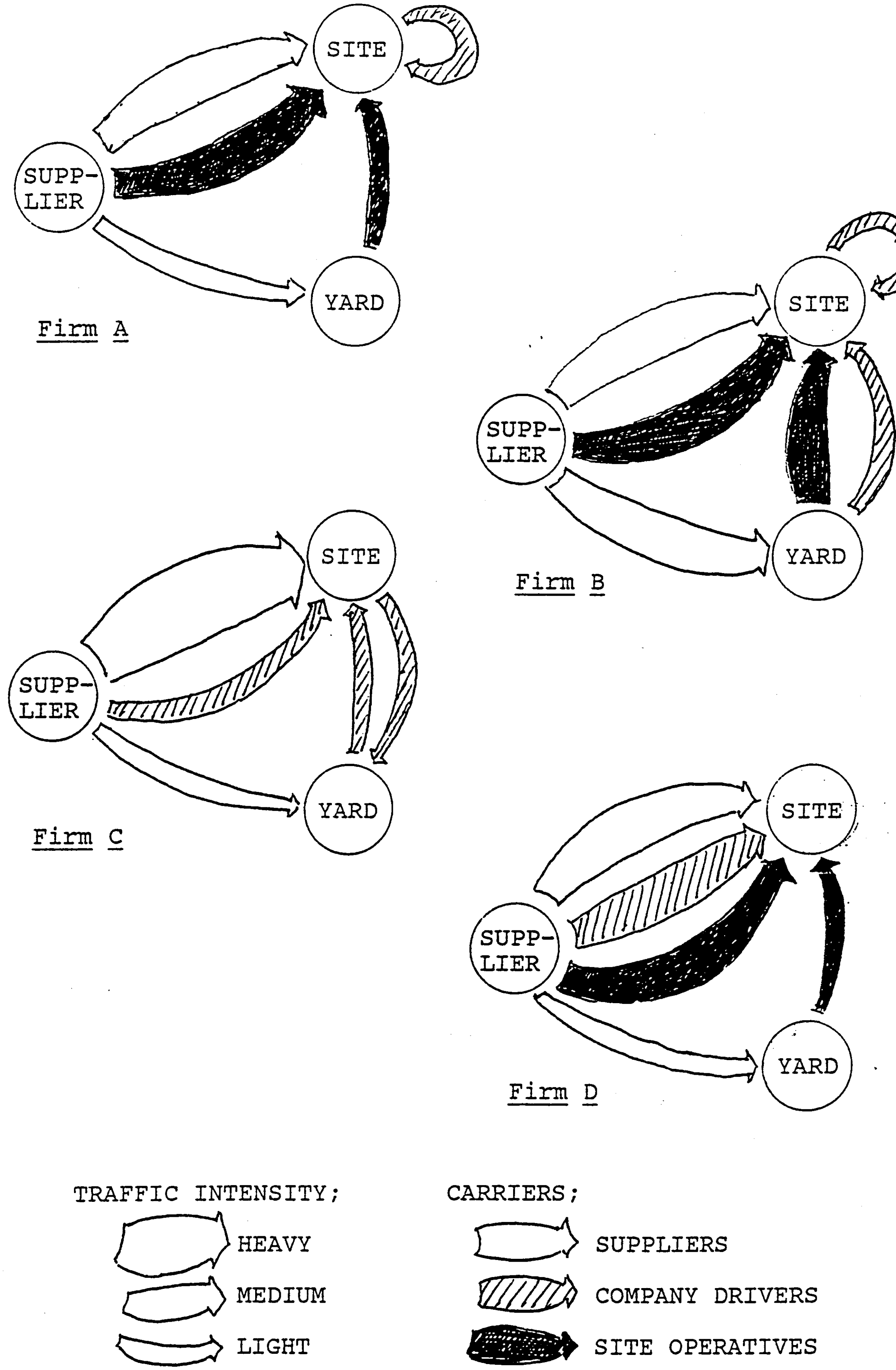


Figure 59. MATERIALS TRANSPORTATION ROUTES

other three firms allowed their site operatives to collect materials, a practice they perceived as costly, either directly in terms of money, or indirectly as a brake on progress. In the morning, the arrival of the workforce on site was often delayed to allow for the collection of materials from the yard, or for a detour to the local supplier. During the day more productive time was lost as individual tradesmen made use of company transport to collect further materials requirements. Such visits to the merchant were rarely co-ordinated, so that several trips were often made to the same merchant for different materials on the same day.

The firms not operating incentive schemes reported that their operatives had little motivation either to reduce the number of trips being made, or to bring materials shortages to the attention of management at an appropriately early time. When firm A included the collection of materials in its targets, a marked improvement in the efficiency of vehicle usage had been detected. One firm reported that the cost in lost discount associated with the small loads being collected amounted to as much as 25% of its materials costs.

11.1.3 Storage In The Yard And The Bulk Purchase

All the firms stored some of their materials centrally, thereby adding an extra leg to the delivery route. The prime reason for this was to allow advantage to be taken of discounts offered on the bulk purchase of those materials for which there could be expected to be a demand from a number of contracts, over a period of time. To the contractor, in financial terms, their were both advantages and disadvantages resulting from this practice;

SAVINGS: - the discount
- less trips to the supplier

COSTS: - a second leg to the delivery route
- returns to the yard, or site transfers (where the initial order is delivered to a site)
- the cost of capital tied up in materials

Lack of site storage space often compelled the retention and intermittent release of materials from a central yard. A reluctance to expose valuable and perishable items to weather damage or possible theft also encouraged the firms to store materials at a secure location before their fixing on site.

11.2 SITE HANDLING METHODS

11.2.1 Characteristics Of The Small Firm's Handling Problems

Discussion of the firms' approach to materials handling revealed four fundamental aspects of the workload of the smaller firm that distinguished their handling problems from those faced by larger firms.

1. The quantities involved were typically small. Consequently the utilisation of an item of handling plant tended to be low.

2. Contracts were shortlived. This limited the potential for production-line processes, which require a long run to recoup the investment of resources in their setting up.

3. The sites were often small in area. Horizontal movement of materials was less in distance, and the relative importance of vertical movement was correspondingly greater. Storage space was restricted.

4. The work was often executed within an existing building. This hindered the.access and operation of handling plant.

11.2.2 Planning Of Materials Handling

For all the firms, decisions regarding major handling problems, such as craneage, were taken at the pre-tender stage and specifically allowed for in the estimate. The outcome of such decisions and any assumptions made by the estimator about handling methods were passed on to the contract manager, either at the inhouse prestart meeting, or less formally during the early life of the contract. Otherwise handling methods were finally decided between the contract manager and his foreman (if there was one), two or three days in advance. One firm reported that it occasionally prepared site layouts showing plans for materials storage for the more confined sites.

11.2.3 Packaging

As part of a general enquiry about materials delivery it was common for a firm's buyer to ask about packaging before or as an order was placed. This was principally to find out about any offloading facility required, and the packaging of a material rarely influenced the decision to place an order with a particular supplier. The only charge made for packaging was that levied for pallets not returned.

The main advantage said to derive from unitisation was the ease of offloading. Suppliers' lorries could be used to drop individual packs close to work positions. The benefit of units or sub-units to the secondary movement of materials was seen as minimal as a consequence of the short distances to be moved, and the small volumes involved. With the important exceptions of bricks and blocks, most orders that might be unitised were for quantities less than that which would constitute a whole unit. Where materials were purchased in bulk to be stored in the yard, the advantages of palletisation were acknowledged. The ability to make an instant assessment of quantity was considered to be a useful consequnce of unitisation.

11.2.4 Offloading And Site Storage

It was common for suppliers' vehicles to be self-unloading. This facility was often requested by the firms at the time of ordering, and a charge was sometimes levied. The contractor benefited by being free of the obligation to provide offloading plant which might have little other function on the site, and by suffering less interruption of the operatives' work. It was expected that the supplier benefited from a reduced turnaround time on site.

On the majority of the firms' sites there was no compound area. It was claimed that most materials, whether delivered or collected, were offloaded as close to the point of use as possible. However the type of work undertaken by the firms (refurbishment, repair and maintenance) would often prohibit the direct unloading of the vehicle adjacent to the material's final location. It can be inferred that movement of materials between the delivery point and the point of fixture often took place immediately following delivery. This would necessitate the peremptory interruption by operatives of their productive labour, or its further postponement where it was the tradesman himself who was collecting his own materials.

11.2.5 Applications Of Handling Methods

The circumstances which would prompt the adoption of specific handling strategies were reported for each firm.

MANHANDLING This was the preferred method of moving small volumes of materials, of less than a specific unit weight, over short distances. It was useful for moving materials in and out of buildings, and around their interiors where no other method was feasible. Vertical movement by this method was limited. Manpower had the advantage that it was always on site, and that it could be engaged in directly productive work when not moving materials.

WHEELBARROW The barrow extended the weight and distance limitations of manhandling. However its use was often restricted to outside the building, and ground conditions were a consideration.

POWER BARROW This had only once been used by a firm. It was indicated that site conditions had to be very good to allow its operation.

DUMPER Distance to be travelled was the main factor determining the choice of a dumper. Where access for delivery vehicles was a problem, the dumper might be used to shuttle materials over the final distance. A dumper represented an appreciable cost to the firms, so the expected utilisation was also an important consideration. Three of the firms owned one or more dumpers. Hence their availability may also have influenced the decision to send one to site, in preference to leaving it idle in the yard. The labour involved in loading a dumper's skip, and the primitive method of depositing its contents by tipping, were mentioned as its demerits.

CONVEYOR The conveyor was favourably regarded by three of the firms for its capacity for simultaneous vertical and horizontal movement in confined conditions. It was normally brought on site to support a particular operation, such as the screeding of a floor, and on completion, it would be immediately dismantled and removed.

MAN AND LADDER This was relied on as a means of moving materials only for the very smallest volumes, such as that required for jobbing work, and rarely for heights over two storeys.

GIN WHEEL The materials moved by this method were limited to the contents of a bucket. It was rarely used by any of the firms.

HOIST For three of the firms this was the preferred method for raising materials required in volume up a height of three or four storeys. As a major cost it was normally separately allowed for in the preliminaries.

FORKLIFT AND TELESCOPIC HANDLER The forklift was seen by all the firms as primarily a means of handling materials in the yard. For this purpose two of the firms were considering the purchase of a truck, and a third firm made use of a truck on loan from a neighbouring warehouse. Otherwise, vulnerability to poor site conditions and access problems were seen by the firms to restrict the forklift's site potential to the loading out of scaffolding on contracts of a type and size they were unlikely ever to undertake.

AERIAL PLATFORMS Only one firm had any experience of aerial platforms. This had been for a contract for the repointing and external repair of buildings spread over five different sites. The difficult location of the work coupled with the mobility of the platform had made it the more economical alternative to scaffolding.

JIB CRANE The movement of heavy indivisible units through both the vertical and horizontal axes represented the only circumstances in which three of the firms would use a crane. The remaining firm was also prepared to consider the use of a crane for several of a site's handling operations, none of which would singly justify the procurement of a crane.

EXCAVATOR The two firms which possessed excavators made use of their forks attachment to lift a range of bulk materials. The other firms would only make use of the excavator's handling capacity for short range movement of topsoil and aggregates, and only where the machine was already on site for other purposes.

12 CONCLUSIONS

An analysis of four small building firms revealed the need for greater co-ordination of organisational functions. Information generated by one function was not shared with others. Contracts were not planned on the basis of the performance of the firm, and were not integrated in terms of their labour requirements.

A planning system was developed to prove that by controlling the format in which functions created project data, a flow of information between them could be achieved. It was shown that this would reduce the duplicate generation of data and allow meaningful evaluation of the results of each functiom to be made. It was possible to use timesheet data to monitor site productivity.

The outcome of the levelling of a multiproject schedule depended on the quality of the decision rule applied. By whatever criterion, a rule should normally be targeted exclusively at reducing duration. There was a limit to the performance of a rule that did not make its analysis during the levelling process.

It was feasible to use a rule to level the labour demand of a small firm's workload. A multiproject schedule could provide management with useful information.

12.1 EXISTING PRACTICES OF SMALL FIRMS

DIFFERENT MANAGEMENT FUNCTIONS POSSESSED COMMON DATA REQUIREMENTS.

An assessment of labour content was found to be integral to the functions of estimating, planning, and targetting. An assessment of progress was integral to planning, targetting, and the production of valuations. However these assessments were often made independently for each function, constituting a duplication of effort.

INFORMATION GENERATED DURING ESTIMATING DID NOT SERVE PRODUCTION FUNCTIONS.

The estimate was not used for planning, targetting and control because;

(a) estimate items were not described in terms of operations that could be planned;

(b) descriptions were commonly not standardised so that there was no definition of an item's work content;

(c) no precise relationship was formed between activities, incentive targets, and estimate items;

(d) the effort of deriving planning information from the estimate was discouraging.

CONTRACTS WERE PLANNED IN ISOLATION

The aggregate labour demand of a small firm's contracts was rarely evaluated. The planning of one contract usually took place without considering the competing demands of other contracts for a shared labour force. The integrated assignment of the operatives only took place a few days before assignments were due to start.

METHODS OF PERFORMANCE EVALUATION FAILED TO BENEFIT FUTURE ACTIVITIES

The methods of costing practised by the firms were not able to highlight specific inequalities between estimated and actual performance. Detailed investigation of costs only took place when an unexpected overall loss was revealed. Unlike materials, plant and subcontractors for whom invoices exist, labour cost was rarely evaluated against subdivisions of the contract. Subsequent estimating, planning, and targeting could not therefore be based on an analysis of the past performance attained by the firm.

12.2 A NEW SYSTEM

A PLANNING SYSTEM CAN CO-ORDINATE THE DATA INFLOWS AND OUTFLOWS OF RELATED FUNCTIONS

A continuous flow of information can be maintained between functions. It is possible for data to be created in a format by one function that makes it accessible to others.

THE SINGLE ENTRY AND GENERATION OF DATA IS ACHIEVABLE

The new system demonstrates that the estimation of work content, the reporting of progress, and the reporting of actual manhours need only occur once. The centralised storage of contract information would allow the accessing and amendment of detailed contract information according to the needs of each management activity.

A WORK BREAKDOWN STRUCTURE WOULD CREATE COMPATIBILITY BETWEEN FUNCTIONS

A coded relationship between the subdivisions of the work required by each function would allow the results of one to be matched with those of another. Thus the estimate, the plan, the targets, the progress report, the valuation, and the timesheet might all be precisely comparable with each other.

CONTRACTS MAY BE INTEGRATED

A new system would allow each contract to be programmed to take account of the competing demands of other contracts for the firm's labour.

A SYSTEM OF PERFORMANCE ANALYSIS CAN BE OPERATED TO BENEFIT FUTURE CONTRACTS

A control report could be produced which would permit the simultaneous review of the accuracy of estimating data, and the productivity being attained by the operatives. The review would take place within a short period of the work's execution, and therefore while the circumstances in which it was carried out are still fresh in the minds of management.

LEVELLING BY DECISION RULES

RESOURCE LEVELLING INVOLVES THE APPLICATION OF DECISION RULES

A system of resource levelling which operates by the delay of activities involves making decisions about the choice of activities to delay. If the system is automated and not random, the decision is determined by the application of a rule.

RULES THAT OPERATE OUTSIDE THE LEVELLING PROCEDURE ARE DISADVANTAGED

The transformation of schedule data that accompanies levelling tends to invalidate the decisions of any rule which is based on an analysis of project data which is undertaken in advance of the levelling process. Only the rule included within the software did not suffer this disadvantage.

EXTERNALLY APPLIED RULES DEPEND ON THE ACCURACY OF THEIR PREDICTIONS

A prerequisite for a good rule is that it successfully predicts the prevailing circumstances of competing activities at the point during levelling when its decision is implemented.

A RULE SHOULD BE DEDICATED TO THE OPTIMISATION OF TOTAL DURATION

The aim of a rule should be the minimisation of the extensions to a multiproject schedule's critical paths. On average this will yield a better result in terms of total overrun of contract periods, total damages, and total overheads than a rule which attempts to optimise any one of these three criteria by selectively distributing levelling delay between projects. Modifying the networks to include contract completion dates does effect an improvement in forecast overrun, but at the cost of a deterioration in total duration.

There remains a possibility that where there exists a very great difference between projects in the rate at which an assessment criterion accumulates, preferential resourcing of individual projects may produce a better result by that criterion.

THE RESULT OF LEVELLING IS DETERMINED BY FIVE FACTORS

There are five aspects of any overscheduling problem that will determine the extension of the critical path(s) arising from a particular resolution;

1. Earliest start dates.
2. Activity duration.
3. Activity normal float.
4. Number of available resource units.
5. Number of resource units assigned to an activity.

These are the exclusive concern of any rule dedicated to minimising overall duration.

THE MOST SUCCESSFUL RULE WAS THE RESULT OF A PARTIAL ANALYSIS

The manner in which the first three of these variables combine with each other to influence the extension of critical path that will follow from a particular choice of activity to delay, was successfully analysed. An algorithm derived from this analysis was the basis of 'Newrule'.

A RULE BASED ON EARLIEST START DATES PERFORMED WELL

Allowing whichever activity has the earlier earliest start date to proceed first is a simple but efficacious rule that could be applied in the absence of a facility to implement 'Newrule'. An activity's earliest start date is a better indicator of its priority in the competition for overscheduled resources than is its normal float.

12.4 MULTIPROJECT SCHEDULES

A multiproject schedule representing the workload of a small building firm was created and maintained through three months of progress. Programmes were successfully derived from estimating data and progress was extracted from timesheets. The schedule successfully absorbed variations and new projects.

'NEWRULE' WAS ABLE TO EFFICIENTLY LEVEL A SMALL FIRM'S WORKLOAD

'Newrule' maintained its superiority over the rule supplied with the software when applied to the levelling of the schedule.

USE OF A MULTIPROJECT SCHEDULE RESULTS IN MORE MANAGEMENT INFORMATION

The creation and maintenance of a rule-levelled multiproject schedule provides useful information:-

1. A schedule of work that can be met by the

workforce, and which represents an efficient deployment of the firm's operatives with regard to the minimisation of contract durations.

2. The demand for labour in terms of the number of weeks of work continuity projected for each trade.

2. Realistic estimates of the contracts' completion dates at a specified level of labour availability.

INFORMATION GENERATED WHILST UPDATING THE SCHEDULE IS AVAILABLE FOR FURTHER ANALYSIS

The retention of data in the computer makes possible the historical analysis of aspects of performance such as the dilution of labour assignments, the introduction of variations and new contracts, the productivity attained at different levels of labour assignment, and the effects on a schedule of revising the trades assigned to activities.

12.5 MATERIALS HANDLING AND TRANSPORTATION

THE COLLECTION OF MATERIALS WAS POORLY ORGANISED

Operatives were not well motivated to report materials requirements at the appropriate time. Many materials were collected by the firm at short notice although there was often no separate delivery charge. The collection of materials by site operatives resulted in lost production. The co-ordination of the operatives individual requirements from a common supplier was rare.

A SMALL FIRMS WORK IS LESS CONDUCIVE TO MECHANISATION THAN THAT OF LARGE FIRMS

The small area of a site, the execution of work within existing buildings, small quantities, and the shortness of contracts are all characteristics of a small firm's work which reduce the scope for conventional handling plant.

12.6 RECOMMENDATIONS FOR FURTHER RESEARCH

1. The further development and coding of the planning system to link with the operations database and estimating system developed on an earlier project.

2. An investigation into the small firm's systems of material procurement, and the development of a new system to link with planning and scheduling.

3. The extension of the 'newrule' algorithm to include labour levels.

4. The incorporation of a rule containing the algorithm into the levelling procedure so that it can operate on updated data relating to the actual instance of overscheduling.

5. A field study of the special materials handling problems faced by small firms.

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CASE STUDY OF FIRM A

TYPE OF FIRM: Limited Company

LOCATION: Rotherham, S. Yks.

APPROXIMATE TURNOVER: # 600,000

WORKFORCE;

	DIRECTLY EMPLOYED	LABOUR-ONLY SUBCONTRACTORS	TOTAL
LABOURERS	2	2	4
JOINERS	2	2	4
BRICKLAYERS	1	1	2
YTS (LABOURERS)	2	0	2
TOTAL	7	5	12

FULL-TIME STAFF: 3 **PART-TIME STAFF:** 3

COMPUTER USAGE: Two microcomputers, used for word processing, wages calculations and estimating.

HISTORY: The firm was formed in 1972 by its three present directors. From a modest turnover, mainly from alterations and extensions, the firm has grown steadily to its current size. Expansion was given additional impetus in the late 70's by the firm's involvement in specialist foundation work for garages. In 1987 the company moved into new purpose-built offices.

TYPE OF WORK: Well over half of the firm's work was reported to come from refurbishments and conversions. The importance of the firms specialist work had declined recently, and now accounted for only about 10% of turnover.

Contracts of this type were fairly standard, and rarely lasted more than a week. The remainder of the firm's business comprised repairs, new work, drainage, and work on concrete slabs.

Contracts tendered for ranged in value from # 1,000 to a maximum of # 400,000. It was reported that recently, the typical size of contracts being won had increased, and that contracts over # 100,000 were becoming common.

Most of the work was within a 20 - 30 mile radius of the firm's offices, but the specialised garage work required the operatives to travel almost anywhere in the country.

MANAGEMENT ORGANISATION: The firm's management comprised two full-time directors, one part-time director, and one full-time menmber of staff. A strict demarcation of their roles was not maintained. Responsibility for estimating, the initial planning of the contract, setting targets, and cost control was shared between the part-time financial director and an estimator/surveyor. Production matters were chiefly the responsibility of the firm's other two directors.

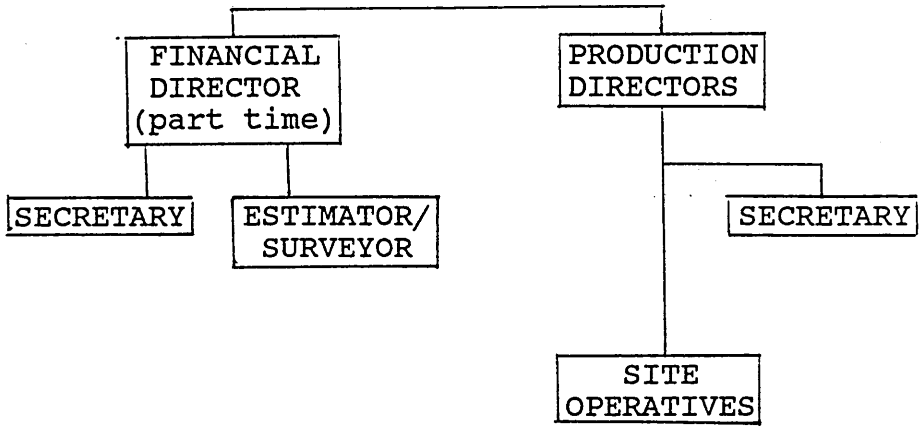
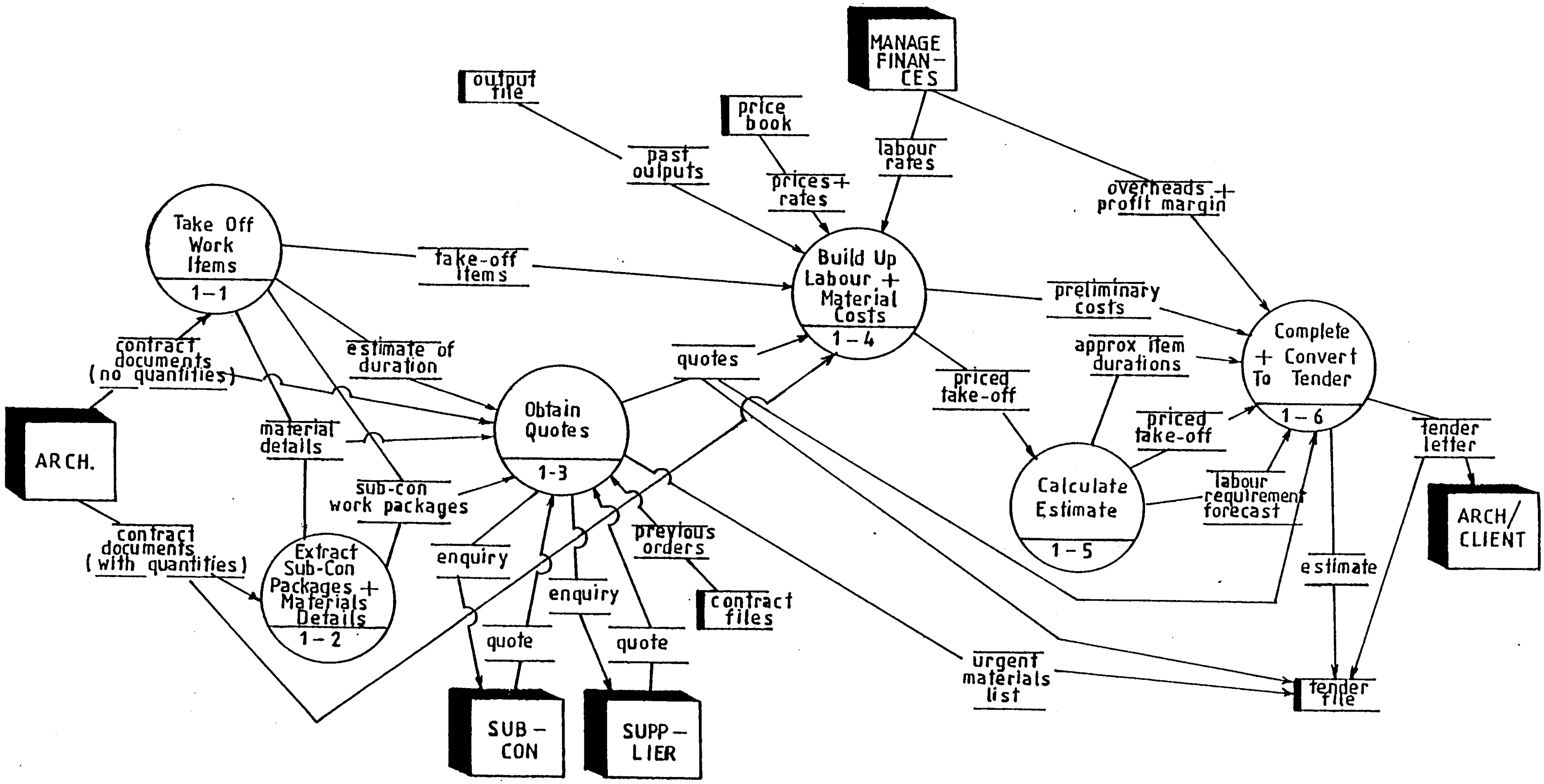


Figure A1.1 MANAGEMENT ORGANISATION - FIRM A



1. PRODUCE TENDERS.

Figure A1.2.

PROCESS DESCRIPTIONS FOR FIRM A

1 PRODUCE TENDERS

1.1 TAKE OFF WORK ITEMS

DESCRIPTION: If there are no quantities provided, measure the work against standard descriptions selected from a library. Create rogue descriptions where no standard description fits. Identify work packages to be subcontracted. Extract details of materials requiring quotes.

INPUTS: contract documents (no quantities), standard descriptions

OUTPUTS: take off items, subcontractor work packages, materials details, estimate of duration

1.2 EXTRACT SUBCONTRACTOR PACKAGES AND MATERIALS DETAILS

DESCRIPTION: (For tenders where quantities are supplied) Identify work packages to be subcontracted. Extract details of materials requiring quotes.

INPUTS: contract documents (with quantities)

OUTPUTS: subcon work packages, materials details

1.3 OBTAIN QUOTES

DESCRIPTION: Assemble tender information (including contract start and finish dates) and issue to subcontractors for quotes. Extract materials prices from files and previous orders. Check prices of major materials with suppliers.

INPUTS: contract documents, materials details, subcon packages, estimate of duration, quotes, previous orders

OUTPUTS: enquiries, quotes, urgent materials list

1.4 BUILD UP LABOUR AND MATERIALS COSTS

DESCRIPTION: Select quotes to include. Build up costs for each resource separately. Amend standard outputs to evaluate labour content.

INPUTS: contract documents, quotes, take off items, past outputs, prices and rates, labour rates

OUTPUTS: take off,sums and rates, preliminaries costs

1.5 CALCULATE COSTS

DESCRIPTION: Evaluate total resource costs.

INPUTS: take off,sums and rates

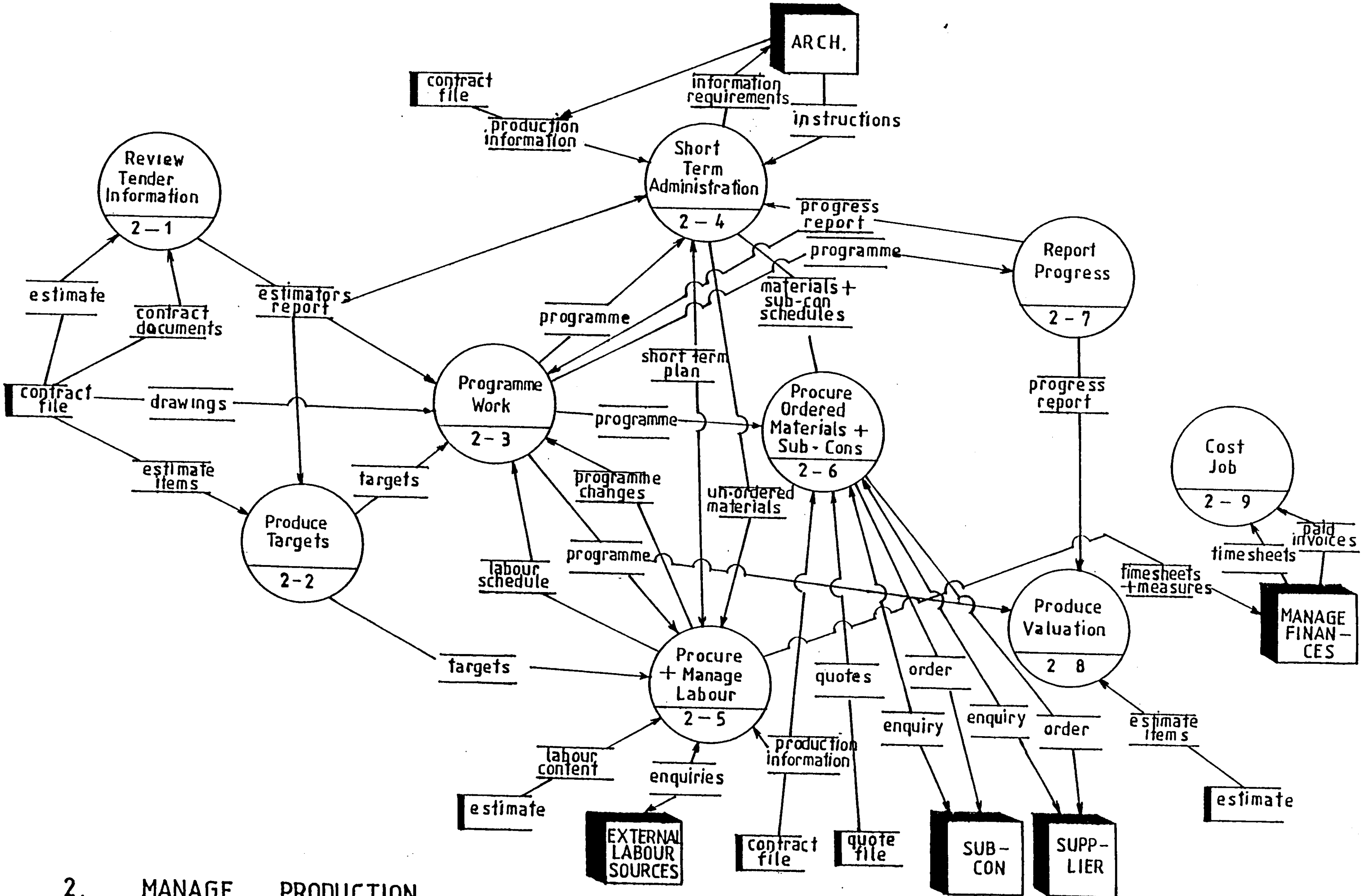
OUTPUTS: priced take off

1.6 COMPLETE AND CONVERT TO TENDER

DESCRIPTION: Build up preliminaries costs. Calculate margin for overheads and profit as percentage of contract sum, or as a proportion of the labour cost. Total and produce tender submission.

INPUTS: priced take off, preliminaries costs, overheads and profit margin, quotes

OUTPUTS: estimate, tender letter



2. MANAGE PRODUCTION.

Figure A1.3.

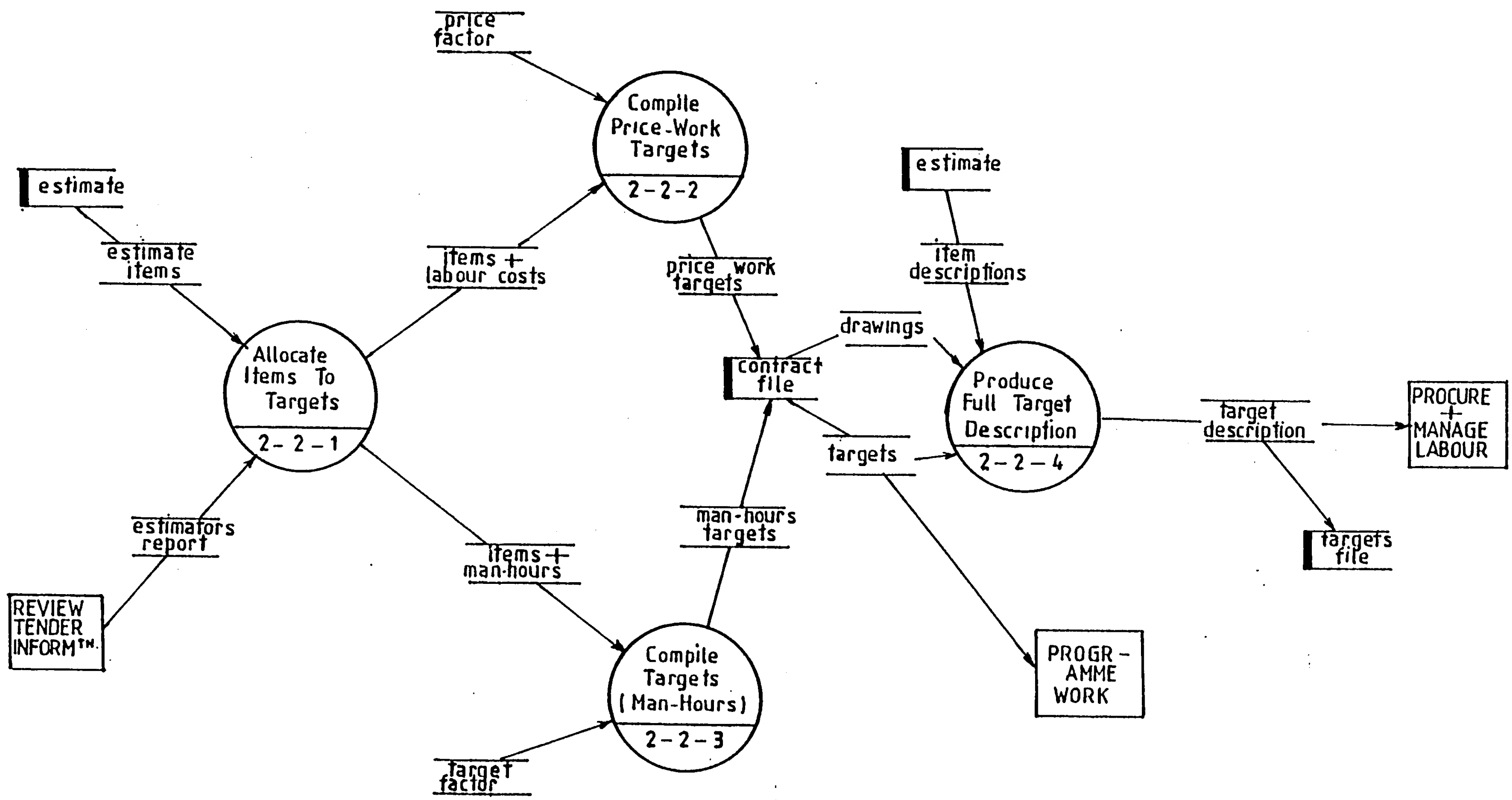
2 MANAGE PRODUCTION

2.1 REVIEW TENDER INFORMATION

DESCRIPTION: Prepare a report summarising the most important features of the contract, the most urgent materials requirements, information requirements, details of subcontractors, and an initial division of the work into targets.

INPUTS: estimate, contract documents

OUTPUTS: estimator's report



2-2. PRODUCE TARGETS.

Figure A1.4.

2.2 PRODUCE TARGETS

2.2.1 ALLOCATE ITEMS TO TARGETS

DESCRIPTION: Group related estimate items into targets and extract each items labour content in manhours or cost from the estimate.

INPUTS: estimate items, estimator's report

OUTPUTS: items and manhours, items and costs

2.2.2 COMPILE PRICEWORK TARGETS - Occasionally Used

DESCRIPTION: Sum costs and amend the total as necessary. Note gang target intended for if known.

INPUTS: items and labour costs, price factor

OUTPUTS: pricework targets

2.2.3 COMPILE TARGETS (MANHOURS) - Usual System

DESCRIPTION: Total target manhours and apply target factor.

INPUTS: items and manhours, target factor

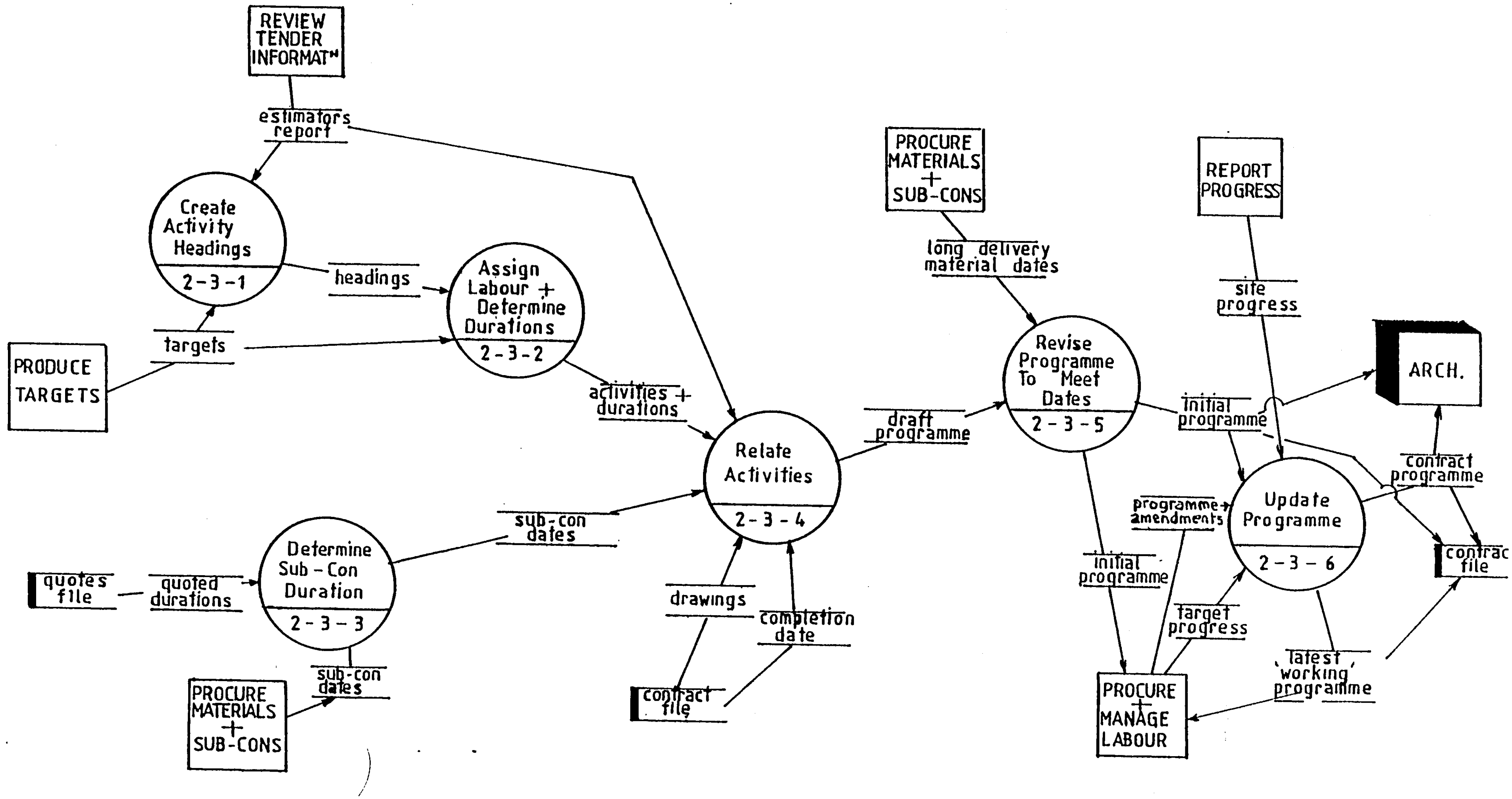
OUTPUTS: manhours targets

2.2.4 PRODUCE FULL TARGET DESCRIPTIONS

DESCRIPTION: Describe work contained in target at length.

INPUTS: targets, drawings, item descriptions

OUTPUTS: target descriptions



2-3. PROGRAMME WORK.

Figure A1.5.

2.3 PROGRAMME WORK

2.3.1 CREATE ACTIVITY HEADINGS

DESCRIPTION: Group targets under activity headings and list in appropriate order.

INPUTS: targets, estimator's report

OUTPUTS: headings

2.3.2 ASSIGN LABOUR AND DETERMINE DURATIONS

DESCRIPTION: Apply inverse of target factor. Divide result by chosen gang size, convert to days and total.

INPUTS: headings, targets

OUTPUTS: activities and durations

2.3.3 DETERMINE SUBCONTRACTOR DURATION

DESCRIPTION: Check for any durations or earliest start dates quoted for the work.

INPUTS: quoted durations, subcon dates

OUTPUTS: subcon dates

2.3.4 RELATE ACTIVITIES

DESCRIPTION: Decide on leads and lags between activities based on physical dependencies and nominal resource constraints.

INPUTS: activities and durations, estimator's report, subcon dates, drawings, completion date

OUTPUTS: draft programme

2.3.5 REVISE PROGRAMME TO MEET DATES

DESCRIPTION: Adjust programme if necessary to suit earliest delivery dates reported by suppliers.

INPUTS: Draft programme, long delivery materials dates

OUTPUTS: initial programme

2.3.6 UPDATE PROGRAMME

DESCRIPTION: Revise programme to take account of results of multiproject scheduling of labour, and of site progress as necessary.

INPUTS: initial programme, programme amendments, target progress, site progress

OUTPUTS: 'contract' programme (as supplied to architect), latest 'working' programme

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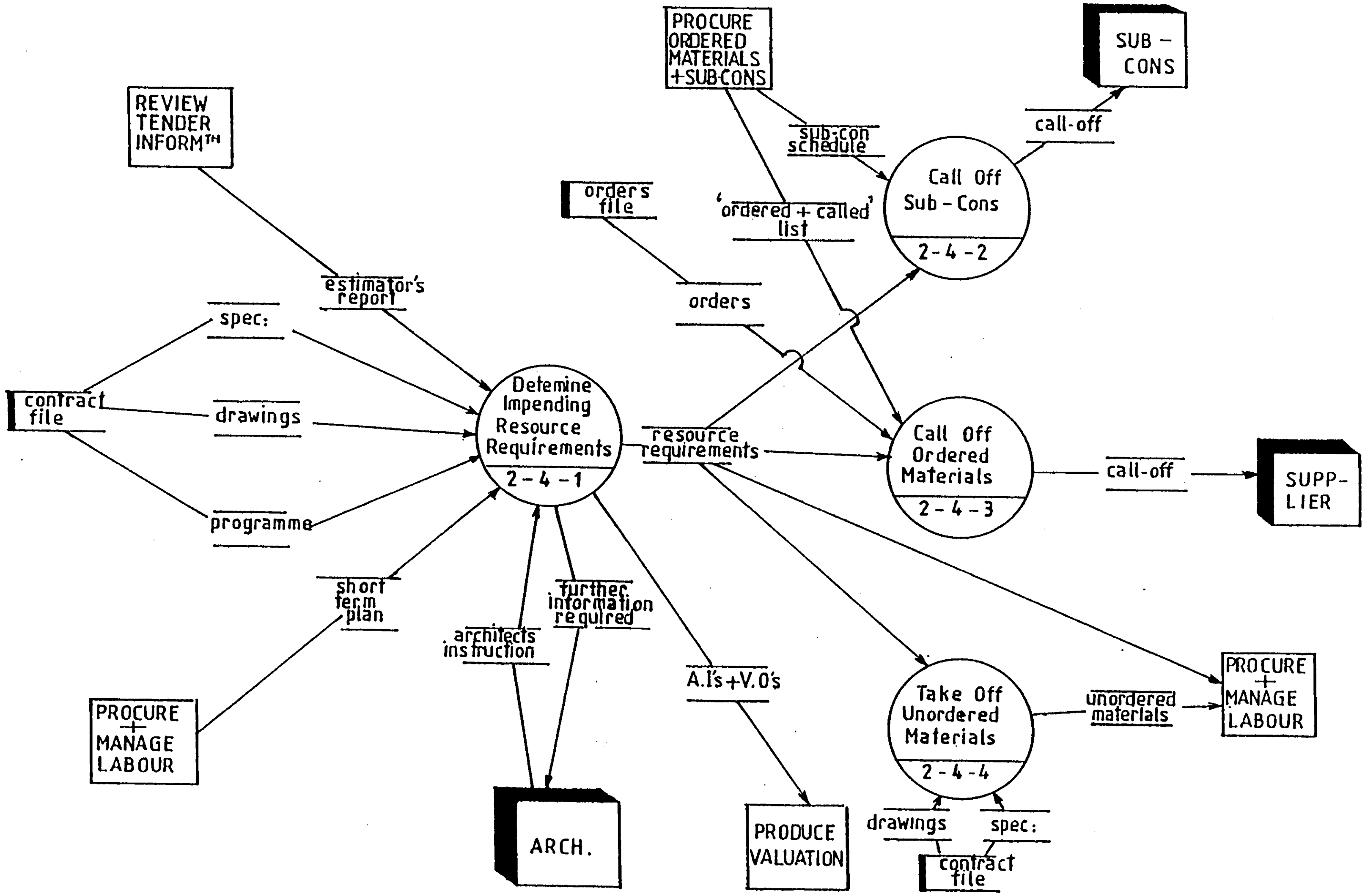


2-4. SHORT TERM ADMINISTRATION.

Figure A1.6.

2.4 SHORT TERM ADMINISTRATION

2.4.1 DETERMINE IMPENDING RESOURCE REQUIREMENTS

DESCRIPTION: Determine which materials, operatives, and subcontractors are needed, and when they are needed, to carry out the short term plan. Request any production information outstanding.

INPUTS: short term plan, estimator's report, specification, drawings, programme, architects instructions

OUTPUTS: resource requirements, AIs and VOs.

2.4.3 CALL OFF SUBCONTRACTORS

DESCRIPTION: Confirm arrival date of subcontractors.

INPUTS: subcontractor requirement, subcontractor schedule,

OUTPUTS: call off

2.4.3 CALL OFF ORDERED MATERIALS

DESCRIPTION: Communicate required delivery date to suppliers.

INPUTS: materials requirements, orders, 'ordered-and-called' list

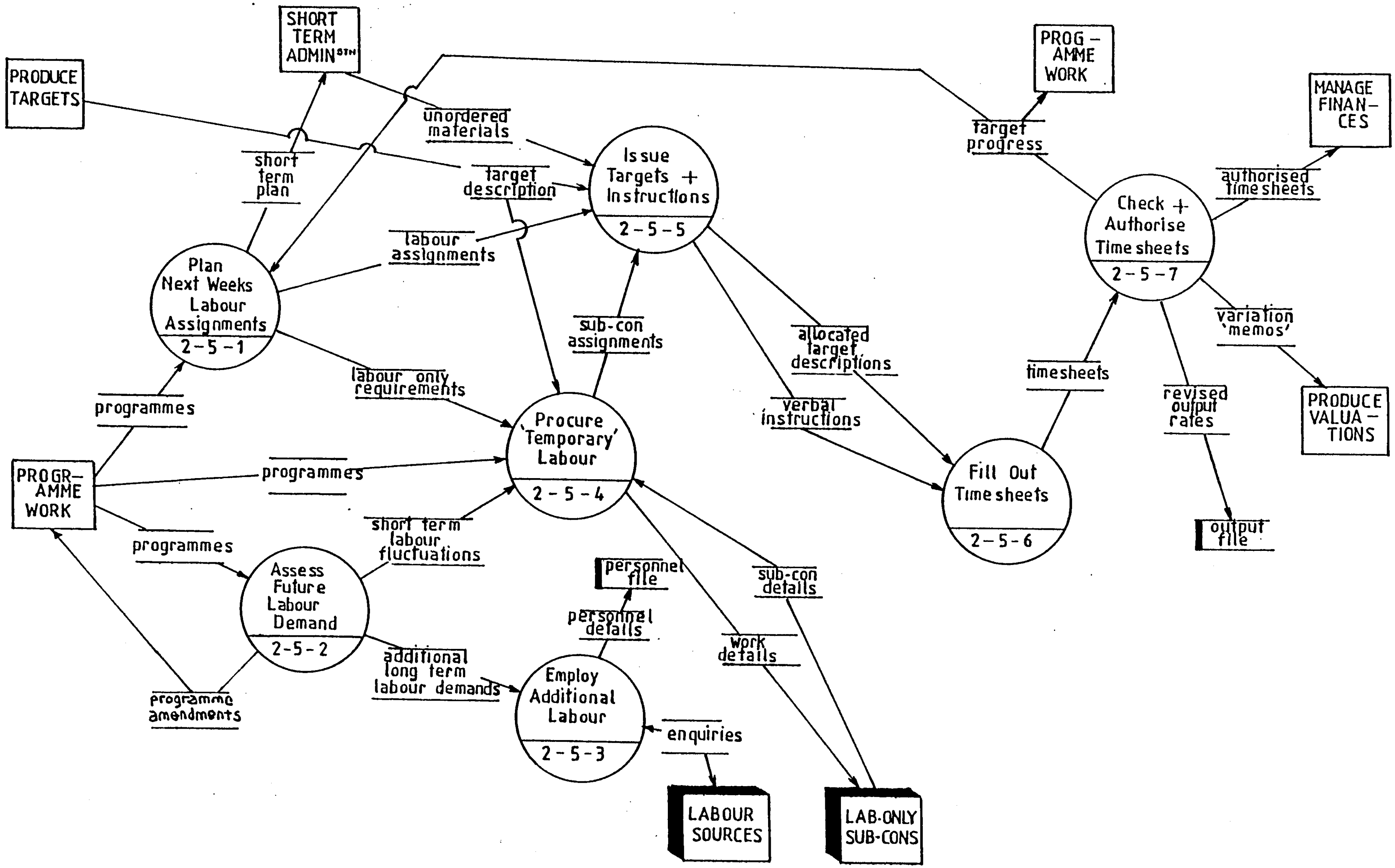
OUTPUTS: call off

2.4.4 TAKE OFF UNORDERED MATERIALS

DESCRIPTION: Take off the unordered materials to be collected by the operatives.

INPUTS: materials requirements, drawings, specification

OUTPUTS: unordered materials



2-5. PROCURE & MANAGE LABOUR.

Figure A1.7.

2.5 PROCURE AND MANAGE LABOUR

2.5.1 PLAN NEXT WEEK'S LABOUR ASSIGNMENTS

DESCRIPTION: Decide on the schedule of work for individuals and gangs for the next week or two. Consider the need for labour-only subcontractors in the short term.

INPUTS: programmes, target progress

OUTPUTS: short term plan, labour assignments, labour-only requirements

2.5.2 ASSESS FUTURE LABOUR DEMAND

DESCRIPTION: Produce a multiproject schedule showing all the activities to be carried out by the firm's workforce. Amend idividual programmes to relieve overscheduling if necessary. Decide whether changes in labour demand are short or long term in nature.

INPUTS: programmes

OUTPUTS: multiproject schedule, short term labour fluctuations, additional long term labour demand

2.5.3 EMPLOY ADDITIONAL LABOUR

DESCRIPTION: Make enquiries to, and receive enquiries from external labour market. Select and employ labour and file personal details.

INPUTS: additional long term labour demand, enquiries

OUTPUTS: enquiries, personnel details

2.5.4 PROCURE 'TEMPORARY' LABOUR

DESCRIPTION: Identify work to be undertaken by labour-only labour. Review subcontractors and select.

INPUTS: programmes, labour-only requirements, short term labour fluctuations, target descriptions, subcon details
OUTPUTS: work details, subcon assignments

2.5.5 ISSUE TARGETS AND INSTRUCTIONS

DESCRIPTION: Complete allocation of targets to gangs and distribute them. Instruct operatives verbally regarding construction details and materials requirements.
INPUTS: labour and subcon assignments, target descriptions, unordered materials
OUTPUTS: allocated target descriptions, verbal instructions

2.5.6 FILL OUT TIMESHEETS

DESCRIPTION: Record hours worked against descriptions of the work.
INPUTS: allocated target descriptions, verbal instructions
OUTPUTS: timesheets

2.5.7 CHECK AND AUTHORISE TIMESHEETS

DESCRIPTION: Assign hours worked to appropriate targets and indicate state of completion. Extract details of any unscheduled work. Amend standard output rates where significant differences are detected between targetted and timesheet hours.
INPUTS: timesheets
OUTPUTS: authorised timesheets, target progress, variation 'memos', revised output rates

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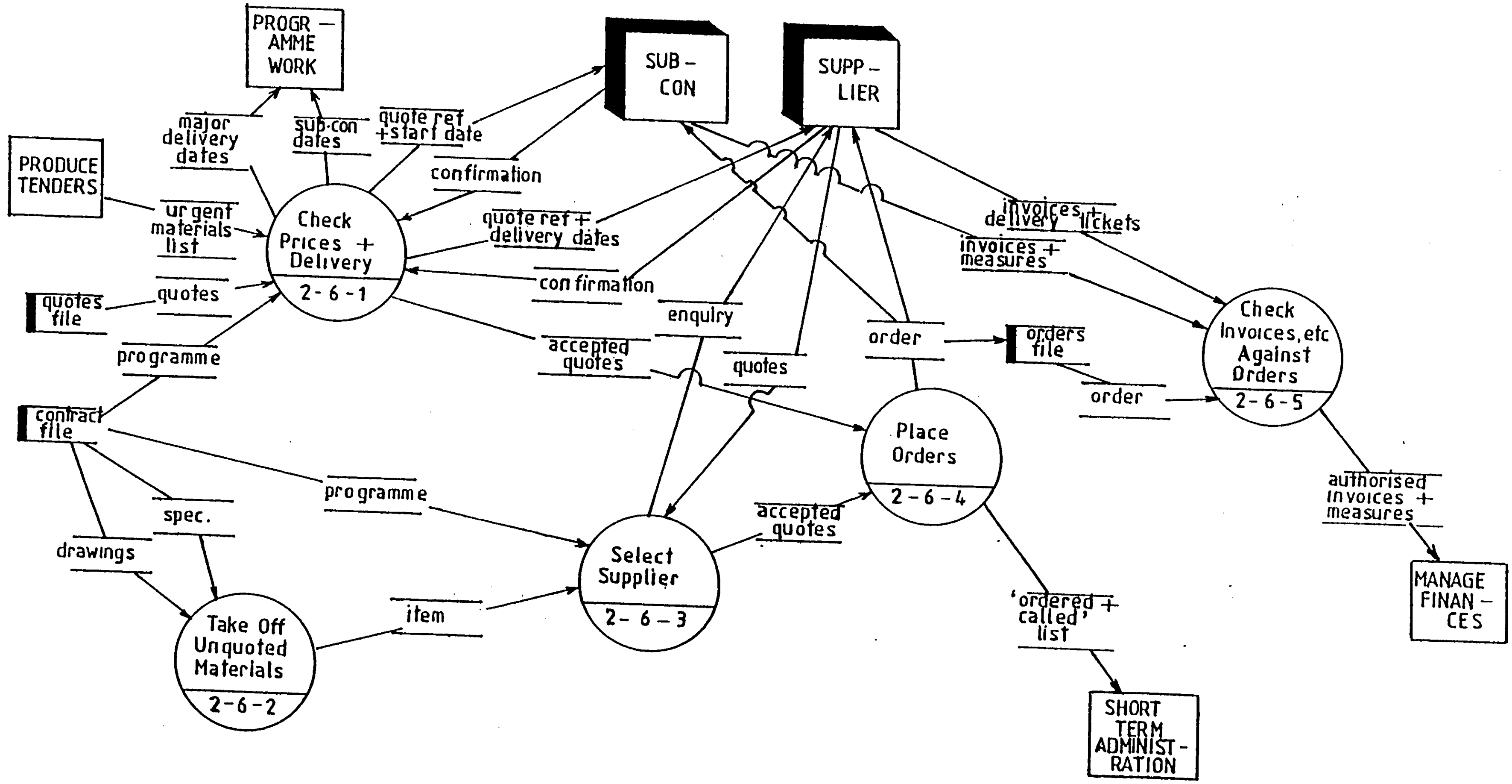


2-6. PROCURE ORDERED MATERIALS & SUBCONTRACTORS.

Figure A1.8.

2.6 PROCURE ORDERED MATERIALS AND SUBCONTRACTORS

2.6.1 CHECK PRICES AND DELIVERY

DESCRIPTION: Verify quoted prices and delivery for urgent materials and subcontractors.

INPUTS: urgent materials list, quotes, programme, confirmation

OUTPUTS: quoted delivery date, quoted start date, major delivery dates, accepted quotes

2.6.2 TAKE OFF UNQUOTED MATERIALS

DESCRIPTION: Measure those materials not previously quoted for, but to be put on order.

INPUTS: drawings, specification

OUTPUTS: item

2.6.3 SELECT SUPPLIER

DESCRIPTION: Communicate materials details and required delivery date to suppliers. Review quotes received and select.

INPUTS: programme, item, quotes

OUTPUTS: enquiry, accepted quotes

2.6.4 PLACE ORDERS

DESCRIPTION: Prepare and issue order. Call for immediate delivery if required.

INPUTS: accepted quote

OUTPUTS: order, 'ordered-and-called' list

2.6.5 CHECK INVOICES AGAINST ORDERS

DESCRIPTION: Check that delivery tickets and invoices match orders. Resolve any discrepancies.

INPUTS: invoices, subcontractor measures, delivery tickets, orders

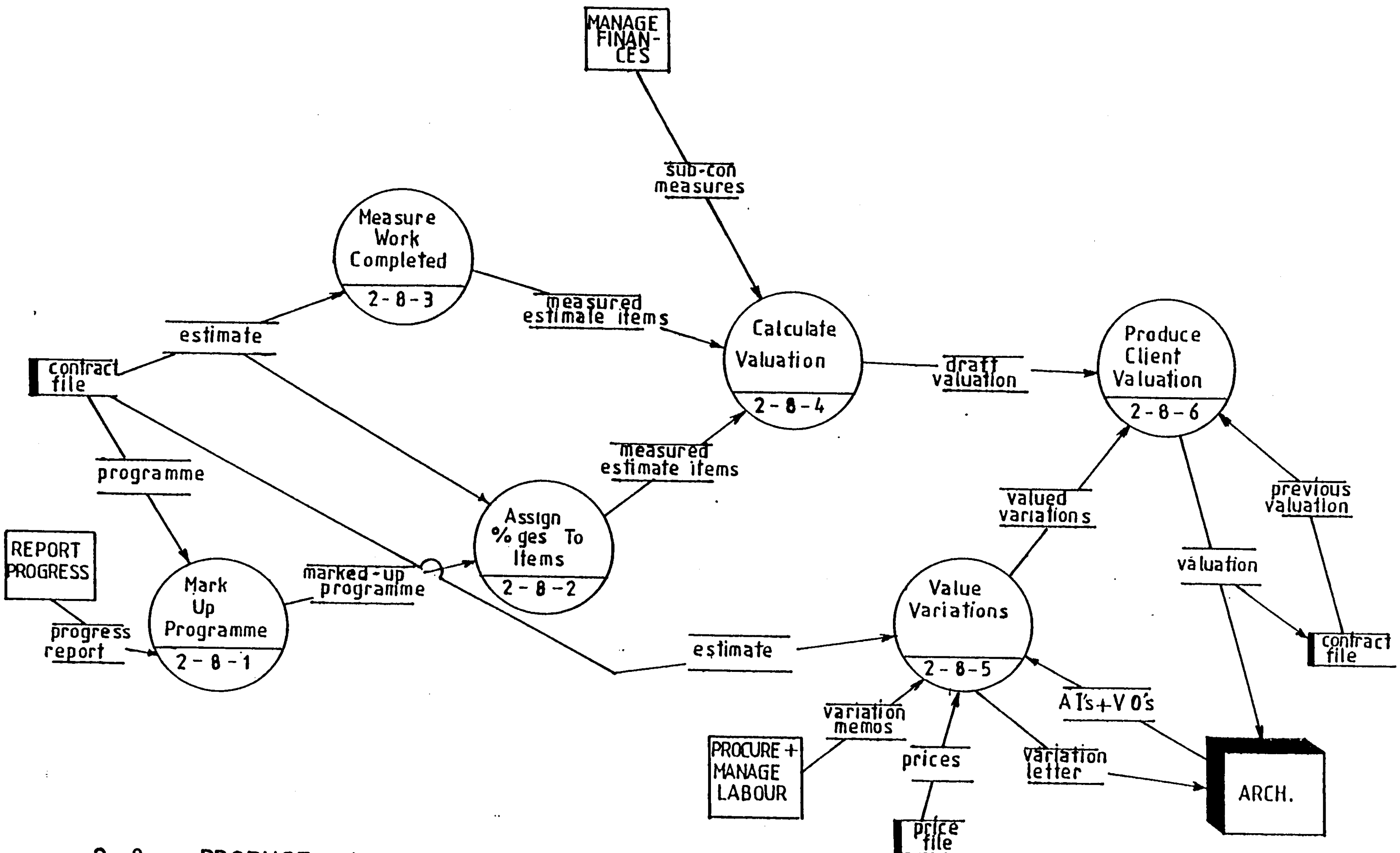
OUTPUTS: authorised invoices and measures

2.7 REPORT PROGRESS

DESCRIPTION: **Assess percentage completion of programme activities.**

INPUTS: **programme**

OUTPUTS: **progress report**



2-8. PRODUCE VALUATION.

Figure A1.9.

2.8 PRODUCE VALUATIONS

2.8.1 MARK UP PROGRAMME

DESCRIPTION: **Indicate on bar chart proportion of each activity completed to date.**

INPUTS: **programme, progress report**

OUTPUTS: **marked-up programme**

2.8.2 ASSIGN PERCENTAGES TO ITEMS

DESCRIPTION: **Determine proportion of estimate items completed from the progress achieved on the activity to which they relate.**

INPUTS: **marked up programme, estimate**

OUTPUTS: **measured estimate items**

2.8.3 MEASURE WORK COMPLETED

DESCRIPTION: **Measure physical quantities of work progressed since previous valuation.**

INPUTS: **estimate**

OUTPUTS: **measured estimate items**

2.8.4 CALCULATE VALUATION

DESCRIPTION: **Calculate value of work completed for each item. Enter latest subcontractor valuations. Total value of work.**

INPUTS: **measured estimate items, previous valuation, subcon measures**

OUTPUTS: **draft valuation**

2.8.5 VALUE VARIATIONS

DESCRIPTION: **Derive/prepare descriptions of work content of** additional work. Request instruction from the architect if none has been received. Produce and apply rates from the estimate against variations where appropriate. Otherwise build up price from new. Produce list of variations to accompany valuation.

INPUTS: variation 'memos', AIs and VOs, estimate, prices

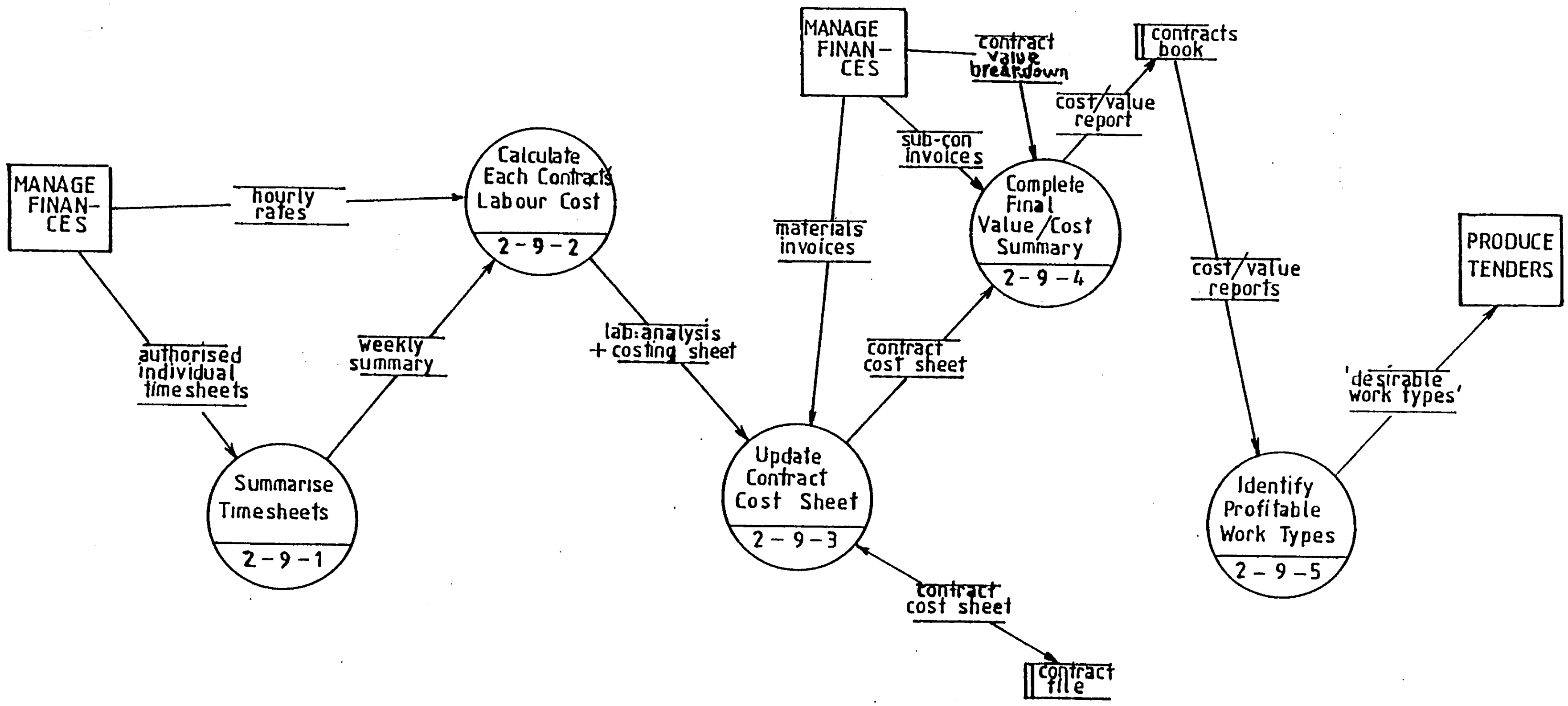
OUTPUTS: variation letter, valued variations

2.8.6 PRODUCE CLIENT VALUATION

DESCRIPTION: Adjust total for variations and retention. Deduct previous valuations and add VAT. Prepare letter of valuation including summarised breakdown of progress.

INPUTS: draft valuation, valued variations, previous valuation

OUTPUTS: valuation



2-9. COST JOB.

Figure A1.10.

2.9 COST JOB

2.9.1 SUMMARISE TIMESHEETS

DESCRIPTION: **Extract non-incentive hours worked by each man, each day, on each site. Total the individual's hours on each site for the week.**

INPUTS: **authorised timesheets**

OUTPUTS: **weekly summary**

2.9.2 CALCULATE EACH CONTRACTS LABOUR COST

DESCRIPTION: **For each site, sum non-incentive hours worked by each trade and multiply by an average cost of labour. Record bonus payments for each site.**

INPUTS: **weekly summary, hourly rates**

OUTPUTS: **labour analysis and costing sheet**

2.9.3 UPDATE CONTRACT COST SHEET

DESCRIPTION: **Add total bonus and non-incentive costs to sheet. Total monthly plant and materials costs and add to sheet.**

INPUTS: **labour analysis and costing sheet, invoices, contract cost sheet**

OUTPUTS: **contract cost sheet (updated)**

2.9.4 COMPILE FINAL VALUE/COST SUMMARY

DESCRIPTION: **Deduct labour, material and plant, and subcontractor cost subtotals from corresponding contract values for breakdown of profit or loss.**

INPUTS: **contract cost sheet, subcontractor invoices, contract value breakdown**

OUTPUTS: **cost/value report**

2.9.5 IDENTIFY PROFITABLE WORK TYPES

DESCRIPTION: **Review profitability of past contracts and determine the types of work at which the firm is most successful.**

INPUTS: **cost/value report**

OUTPUTS: **'desirable work types'**

CASE STUDY OF FIRM B

TYPE OF FIRM: Owner-Managed

LOCATION: Worksop, N. Derbyshire

APPROXIMATE TURNOVER: # 750,000

WORKFORCE;

	DIRECTLY EMPLOYED	LABOUR-ONLY SUBCONTRACTORS	TOTAL
	(NO BREAKDOWN RETURNED)		
TOTAL	40	0	40

FULL-TIME STAFF: 5 **PART-TIME STAFF**: 0

COMPUTER USAGE: None.

HISTORY: Since its formation in 1953, the firm had remained in the ownership of the same proprietor. The firm established itself as a general contractor, and grew steadily during the 60's and 70's. During the recession of the early 80's the proportion of its work comprising repair and maintenance expanded considerably, whilst the size of individual contracts declined.

TYPE OF WORK: Although there was a significant volume of alterations and extensions, short term repair work dominated the firm's workload. By value, about one third of the work was carried out as jobs lasting less than six weeks, and many took less than a week. At the time of the study, the hope was expressed that an anticipated improvement in demand for building work would allow the firm to reduce its dependence on short term repair and maintenance work. Contracts up to # 250,000 in value were being tendered for. Local authorities and British Coal were the firm's most frequent clients.

MANAGEMENT ORGANISATION: Each of the three contract managers was responsible for almost all aspects of a contract from estimating to the settlement of final accounts. Most of the fourth manager's time was occupied with estimating, and consequently it was common for his colleagues to take over the contracts he had successfully tendered for. The day to day organisation of all the firm's operatives and subcontractors was executed by the proprietor in consultation with his managers. There was no system of foremen on sites, but a senior tradesman was usually appointed to receive instructions. The costing and wage calculation were carried out by clerical staff.

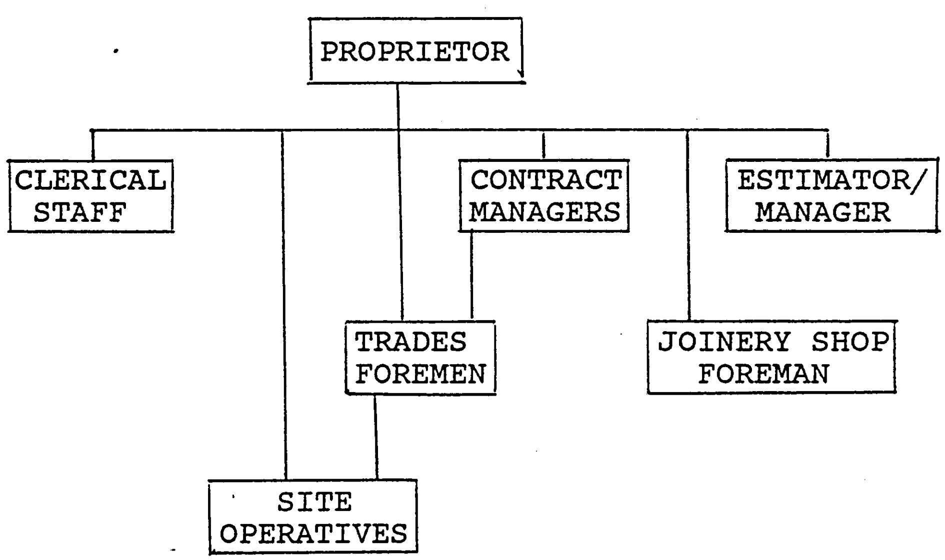
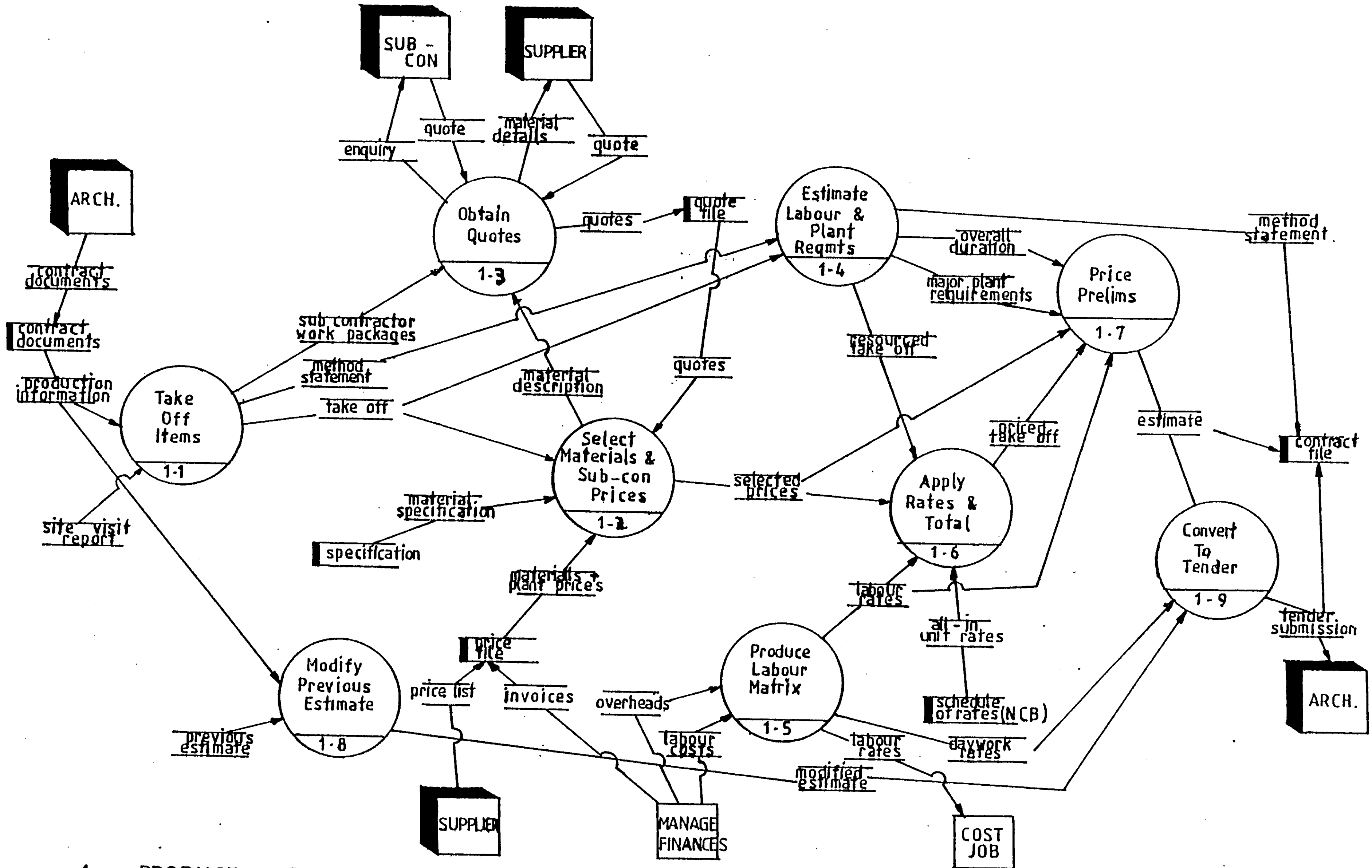


Figure A2.1. MANAGEMENT ORHGANISATION - FIRM B



1. PRODUCE TENDERS

Figure A2.2.

PROCESS DESCRIPTIONS FOR FIRM B

1 PRODUCE TENDERS

1.1 TAKE OFF ITEMS

DESCRIPTION: Create work descriptions and measure related quantities. Describe unusual and complex work in form of method statement. Extract work sections to be subcontracted.

INPUTS: production information, site visit report

OUTPUTS: take off, method statement, subcon work packages

1.2 SELECT MATERIALS AND SUBCONTRACTOR PRICES

DESCRIPTION: Take materials prices from files. Prepare materials details for quotes. Choose suppliers and subcontractors to quote from past records. Review quotes and file prices. Select those to be included in estimate.

INPUTS: take off, materials specification, filed materials and plant prices, quotes

OUTPUTS: materials descriptions, selected quotes

1.3 OBTAIN QUOTES

DESCRIPTION: Send out enquiries to materials suppliers and subcontractors including approximate contract start and completion dates. Receive quotes.

INPUTS: subcon work packages, materials descriptions, quotes

OUTPUTS: subcon enquiries, materials details, quotes received

1.4 ESTIMATE LABOUR AND PLANT REQUIREMENTS

DESCRIPTION: Decide the trade, number of men, and duration for each item from experience. Specify plant requuired. Estimate overall contract duration.

INPUTS: take off, method statement

OUTPUTS: resourced take off, major plant requirements, overall duration

1.5 PRODUCE LABOUR MATRIX

DESCRIPTION: Calculate hourly labour rates for each trade, allowing for overtime, overheads, and profit margin.

INPUTS: labour costs, overheads

OUTPUTS: labour rates, daywork rates

1.6 APPLY RATES AND TOTAL

DESCRIPTION: Apply labour rates to the estimated number of manhours. Enter spot material prices and selected subcontractor quotes. Compare doubtful rates with those taken from schedule of rates normally used to price work of a specific client. Amend as necessary.

INPUTS: resourced take off, selected prices, labour rates, all-in unit rates

OUTPUTS: priced take off

1.7 PRICE PRELIMINARIES

DESCRIPTION: Calculate preliminaries based on estimate of overall duration or that specified by client. Calculate total of estimate.

INPUTS: priced take off, labour rates, major plant requirement overall duration, selected prices

OUTPUTS: estimate

1.8 MODIFY PREVIOUS ESTIMATE

DESCRIPTION: Where contract very similar to previous, modify previous estimate where appropriate.

INPUTS: production information, previous estimate

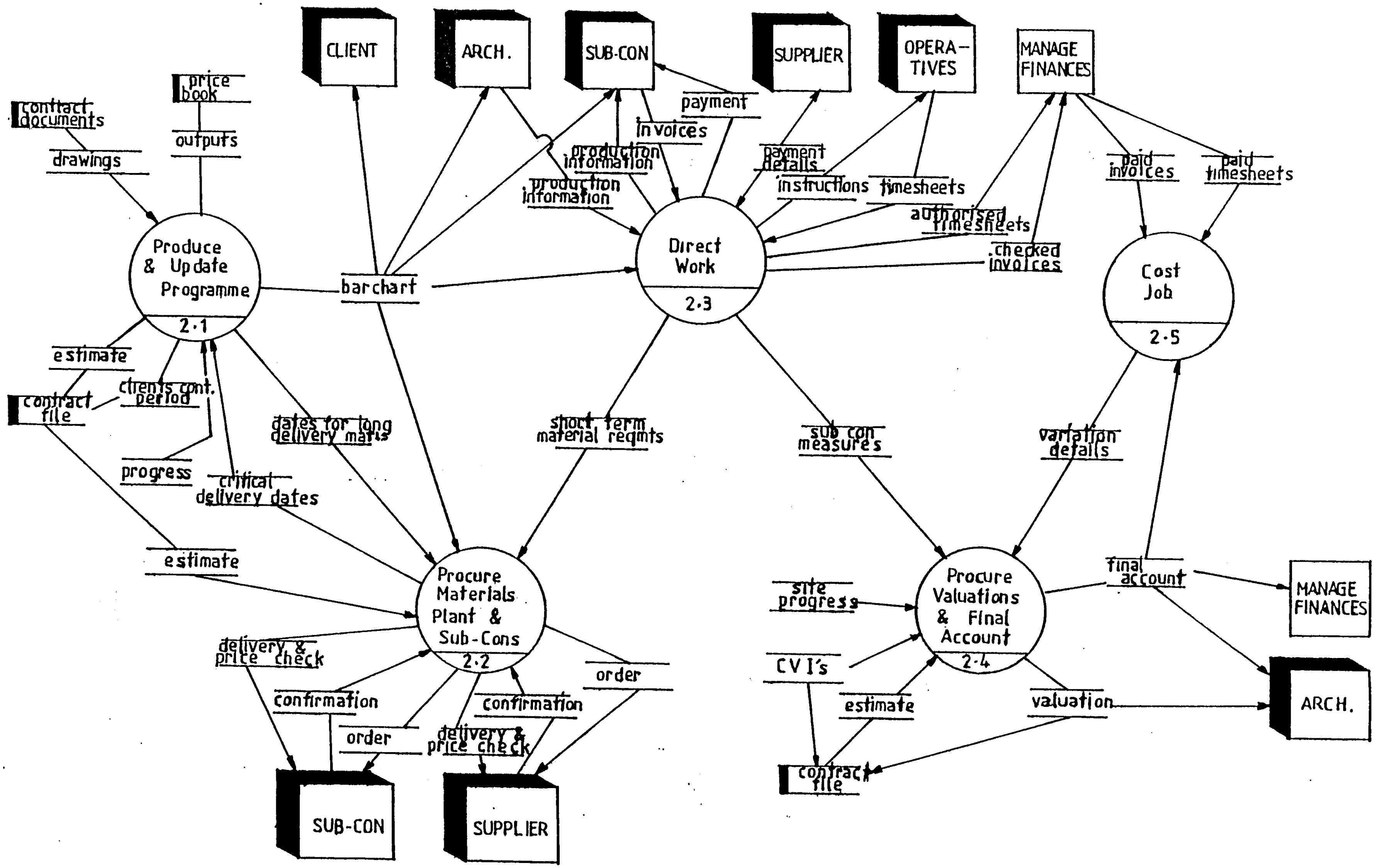
OUTPUTS: modified estimate

1.9 CONVERT TO TENDER

DESCRIPTION: Add any further mark-up as appropriate. State dayworks if required. Produce summarised descriptions of the work from take off descriptions if required. Otherwise complete and return standard tender document.

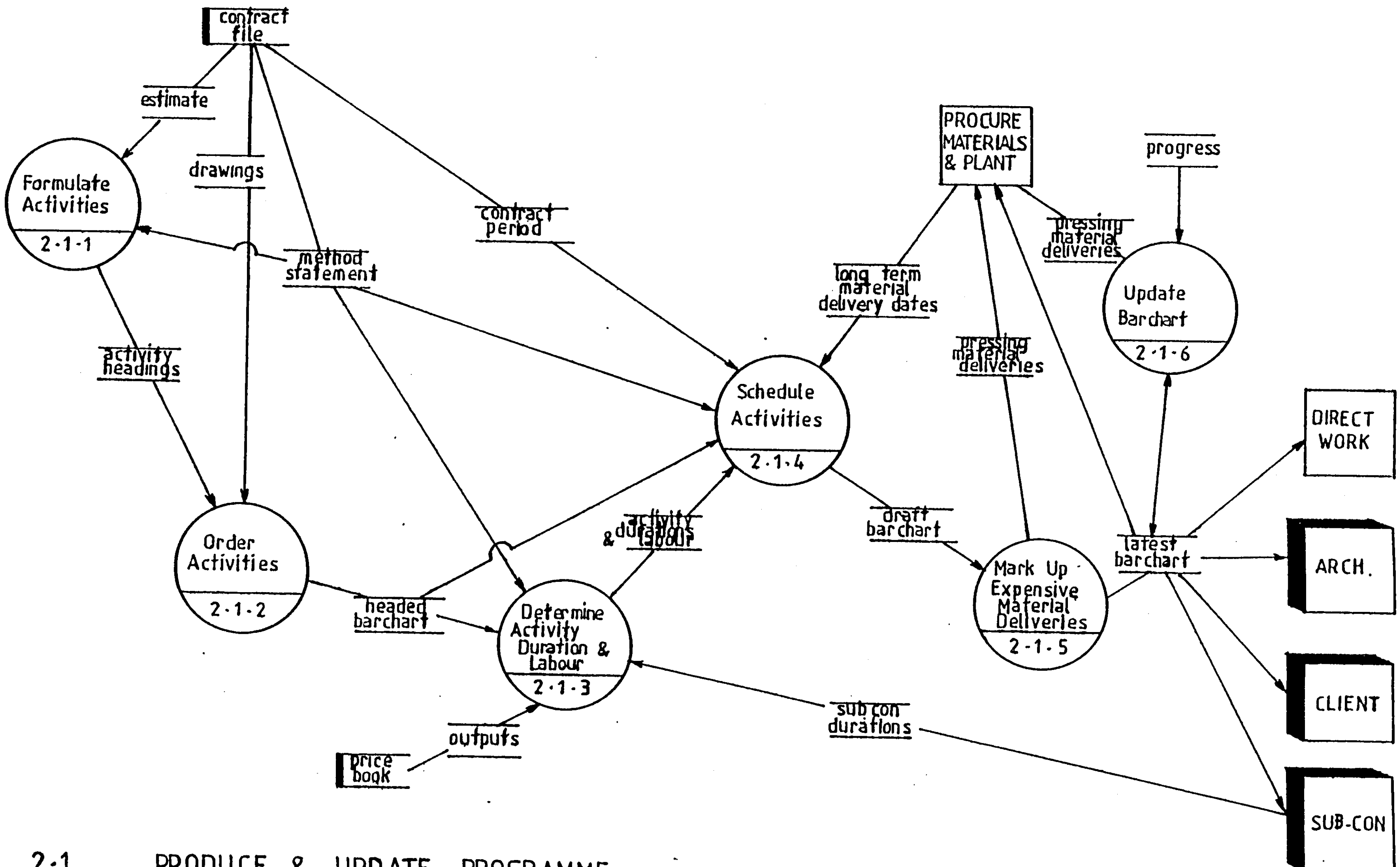
INPUTS: estimate, dayworks rates

OUTPUTS: tender submission



2. MANAGE PRODUCTION.

Figure A2.3.



2·1 PRODUCE & UPDATE PROGRAMME

Figure A2.4.

2 MANAGE PRODUCTION

2.1 PRODUCE AND UPDATE PROGRAMME

2.1.1 FORMULATE ACTIVITIES

DESCRIPTION: Divide work into activities and create headings.

INPUTS: estimate, method statement

OUTPUTS: activity headings

2.1.2 ORDER ACTIVITIES

DESCRIPTION: List headings in probable chronological order.

INPUTS: activity headings, activity dependencies, drawings

OUTPUTS: headed bar chart

2.1.3 DETERMINE ACTIVITY DURATION AND LABOUR

DESCRIPTION: From estimate calculations extract item durations and combine to produce activity durations. Use price book output rates when uncertain. Receive estimate of subcontractor durations from subcontractors.

INPUTS: headed bar chart, estimate, method statement, contract period, outputs, subcon durations

OUTPUTS: activity durations and labour

2.1.4 SCHEDULE ACTIVITIES

DESCRIPTION: For each activity, determine both physical and resource dependencies on preceding activities, and hence establish start date of activity. Check materials required for activity can be delivered on time. Enter activity on bar chart.

INPUTS: headed bar chart, activity durations and labour, method statement, contract period, activity dependencies, long term material delivery dates

OUTPUTS: preliminary bar chart

2.1.5 MARK UP EXPENSIVE MATERIAL DELIVERIES

DESCRIPTION: Indicate on bar chart the dates scheduled for the delivery of major materials. Take note of those urgently requiring to be ordered.

INPUTS: preliminary bar chart

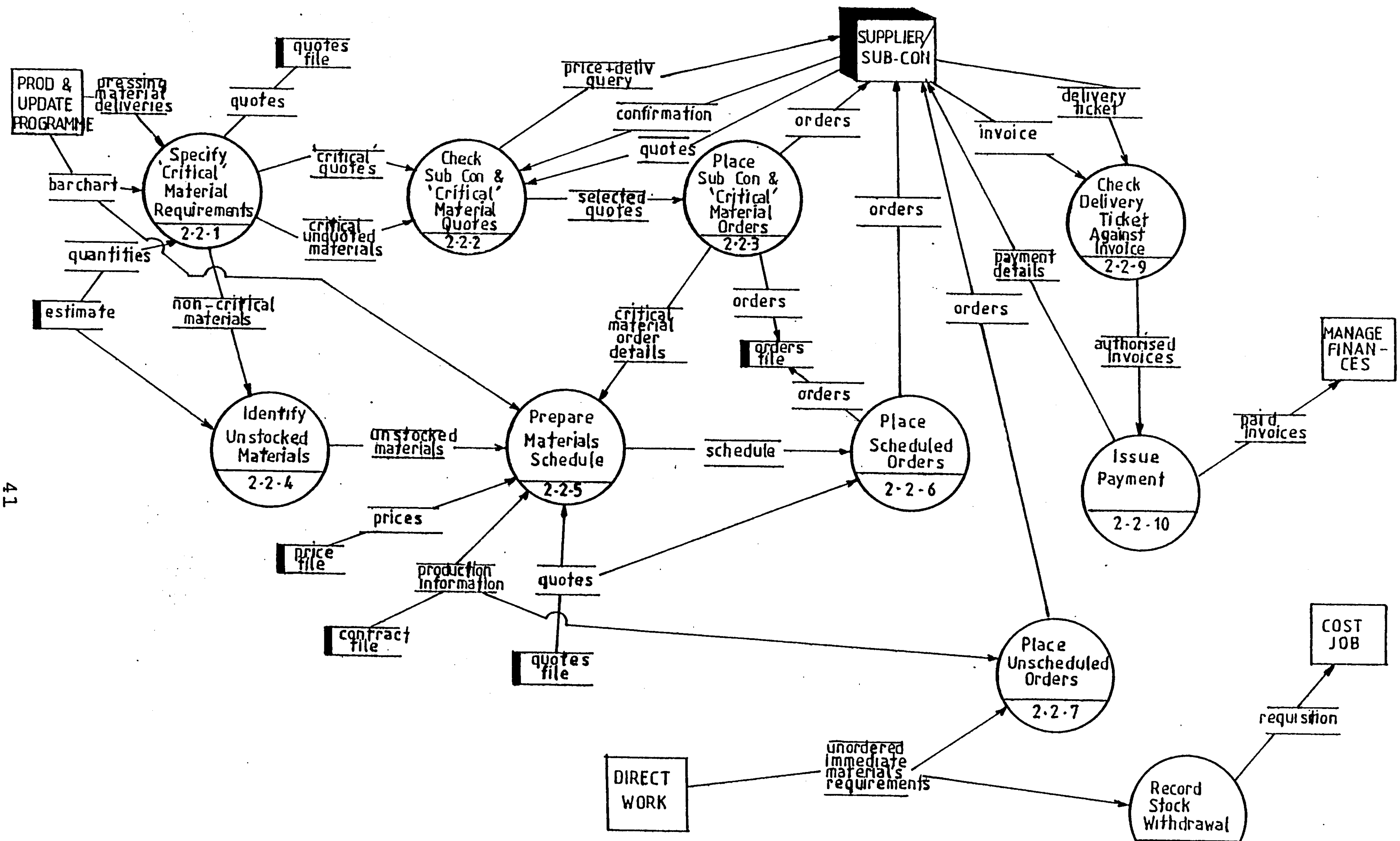
OUTPUTS: pressing material deliveries, latest bar chart

2.1.6 UPDATE BAR CHART

DESCRIPTION: If progress radically different from that forecast, alter programme shortly before monthly progress meeting to match actual progress. Extract revised materials delivery dates from programme.

INPUTS: latest bar chart, progress

OUTPUTS: latest bar chart, pressing material deliveries



2·2 PROCURE MATERIALS, PLANT & SUBCONTRACTORS

Figure A2.5.

2.2 PROCURE MATERIALS, PLANT, AND SUBCONTRACTORS

2.2.1 SPECIFY 'CRITICAL' MATERIALS AND SUBCONTRACTORS

DESCRIPTION: Identify quotes for materials urgently in need of ordering. Identify materials urgently required for which no quotes have been received. Identify quotes for subcontractors scheduled to commence on site soon.

INPUTS: latest bar chart, pressing material deliveries, quantities, quotes

OUTPUTS: critical quotes, critical unquoted materials, non critical materials

2.2.2 CHECK SUBCONTRACTOR AND MATERIAL QUOTES

DESCRIPTION: Confirm subcontractor and supplier quoted price, and ability to commence/make delivery on time. Seek quotes for previously unquoted materials and select quotes received.

INPUTS: 'critical' quotes, 'critical' unquoted materials, confirmation, quotes

OUTPUTS: price and delivery query, selected quotes

2.2.3 PLACE SUBCONTRACTOR AND 'CRITICAL' MATERIAL ORDERS

DESCRIPTION: Prepare formal orders.

INPUTS: selected quotes

OUTPUTS: orders, critical material order details

2.2.4 IDENTIFY UNSTOCKED MATERIALS

DESCRIPTION: Of the non urgent materials, identify those to be drawn from stock, and those requiring ordering.

INPUTS: estimate, 'non critical' materials

OUTPUTS: unstocked materials

2.2.5 PREPARE MATERIALS SCHEDULE

DESCRIPTION: For each major material, make a record of quantity, supplier, price and date required.

INPUTS: unstocked materials, 'critical' materials order details, bar chart, production information, prices, quotes

OUTPUTS: schedule

2.2.6 PLACE SCHEDULED ORDERS

DESCRIPTION: Review schedule periodically, and prepare orders sufficiently in advance of scheduled delivery date.

INPUTS: schedule, quotes

OUTPUTS: orders

2.2.7 PLACE UNSCHEDULED ORDERS

DESCRIPTION: Take off materials not appearing on schedule. Check prices and delivery with supplier. Prepare order.

INPUTS: production information, unordered immediate materials requirements

OUTPUTS: orders

2.2.8 RECORD STOCK WITHDRAWAL

DESCRIPTION: Record description, quantity and date of withdrawal of materials from stock on requisition form.

INPUTS: unordered immediate materials requirements

OUTPUTS: requisition

2.2.9 CHECK DELIVERY TICKET AGAINST INVOICES

DESCRIPTION: Check invoice and delivery ticket agree. Indicate on invoice contract to which it is to be allocated.

INPUTS: invoices, delivery ticket

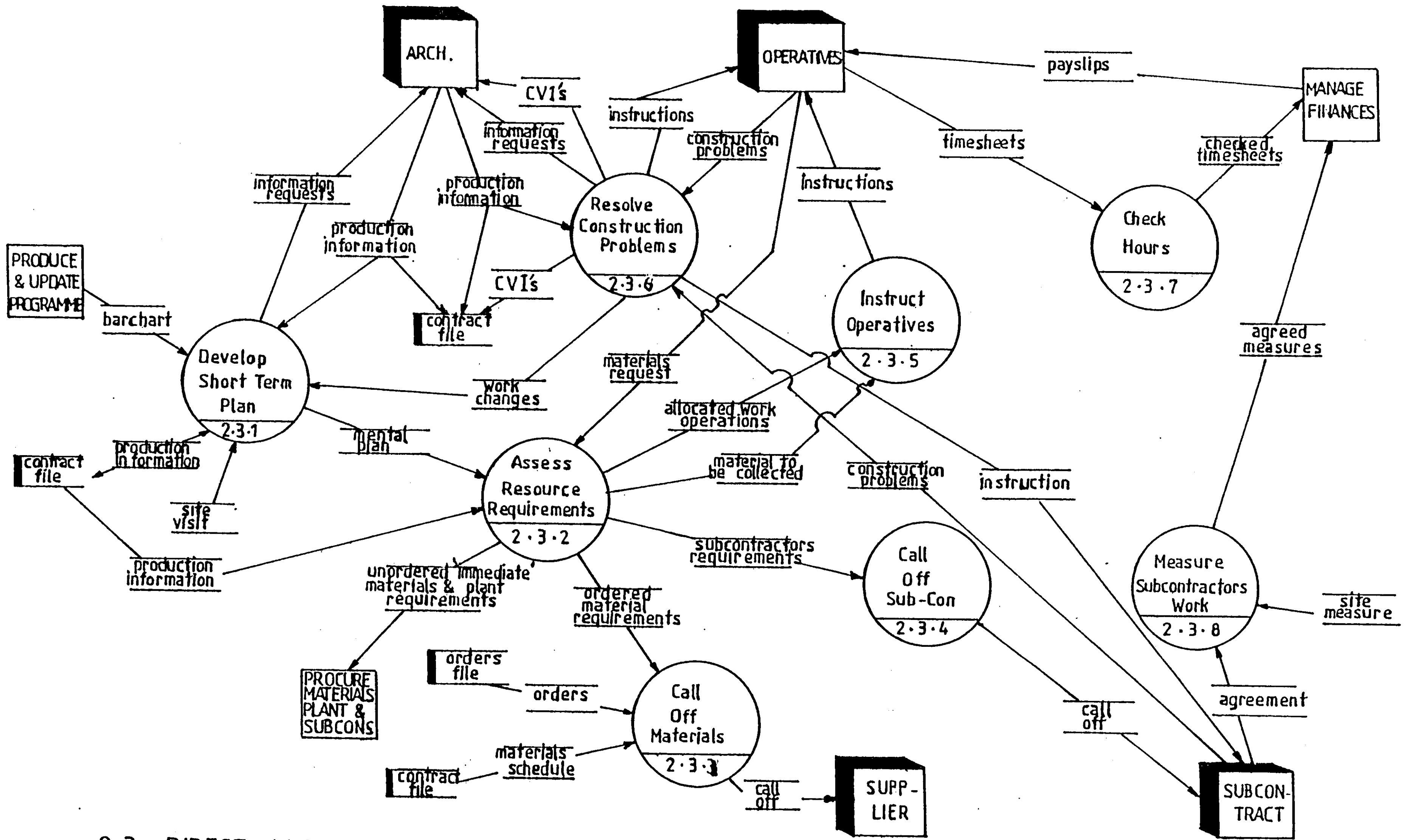
OUTPUTS: authorised invoices

2.2.10 ISSUE PAYMENT

DESCRIPTION: Prepare payments details. Mark invoices paid.

INPUTS: authorised invoices

OUTPUTS: payment details, paid invoices



2-3 DIRECT WORK.

Figure A2.6.

2.3 DIRECT WORK

2.3.1 DEVELOP SHORT TERM PLAN

DESCRIPTION: Determine operations to be carried out over next week (and beyond) from bar chart and knowledge of site progress. Determine and request any outstanding information requirements.

INPUTS: bar chart, production information, site visit, work changes

OUTPUTS: 'mental plan', information requests

2.3.2 ASSESS RESOURCE REQUIREMENTS

DESCRIPTION: Decide materials, plant and subcontractors to be brought on site in the near future. Make provisional assignment of operatives and gangs to operations planned to take place over the following week.

INPUTS: 'mental plan', materials requests, production information

OUTPUTS: unordered immediate materials and plant requirements, ordered material requirements, materials to be collected by operatives, subcontractor requirements, allocated work operations

2.3.3 CALL OFF MATERIALS

DESCRIPTION: Request/confirm delivery on required date.

INPUTS: ordered materials requirements, orders, materials schedule

OUTPUTS: call off

2.3.4 CALL OFF SUBCONTRACTORS

DESCRIPTION: Request/confirm arrival on required date.

INPUTS: subcon requirements

OUTPUTS: call off

2.3.5 INSTRUCT OPERATIVES

DESCRIPTION: Decide final assignment of labour (daily). Inform workforce of work operations and sources of required materials.

INPUTS: allocated work operations, stock and merchant materials

OUTPUTS: instructions

2.3.6 RESOLVE CONSTRUCTION PROBLEMS

DESCRIPTION: Receive requests for clarification and further information from workforce and subcontractors. Request and receive further information from architect. Instruct operatives. Issue CVIs to architect.

INPUTS: production information, construction problems

OUTPUTS: information requests, CVIs, instructions, work changes

2.3.7 CHECK HOURS

DESCRIPTION: Verify timesheets.

INPUTS: timesheets

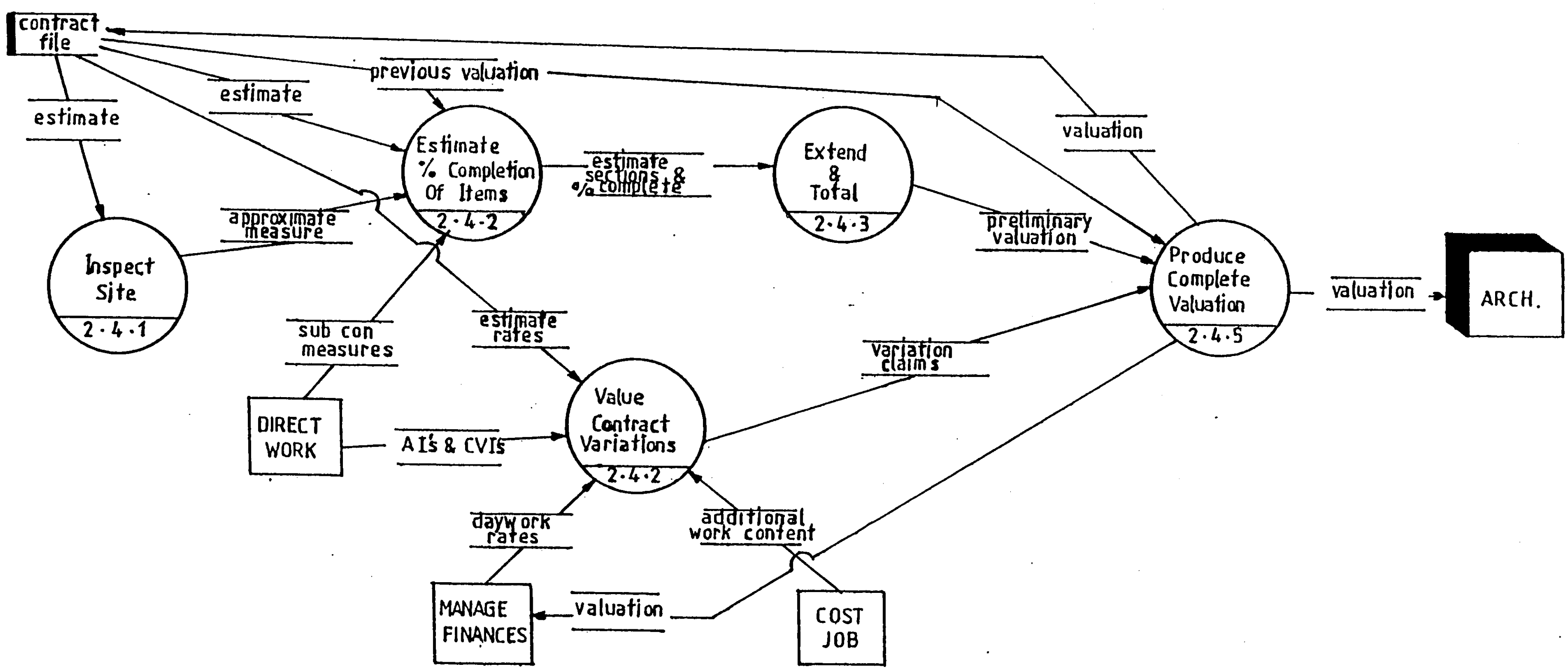
OUTPUTS: checked timesheets

2.3.8 MEASURE SUBCONTRACTOR WORK

DESCRIPTION: Measure completed subcontractor's work. Apply rates and total. Agree value with subcontractor.

INPUTS: site measure, agreement of subcontractor

OUTPUTS: agreed measures



2-4 PRODUCE VALUATIONS & FINAL ACCOUNT.

Figure A2.7.

2.4 PRODUCE VALUATIONS AND FINAL ACCOUNT

2.4.1 INSPECT SITE

DESCRIPTION: Estimate proportion of each major estimate operation completed in terms of quantities or percentages.

INPUTS: estimate

OUTPUTS: approximate measure

2.4.2 ESTIMATE % COMPLETION OF ITEMS

DESCRIPTION: Based on site inspection, for every item on which there has been progress since previous valuation, estimate percentage completion. Enter subcontract valuations.

INPUTS: estimate, previous valuation, approximate measure, subcon measures

OUTPUTS: estimate items and % completion

2.4.3 EXTEND AND TOTAL

DESCRIPTION: Multiply item values by % completion. Total value.

INPUTS: estimate items and % completion

OUTPUTS: preliminary valuation

2.4.4 VALUE CONTRACT VARIATIONS

DESCRIPTION: Where possible extract and apply estimate rates to variations. Or build up and apply new rates to variation. Or apply dayworks to measure of additional work carried out.

INPUTS: estimate rates, AIs and CVIs, daywork rates, additional work content

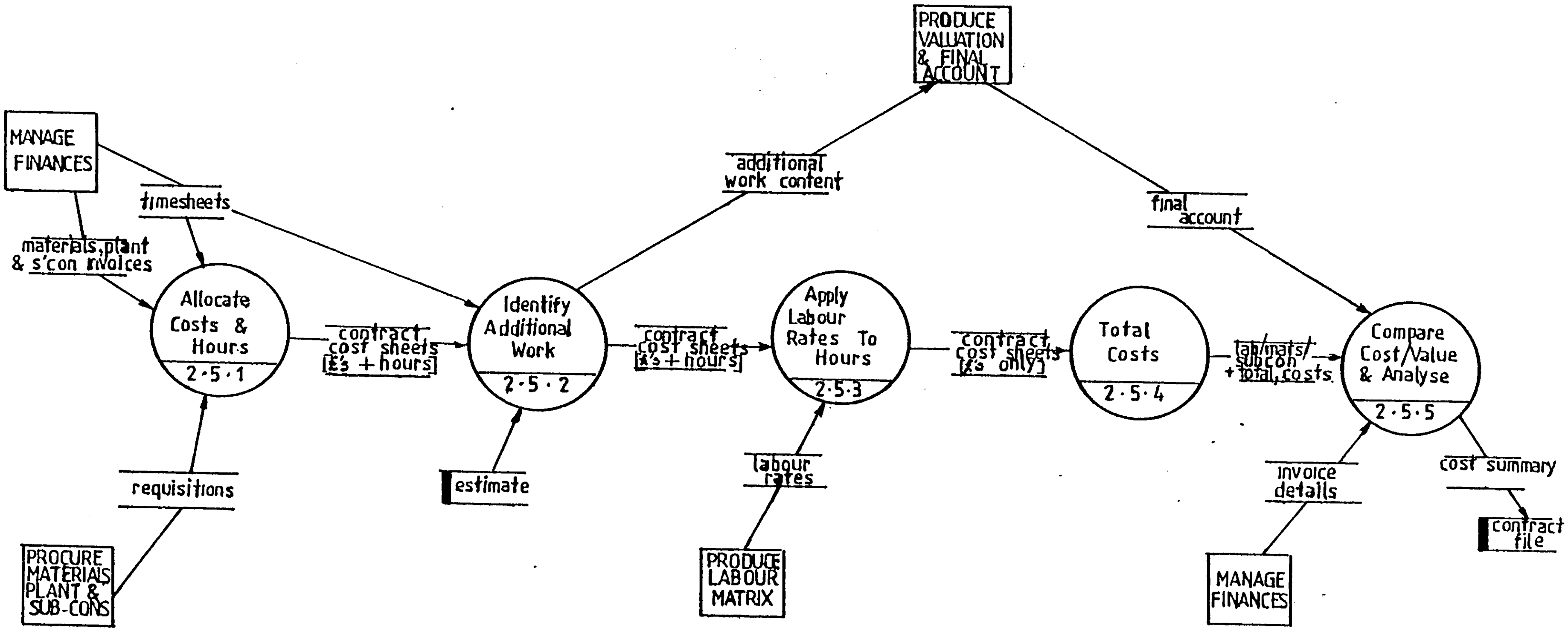
OUTPUTS: variations

2.4.5 PRODUCE COMPLETE VALUATION

DESCRIPTION: Deduct value of previous valuation. Add variation values. Deduct retention. Prepare valuation in form of itemised breakdown.

INPUTS: preliminary valuation, previous valuation, variation claims

OUTPUTS: valuation



2·5 COST JOB

Figure A2.8.

2.5 COST JOB

2.5.1 ALLOCATE COSTS AND HOURS

DESCRIPTION: Extract materials used and hours worked from timesheets and requisitions. Cost materials from invoices. Record subcontractor payments.

INPUTS: requisitions, materials and plant and subcontractor invoices, timesheets

OUTPUTS: contract cost sheets

2.5.2 IDENTIFY ADDITIONAL WORK

DESCRIPTION: Indicate work additional to that estimated for. Check timesheets for fuller breakdown of additional work.

INPUTS: contract cost sheets, estimate, timesheets

OUTPUTS: additional work content, contract cost sheets

2.5.3 APPLY LABOUR RATES TO HOURS

DESCRIPTION: Calculate labour costs using rates from labour matrix.

INPUTS: contract cost sheets, labour rates

OUTPUTS: contract cost sheets

2.5.4 TOTAL COSTS

DESCRIPTION: Subtotal costs under labour, materials and subcontractor headings. Compute overall contract cost.

INPUTS: contract cost sheets

OUTPUTS: lab/materials/subcon costs, overall cost

2.5.5 COMPARE COST/VALUE AND ANALYSE

DESCRIPTION: On completion, compare final cost with final contract sum. Examine build up of individual costs to explain any unexpected result.

INPUTS: labour/materials/subcon costs, total cost, invoice details, final account

OUTPUTS: cost summary

CASE STUDY OF FIRM C

TYPE OF FIRM: Limited Company

LOCATION: Sheffield

APPROXIMATE TURNOVER: # 3,000,000

WORKFORCE;

	DIRECTLY EMPLOYED	LABOUR-ONLY SUBCONTRACTORS	TOTAL
LABOURERS	16	8	24
JOINERS	12	8	20
BRICKLAYERS	9	12	21
PAVIOURS	4	6	10
PLUMBERS	2	0	2
PROPERTY REPAIRER	8	0	8
TOTAL	51	34	85

FULL-TIME STAFF: 22 **PART-TIME STAFF**: 0

COMPUTER USAGE: One microcomputer used for costing, estimating, and general accounts.

HISTORY: The firm was established in 1916. Until the late 60's the major concern of business was repairs and renovations. A slump in demand for this type of work encouraged the firm to diversify into other areas. Subsequently the firm has specialised in certain types of industrial work, and has formed commercial relationships with particular architects, engineers and clients.

TYPE OF WORK: Approximately one third of the firm's work took the form of 'design and build' contracts for industrial clients. For such work an architect or engineer was contracted to the firm to prepare the design. These contracts ranged up to # 1,000,000 in value, and took as long as fifteen months to complete.

In contrast the remainder of the workload was composed of contracts typically of less than a month's duration. The diversity of its business was reflected in the organisation of the firm into four independently managed sections. These were 'large contract works', 'small contract works', 'dayworks', and one section dedicated to the custom of one important client.

MANAGEMENT ORGANISATION: Estimating was carried out by the firm's two quantity surveyors, one of whom was also a director. On request, the buyers would seek quotations for inclusion in the estimate. A financial director oversaw the conversiion to a tender.

A third director was responsible for production management. As senior contracts manager he was directly involved in the management of the larger contracts, and shared the tasks of producing valuations and final accounts with the quantity surveyors.

Two contracts managers were permanently assigned to the 'large works' section, while the remaining three managers shared the supervision of the other three work sections. The tasks of programming the work, procuring labour, and the operation of any bonus scheme, were shared between the contracts manager and the senior contracts manager. The requisitioning of materials, short term programming, and the daily organisation of the foremen and operatives were the sole responsibilities of the contracts managers.

Management of the firm's accounts was undertaken by the financial director. He also carried out cost reconciliations in conjunction with the senior contracts manager.

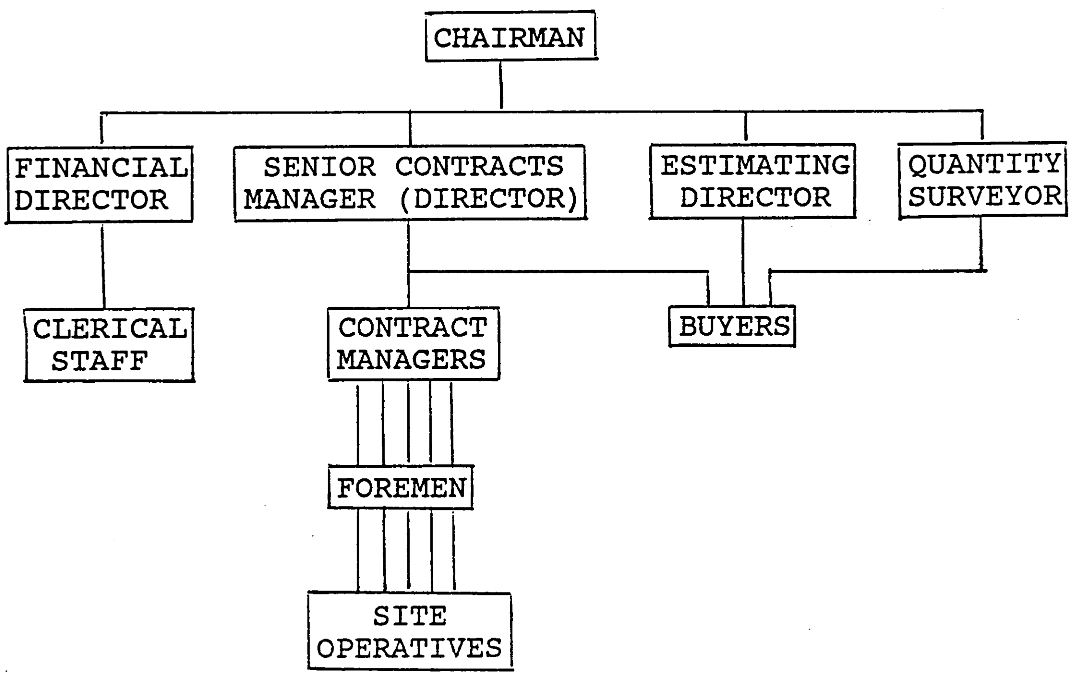
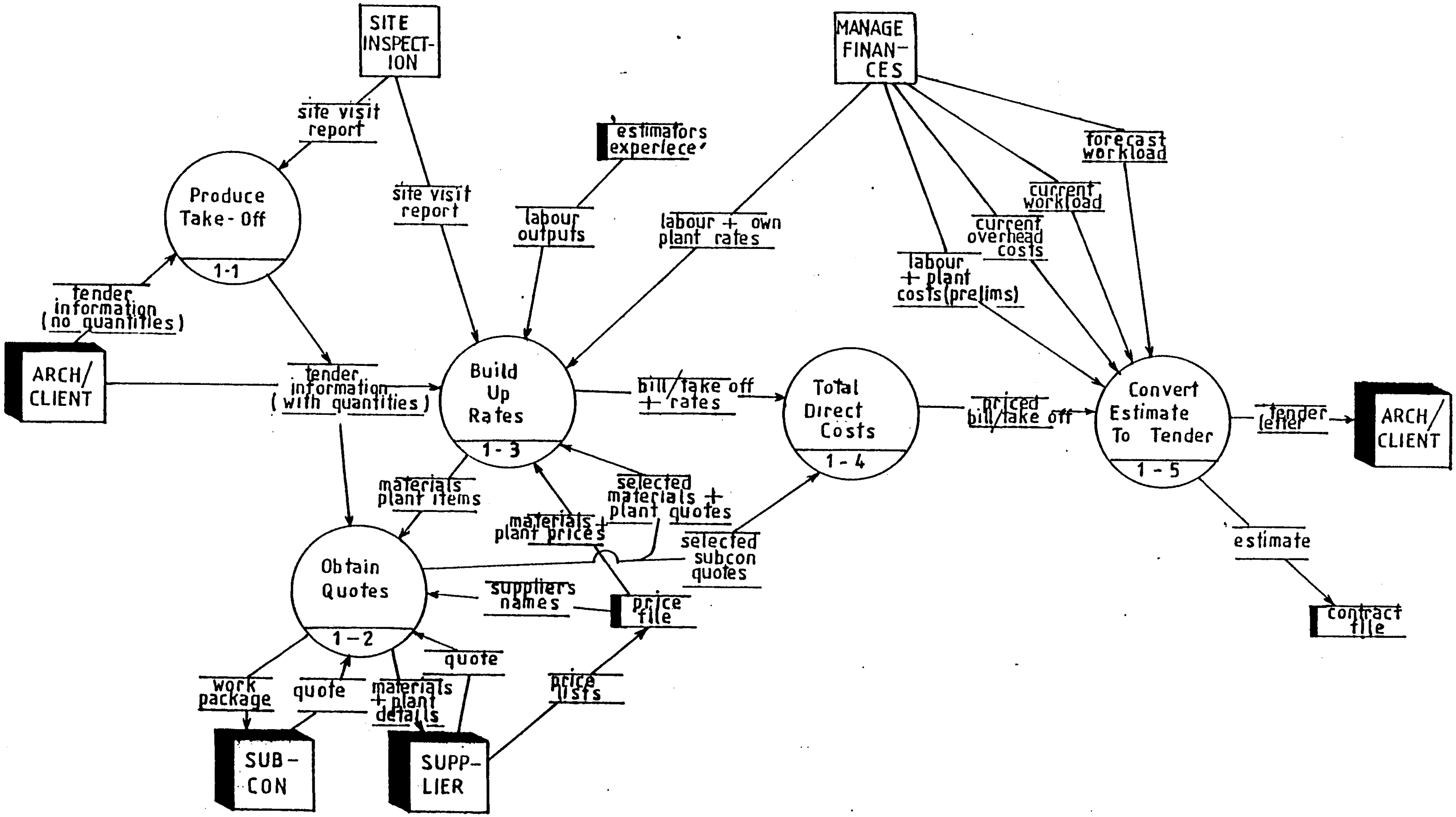


Figure A3.1 MANAGEMENT ORGANISATION - FIRM C



1. PRODUCE TENDERS.

Figure A3.2.

PROCESS DESCRIPTIONS FOR FIRM C

1 PRODUCE TENDER

1.1 PRODUCE TAKE OFF

DESCRIPTION: Measure quantities approximately according to the Standard Method of Measurement.

INPUTS: tender information (no quantities), site visit report

OUTPUTS: tender information (with quantities)

1.2 OBTAIN QUOTES

DESCRIPTION: Extract and assemble tender information for subcontractors. Determine potential suppliers for materials and receive and select quotes.

INPUTS: tender information (with quantities), materials and plant items (for quotes), suppliers names, quotes

OUTPUTS: subcon work package, materials and plant details, selected quotes

1.3 BUILD UP RATES

DESCRIPTION: Decide labour output for each item. Apply labour rate to output. Determine the plant required and extract rates from a price file, from the firm's own plant records, or from quotes received for hire. Determine material rates from price file, previous invoices or quotes. Combine to form unit rates.

INPUTS: tender information (with quantities), site visit report, labour outputs, labour and own plant rates, materials and plant prices, selected materials and plant quotes

OUTPUTS: materials and plant items (for quotes), BOQ/take off with rates

1.4 TOTAL DIRECT COSTS

DESCRIPTION: Apply unit rates to quantities. Add selected subcontractor quotes. Total all costs.

INPUTS: BOQ/take off with rates, selected subcon quotes

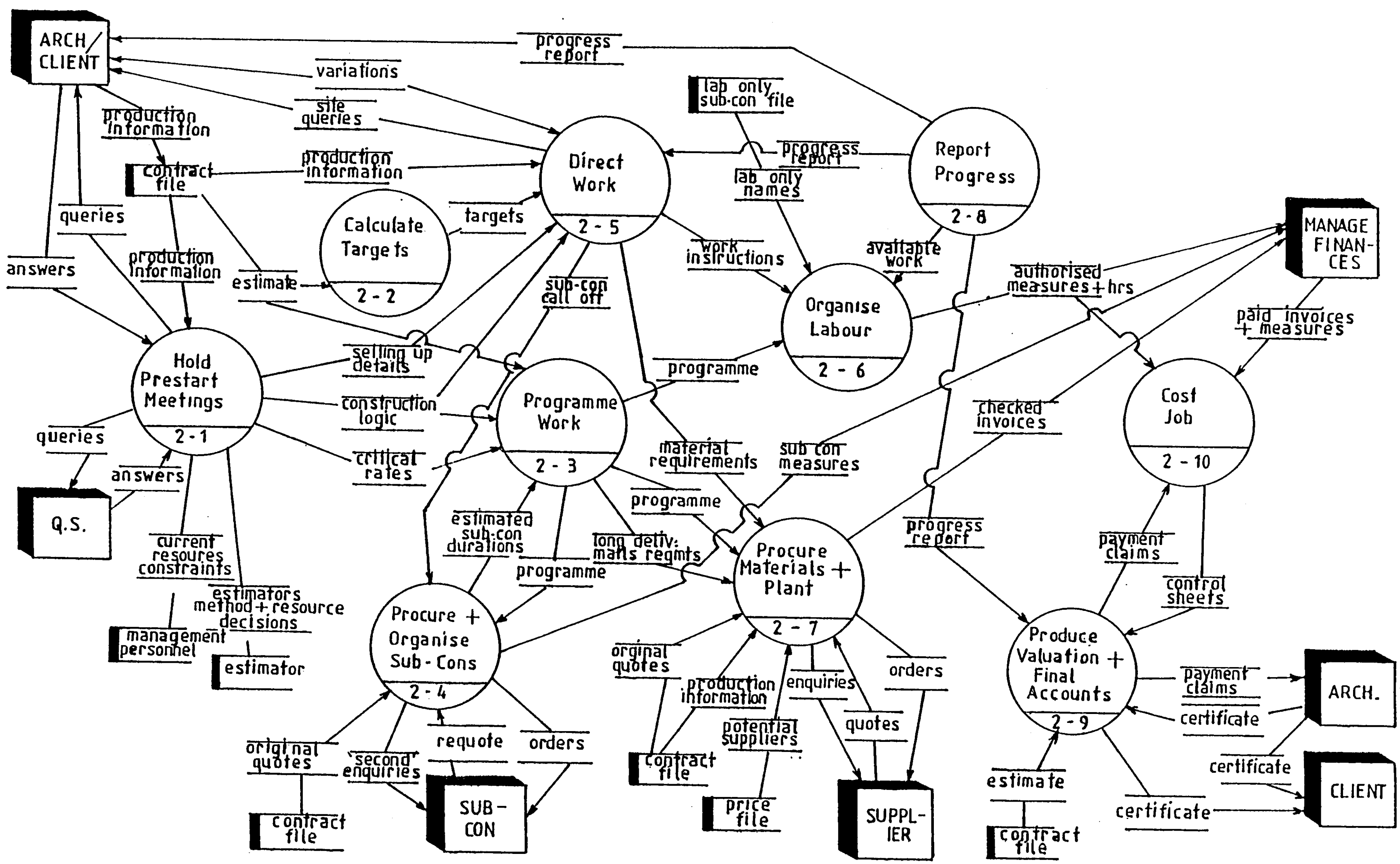
OUTPUTS: priced BOQ/take off

1.5 CONVERT ESTIMATE TO TENDER

DESCRIPTION: Estimate duration and apply preliminaries rates to determine preliminaries costs. Compare current rate of overhead recovery from all contracts with annual forecast, and with an estimate of the actual overheads being incurred recently. Accordingly set a weekly overhead and profit rate and apply to estimate of duration. Add margin and VAT to total sum. Prepare tender letter including estimate of contract duration.

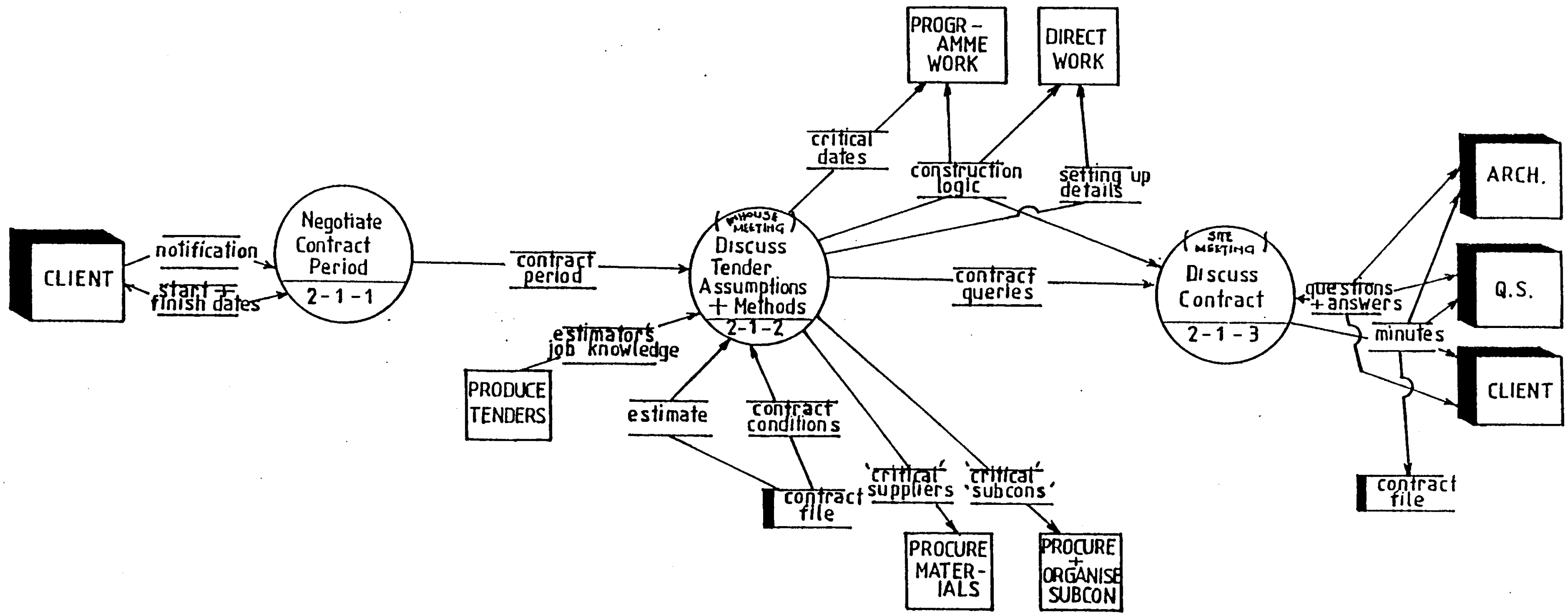
INPUTS: priced BOQ/take off, labour and plant costs (prelims), current workload (inc. margins), forecast workload, current overheads costs

OUTPUTS: estimate, tender letter



2. MANAGE PRODUCTION.

Figure A3.3.



2-1 HOLD PRE-START MEETINGS

Figure A3.4.

2 MANAGE PRODUCTION

2.1 HOLD PRESTART MEETINGS

2.1.1 NEGOTIATE CONTRACT PERIOD

DESCRIPTION: Consider possible commencement dates for contract. Agree date and contract period with client.

INPUTS: Notification (start and finish dates)

OUTPUTS: start and finish dates, contract period

2.1.2 DISCUSS TENDER ASSUMPTIONS AND METHODS (inhouse)

DESCRIPTION: Communicate to members of management the principle features of the work involved as perceived at tender stage, including any unusual aspects of the construction, any urgent materials or subcontractors, etc.. Prepare query list to present to client or architect.

INPUTS: contract period, estimator's job knowledge, estimate, contract conditions

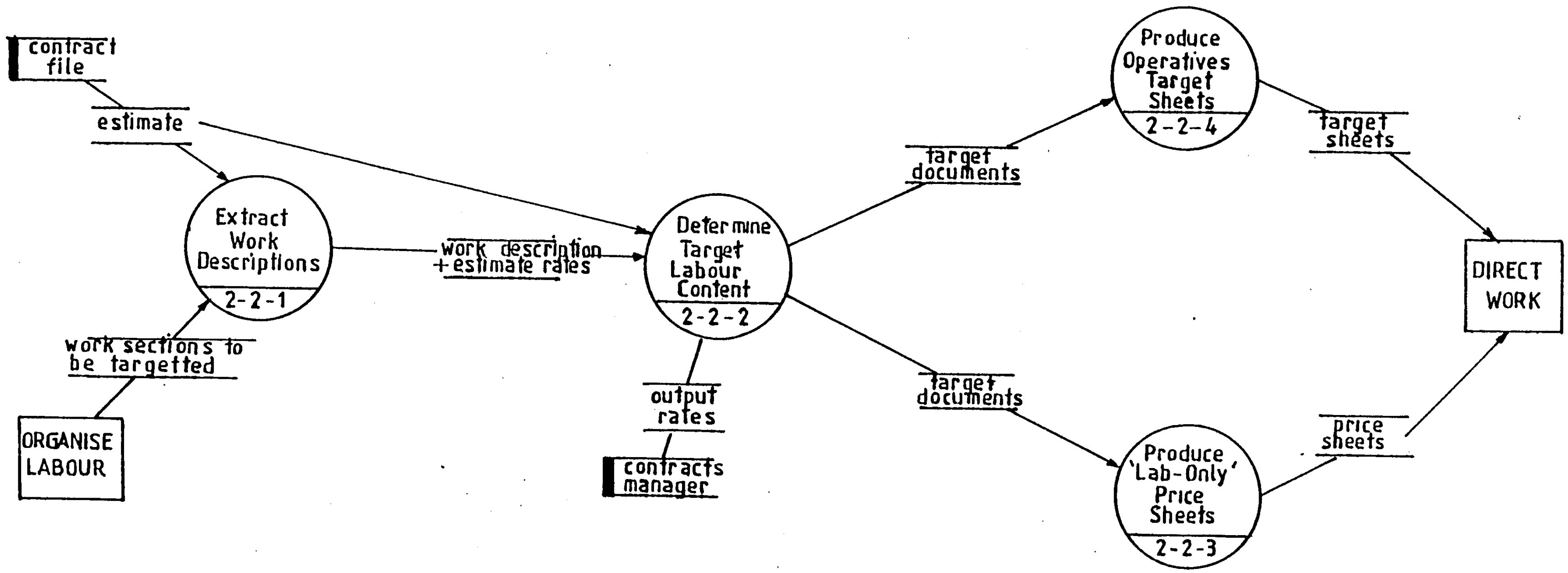
OUTPUTS: construction logic, setting up details, contract queries, critical dates, critical suppliers, critical subcons

2.1.3 DISCUSS CONTRACT (with client and representatives)

DESCRIPTION: Resolve all queries regarding site set up, immediate information requirements, etc..

INPUTS: contract queries, construction logic, questions, answers

OUTPUTS: meeting minutes, questions, answers



2-2 CALCULATE TARGETS.

Figure A3.5.

2.2 CALCULATE TARGETS

2.2.1 EXTRACT WORK DESCRIPTIONS

DESCRIPTION: Extract estimate items and labour rates relating to work sections to be targeted. Prepare target work desriptions.

INPUTS: estimate, work sections to be targeted.

OUTPUTS: work descriptions and estimate rates

2.2.2 DETERMINE TARGET LABOUR CONTENT

DESCRIPTION: Derive target manhours or prices from estimate rates and personal experience.

INPUTS: work descriptions, estimate rates, output rates

OUTPUTS: target documents

2.2.3 PRODUCE LABOUR ONLY PRICE SHEETS

DESCRIPTION: Prepare descriptions of individual pricework targets for labour-only subcontractors.

INPUTS: target documents

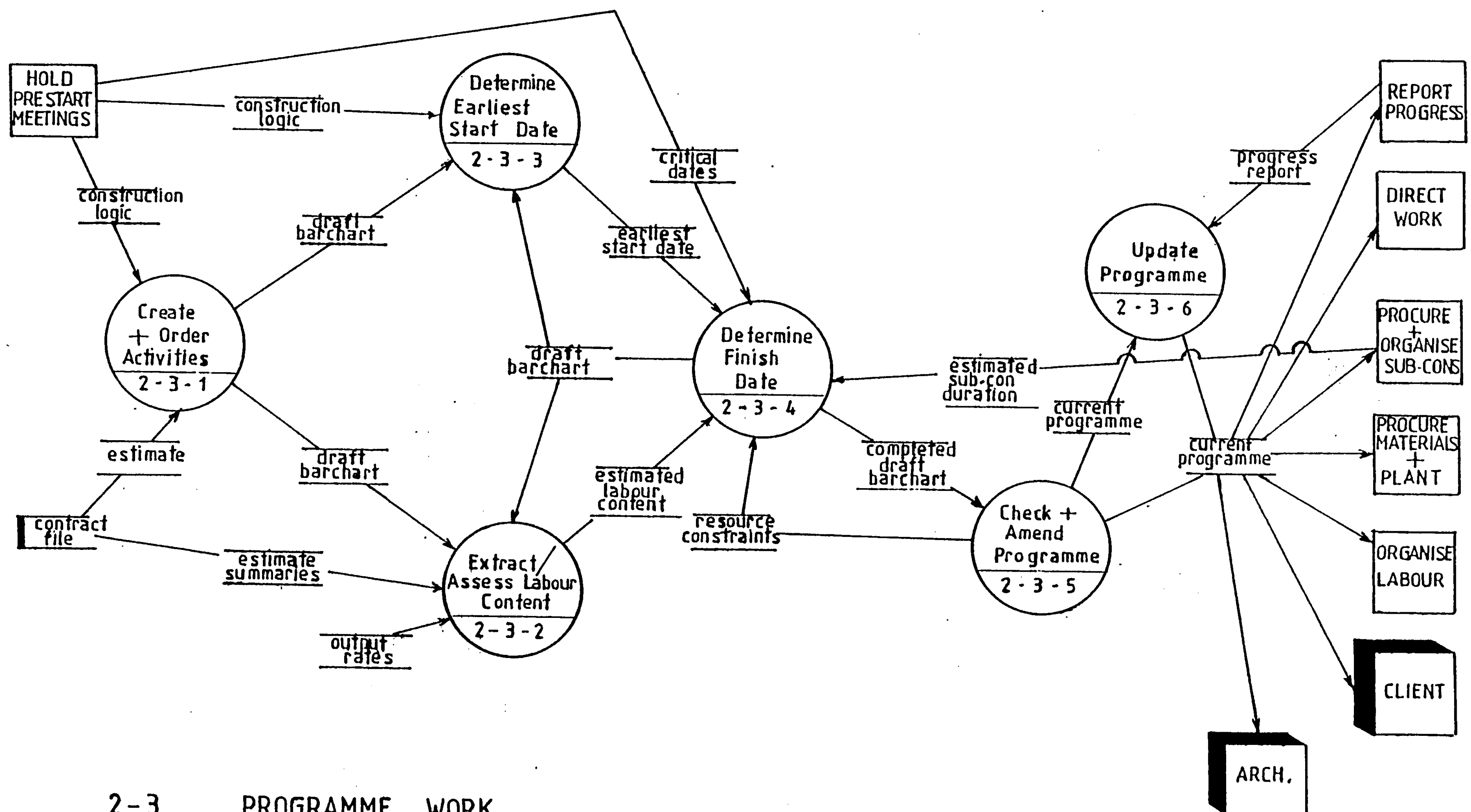
OUTPUTS: price sheets

2.2.4 PRODUCE OPERATIVES TARGET SHEETS

DESCRIPTION: Prepare descriptions of individual manhours based targets for firm's operatives.

INPUTS: target documents

OUTPUTS: target sheets



2-3 PROGRAMME WORK.

Figure A3.6.

2.3 PROGRAMME WORK

2.3.1 CREATE AND ORDER ACTIVITIES

DESCRIPTION: Divide work into trade based sections related loosely to sections of the estimate. Create activity headings and list on bar chart in approximate sequence of construction.

INPUTS: estimate, construction logic

OUTPUTS: draft bar chart

2.3.2 EXTRACT/ASSESS LABOUR CONTENT

DESCRIPTION: For each activity, if principle estimate item was estimated by unit rate, extract labour rate, divide by labour cost, and multiply by quantity to give manhours. Otherwise derive manhours from experience.

INPUTS: estimate summaries, output rates, draft bar chart

OUTPUTS: estimated labour content

2.3.3 DETERMINE EARLIEST START DATE

DESCRIPTION: Analyse the activity's relationship with preceding activities to determine its earliest start date.

INPUTS: draft bar chart, construction logic

OUTPUTS: earliest start date

2.3.4 DETERMINE FINISH DATE

DESCRIPTION: If the activity is a subcontract item, add estimate of duration to start date to determine finish date. Otherwise divide estimated labour content by alternative labour assignments to determine alternative durations. Analyse dependency of activity completion on other activities. Decide on labour/duration option, verify major resources will be available for activity dates, and draw bar on chart.

INPUTS: draft bar chart, earliest start date, estimated labour content, estimated subcon duration, resource constraints, critical dates (for availability of resources)

OUTPUTS: draft bar chart, completed draft bar chart

2.3.5 CHECK AND AMEND PROGRAMME

DESCRIPTION: Verify that resulting contract duration is acceptable. Check for serious overscheduling of labour, and revise programme if necessary.

INPUTS: complete draft bar chart, resource constraints

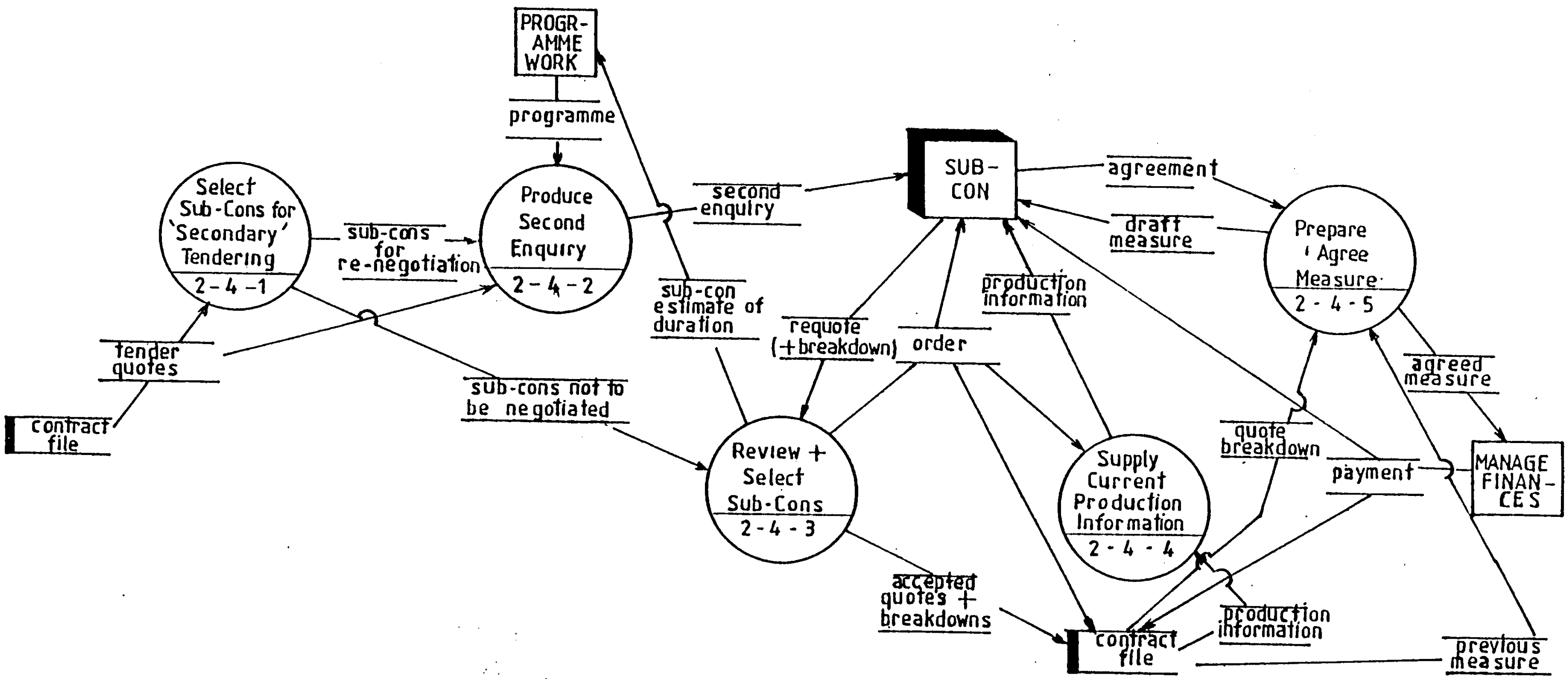
OUTPUTS: current programme

2.3.6 UPDATE PROGRAMME

DESCRIPTION: Compare progress to date with planned progress. If difference is substantial, revise programme to match progress.

INPUTS: current programme, progress

OUTPUTS: current programme (revised)



2-4. PROCURE & ORGANISE SUBCONTRACTORS.

Figure A3.7.

2.4 PROCURE AND ORGANISE SUBCONTRACTORS

2.4.1 SELECT SUBCONTRACTORS FOR 'SECONDARY' TENDERING

DESCRIPTION: Review tender quotes for work where it is perceived there is potential for further reduction in price.

INPUTS: tender quotes

OUTPUTS: subcontractors to be renegotiated, subcontractors not to be renegotiated

2.4.2 PRODUCE SECOND ENQUIRY

DESCRIPTION: Issue subcontractor with a programme, and request him to requote and provide a breakdown of his price.

INPUTS: tender quotes, programme, subcontractors for renegotiation

OUTPUTS: second enquiry (inc. programme)

2.4.3 REVIEW AND SELECT SUBCONTRACTORS

DESCRIPTION: Review all quotes and make final selection. Prepare order. Revise subcontractor's scheduled dates on programme if necessary.

INPUTS: requotes, subcon quotes not renegotiated

OUTPUTS: order, accepted quote, subcon estimate of duration

2.4.4 SUPPLY CURRENT PRODUCTION INFORMATION

DESCRIPTION: Issue information relevant to the subcontractor's work as it is received from the architect.

INPUTS: production information, order

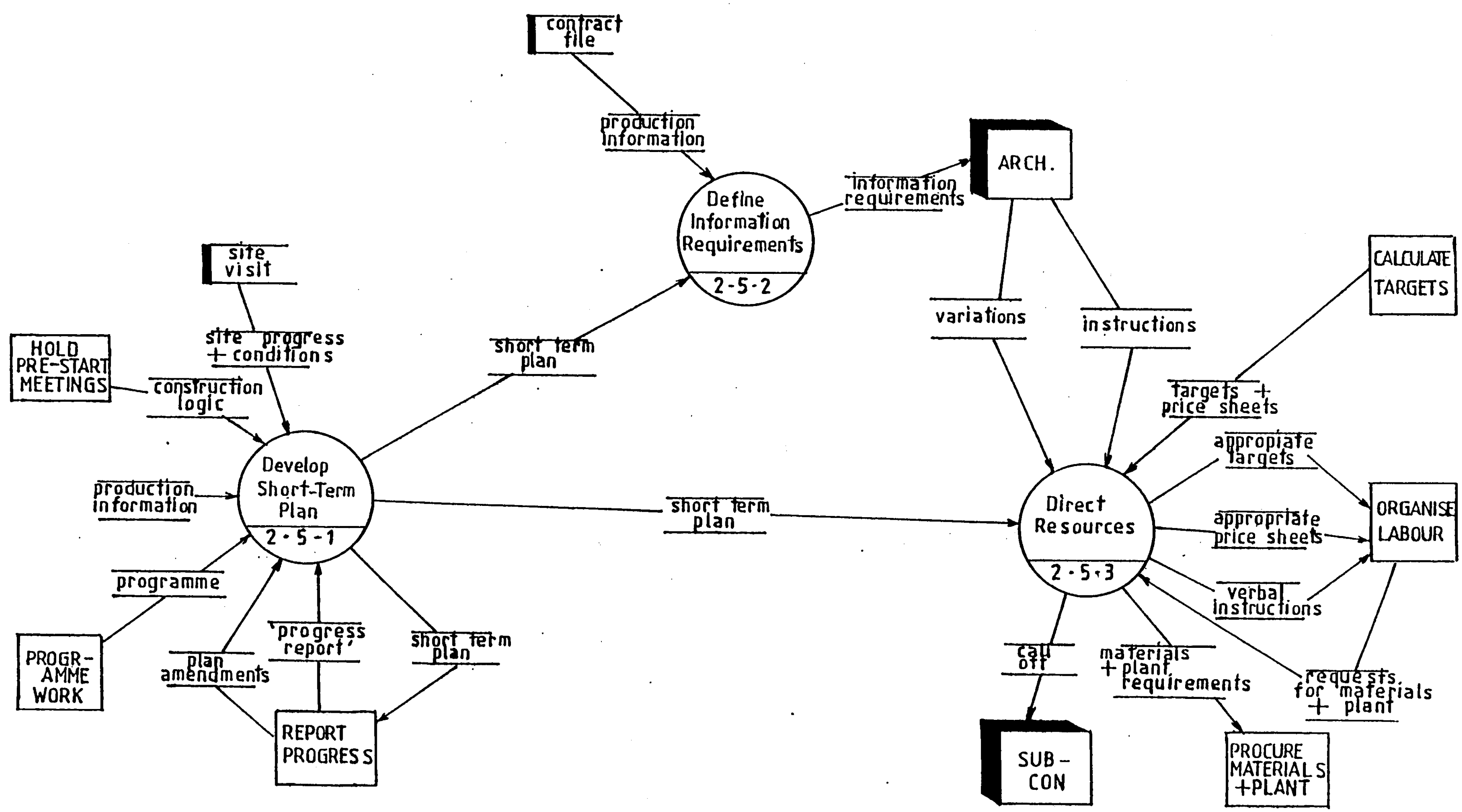
OUTPUTS: production information

2.4.5 PREPARE AND AGREE MEASURE

DESCRIPTION: Prepare measure of work completed against quote items. Calculate item values and total. Agree valuation with subcon. Prepare formal valuation to accompany payment.

INPUTS: quote breakdown, previous measure, agreement

OUTPUTS: draft measure, agreed measure



2–5 DIRECT WORK.

Figure A3.8.

2.5 DIRECT WORK

2.5.1 DEVELOP SHORT TERM PLAN

DESCRIPTION: Decide the detailed sequence of operations to be carried out in the immediate future.

INPUTS: production information, construction logic, programme, progress report, site progress and conditions, plan amendments

OUTPUTS: short term plan

2.5.2 DEFINE INFORMATION REQUIREMENTS

DESCRIPTION: Request any information relating to ongoing or imminent site operations that has not yet been provided by the architect.

INPUTS: production information, short term plan

OUTPUTS: information requirements

2.5.3 DIRECT RESOURCES

DESCRIPTION: Identify targets for impending site operations. Analyse architect's instructions for information to be passed on to site operatives. Identify materials and plant requirements. Call off subcontractors.

INPUTS: short term plan, architect's instructions, variations, targets and price sheets, requests for materials and plant (from operatives)

OUTPUTS: verbal instructions, approporiate targets and price sheets, materials and plant requirements, subcon call off

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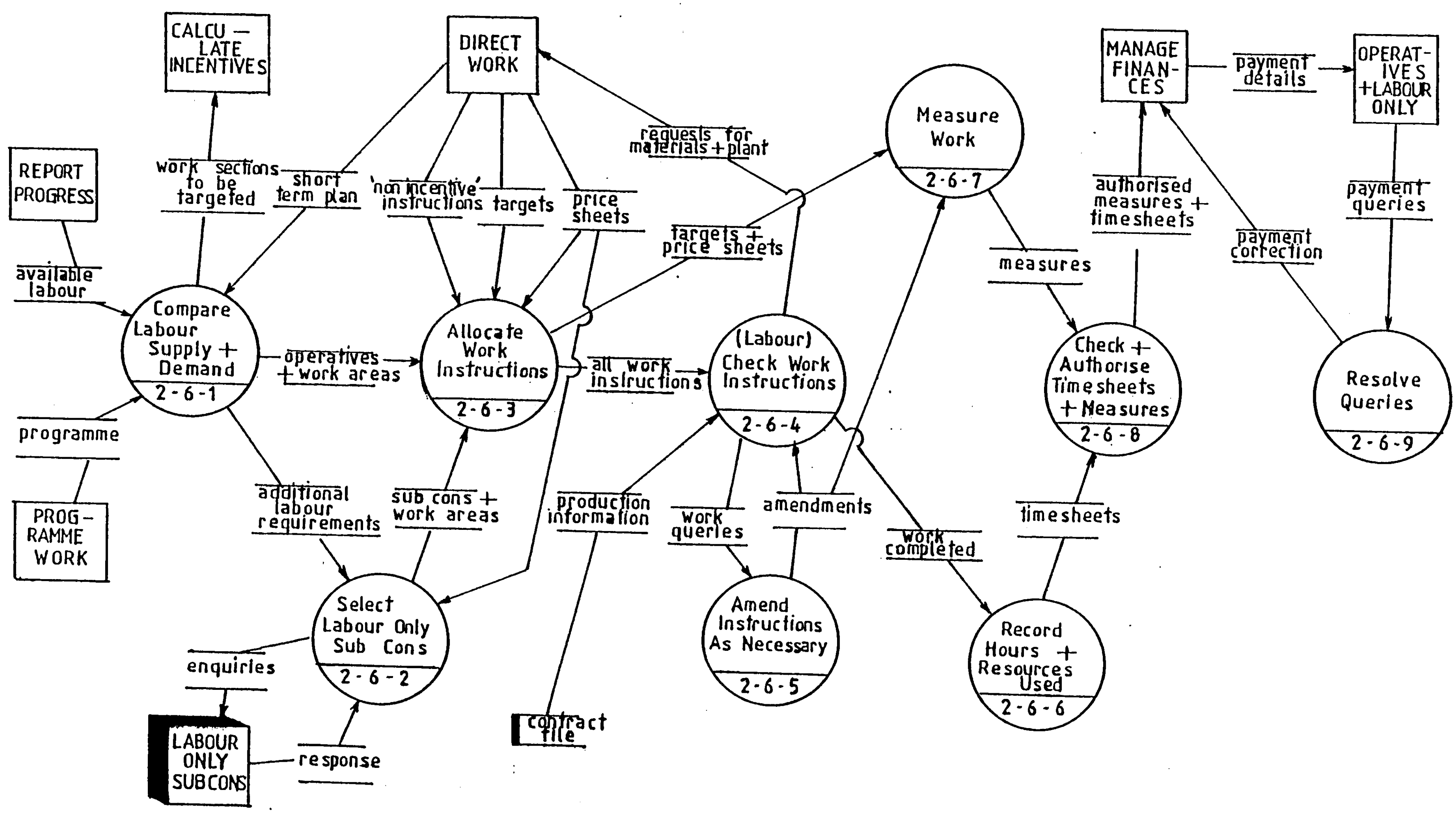


2-6. ORGANISE LABOUR.

Figure A3.9.

2.6 ORGANISE LABOUR

2.6.1 COMPARE LABOUR DEMAND AND SUPPLY

DESCRIPTION: For each of the four divisions of the firm, compare (approximately) available labour (inc. labour-only subcontractors) with the demands from the contracts in the short and medium term. Assign operatives to operations over the next week. Evaluate any additional labour required. Decide work sections to be assigned to operatives as targets.

INPUTS: programme, short term plan, available labour

OUTPUTS: operatives and work 'areas', work sections to be targetted, additional labour requirements

2.6.2 SELECT LABOUR-ONLY SUBCONTRACTORS

DESCRIPTION: Communicate prices and rates for work to be carried out by additional labour to potential subcontractors. Negotiate and reach agreement with them.

INPUTS: additional labour requirements, price sheets, subcontractor response

OUTPUTS: enquiries, subcons and work areas

2.6.3 ALLOCATE WORK INSTRUCTIONS

DESCRIPTION: Instruct operatives and pass on targets as they are required.

INPUTS: operatives and work areas, labour-only subcons and work areas, instructions, targets, price sheets

OUTPUTS: work instructions, targets, price sheets

2.6.4 CHECK WORK INSTRUCTIONS (operatives and lab-only subcontractors)

DESCRIPTION: Assess instructions and make request for further clarification, materials, and plant necessary to execute the work. Receive amendments to initial instructions.

INPUTS: work instructions, production information, amendments

OUTPUTS: work queries, requests for materials and plant, work completed

2.6.5 AMEND INSTRUCTIONS AS NECESSARY

DESCRIPTION: Revise and clarify previous instructions as requested.

INPUTS: work queries

OUTPUTS: amendments

2.6.6 RECORD HOURS AND RESOURCES (operatives and foremen)

DESCRIPTION: Record hours worked and materials and plant used against own descriptions of the work or targets, for each day of the week.

INPUTS: work completed

OUTPUTS: timesheets

2.6.7 MEASURE WORK (labour-only subcontractors)

DESCRIPTION: Measure quantity of work completed and record against target descriptions.

INPUTS: targets and price sheets, amendments

OUTPUTS: measures

2.6.8 CHECK AND AUTHORISE TIMESHEETS AND MEASURES

DESCRIPTION: Verify, discuss, and correct timesheets and measures if necessary.

INPUTS: measures, timesheets

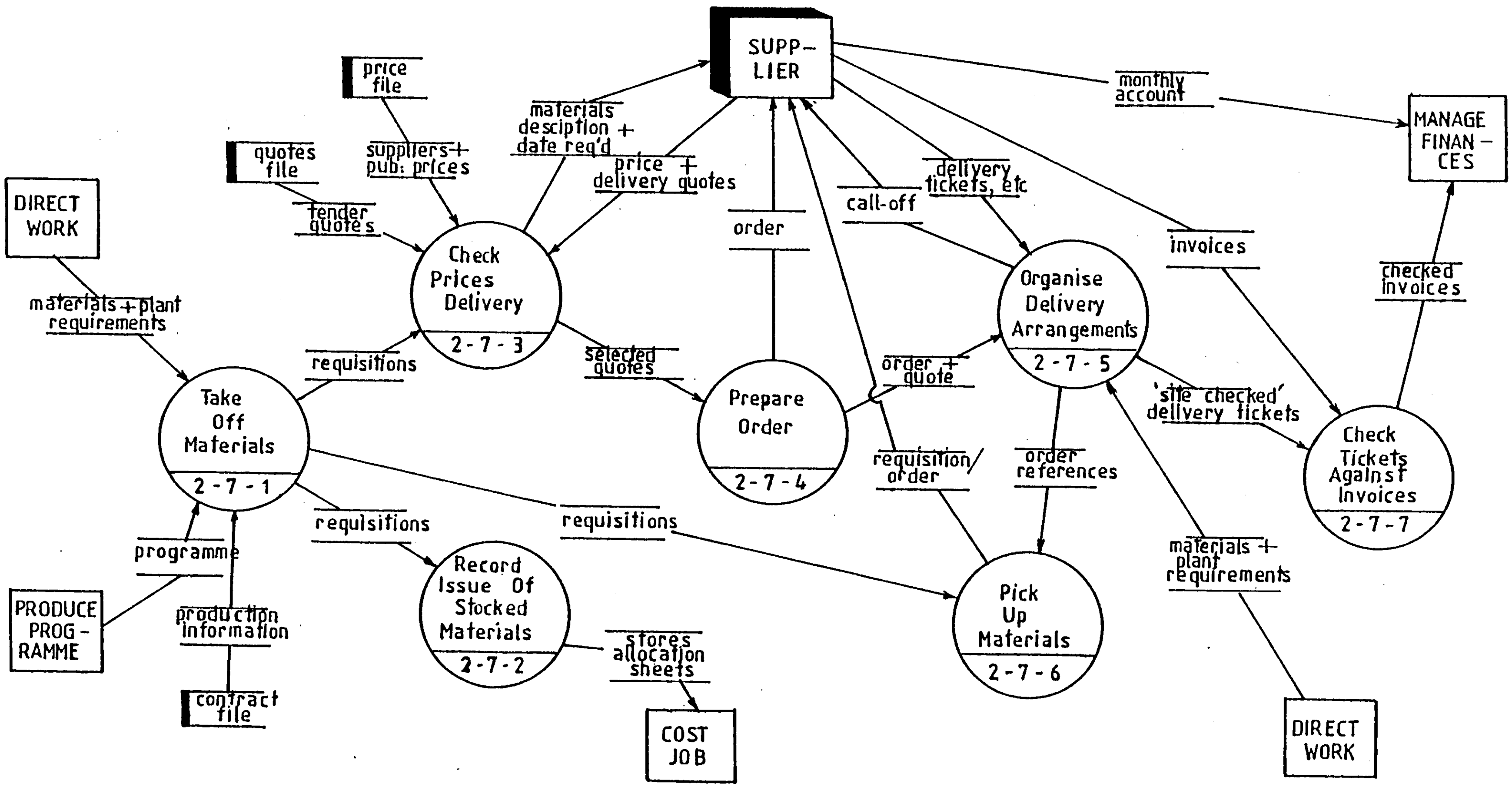
OUTPUTS: authorised measures and timesheets

2.6.9 RESOLVE QUERIES

DESCRIPTION: Consider operatives queries over previous payments and pass on instruction to make amends in subsequent payments if necessary.

INPUTS: payment queries

OUTPUTS: payment correction



2-7 PROCURE MATERIALS & PLANT.

Figure A3.10.

2.7 PROCURE MATERIALS AND PLANT

2.7.1 TAKE OFF MATERIALS

DESCRIPTION: Take off material quantities against specification descriptions. Extract required delivery dates from programme.

INPUTS: programme, production information, materials requirements

OUTPUTS: requisitions

2.7.2 RECORD ISSUE OF STOCKED MATERIALS

DESCRIPTION: Record issue of stocked materials.

INPUTS: requisitions

OUTPUTS: stores allocation sheets

2.7.3 CHECK PRICES AND DELIVERY

DESCRIPTION: Check tender quotes for delivery. Communicate material and plant descriptions and delivery requirements to potential suppliers. Receive quotes and make selection.

INPUTS: tender quotes, requisitions, suppliers and published prices, quotes

OUTPUTS: materials descriptions and date required, selected quotes

2.7.4 PREPARE ORDERS

DESCRIPTION: Produce orders based on quotes, adding conditions, etc.

INPUTS: selected quotes

OUTPUTS: orders, orders and quotes

2.7.5 ORGANISE DELIVERY ARRANGEMENTS

DESCRIPTION: For materials required shortly, check order and quote for delivery arrangements. If materials to be delivered, confirm date with supplier. If materials to be collected by the firm, confirm order is in supplier's stock, and convey order reference and instructions to driver. Check delivery tickets against materials received on site.

INPUTS: order and quote, materials and plant requirements, delivery ticket

OUTPUTS: call off, order reference, site-checked delivery tickets

2.7.6 PICK UP MATERIALS

DESCRIPTION: Organise schedule for company transport to collect materials on order and unordered daily materials requirements.

INPUTS: requisitions, order references

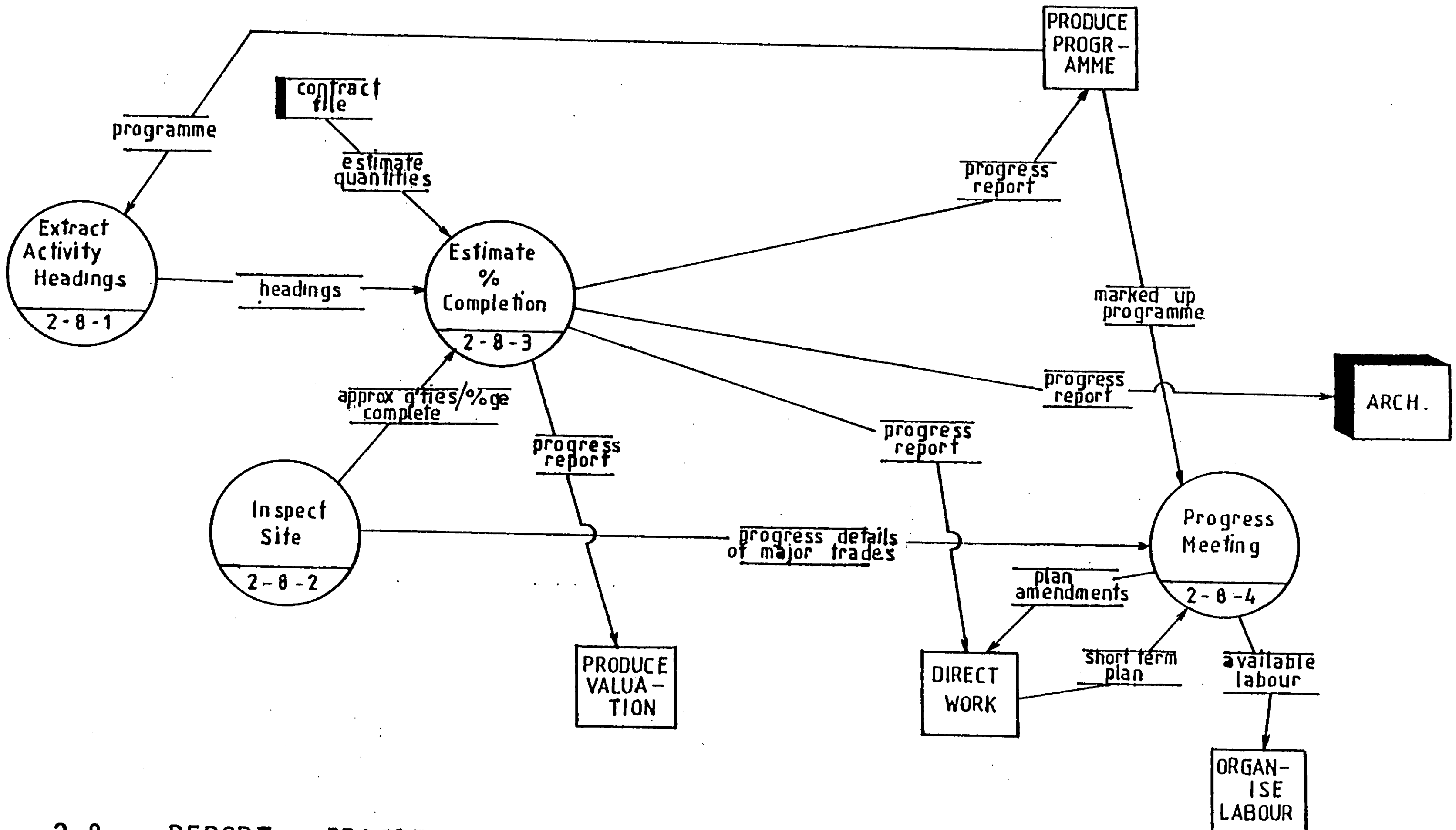
OUTPUTS: requisition/order

2.7.7 CHECK TICKETS AGAINST INVOICES

DESCRIPTION: Check invoices are for materials and plant supplied.

INPUTS: site-checked delivery tickets, invoices

OUTPUTS: checked invoices



2-8 REPORT PROGRESS

Figure A3.11.

2.8 REPORT PROGRESS

2.8.1 EXTRACT ACTIVITY HEADINGS

DESCRIPTION: When report required by architect, prepare headings based on sections of the programme, relating to any work progressed since previous report.

INPUTS: programme

OUTPUTS: headings

2.8.2 INSPECT SITE

DESCRIPTION: Make a broad assessment of progress based on site visits.

INPUTS: NONE

OUTPUTS: approximate quantities or %ges of work sections complete, progress details of major trades

2.8.3 ESTIMATE % COMPLETION

DESCRIPTION: Make an estimate of percentage completion of work covered by headings.

INPUTS: headings, approx. quantities or %ges of work sections complete, estimate quantities

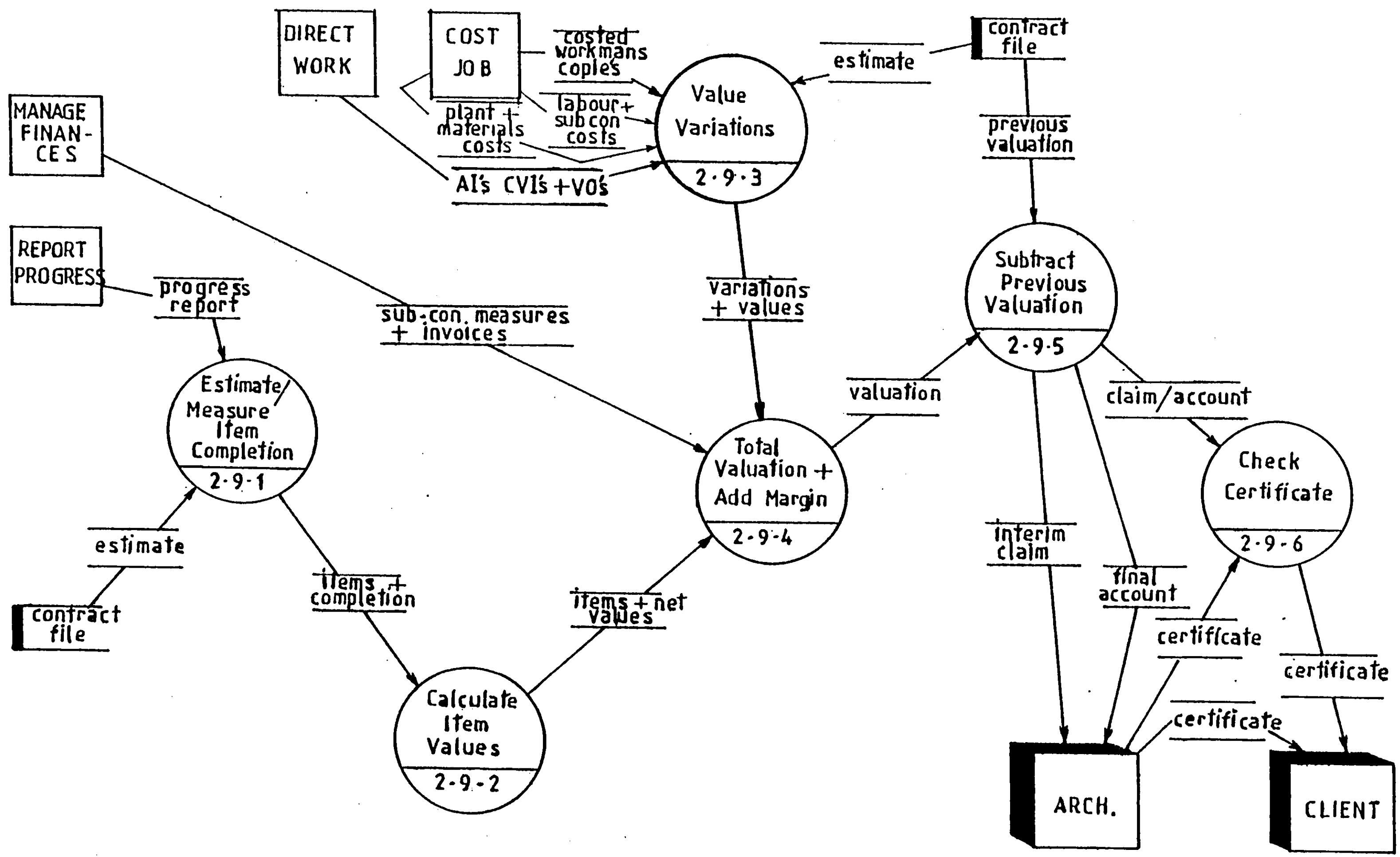
OUTPUTS: progress report

2.8.4 PROGRESS MEETING (amongst contract managers)

DESCRIPTION: Exchange reports of progress between managers. Compare each company division's demand for labour and reallocate labour as necessary.

INPUTS: progress details of major trades, marked-up programme, short term plan

OUTPUTS: labour available (to each division), plan amendments



2—9 PRODUCE VALUATIONS & FINAL ACCOUNTS.

Figure A3.12.

2.9 PRODUCE VALUATIONS AND FINAL ACCOUNTS

2.9.1 ESTIMATE/MEASURE ITEM COMPLETION

DESCRIPTION: Measure quantity of estimate item completed or estimate proportion completed.

INPUTS: estimate, progress report

OUTPUTS: items and completion

2.9.2 CALCULATE ITEM VALUES

DESCRIPTION: Calculate item value from measured/estimated completion and sum in estimate.

INPUTS: estimate items, completion

OUTPUTS: items and net values

2.9.3 VALUE VARIATIONS

DESCRIPTION: Establish if variation is to be valued by (1) estimate rates; (2) new rates; (3) dayworks.

If (1) locate estimate rate, apply it to quantity, set result against instruction reference number.

If (2) build up and apply new rate to quantity. Agree rate with quantity surveyor. Set result against instruction reference number.

If (3), extract labour content from 'workmans copy' and apply dayworks rate. Add plant and materials costs from invoices, etc. Set result against instruction reference number.

INPUTS: AIs, CVIs, VOs, costed 'workmans copies', estimate, plant and materials costs, labour and subcon costs,

OUTPUTS: variations and values

2.9.4 TOTAL VALUATION AND ADD MARGIN

DESCRIPTION: Total net value of work and add margin when not included in estimate rates.

INPUTS: items and net values, variations and values, subcon measures and invoices

OUTPUTS: valuation

2.9.5 SUBTRACT PREVIOUS VALUATION

DESCRIPTION: Subtract value of previous valuation, and deduct retention. Prepare interim claim in detail prescribed by contract conditions. If final account, verify all items and variations accounted for.

INPUTS: valuation, previous valuation

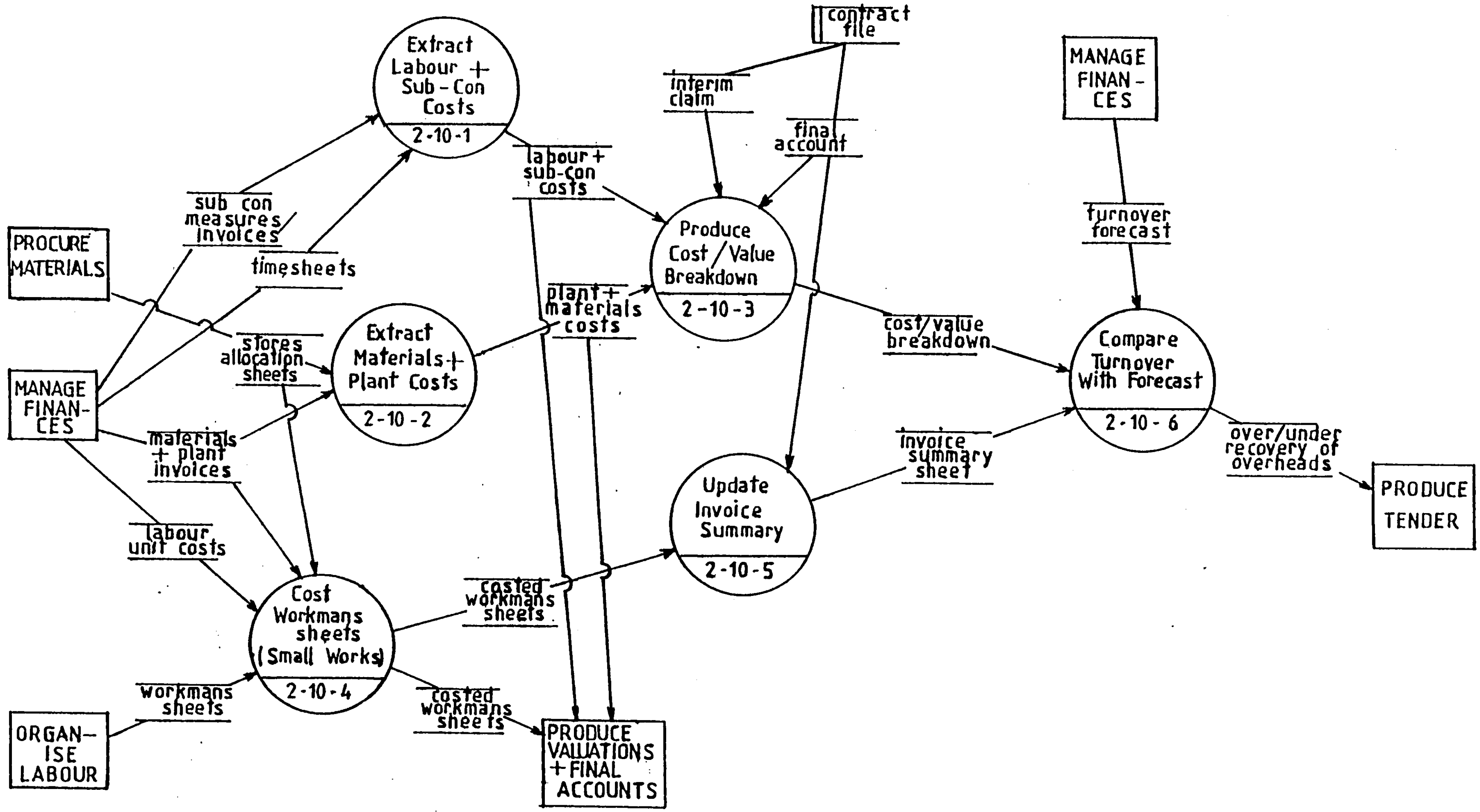
OUTPUTS: interim claim/final account

2.9.6 CHECK CERTIFICATE

DESCRIPTION: Check certificate agrees with claim and pass copy to client for payment.

INPUTS: claim/final account, architect's certificate

OUTPUTS: certificate



2-10 COST JOB

Figure A3.13.

2.10 COST JOB

2.10.1 ENTER LABOUR AND SUBCONTRACTOR COSTS

DESCRIPTION: For each major job determine labour and subcontractor costs.

INPUTS: subcon measures and invoices, timesheets

OUTPUTS: labour and subcon costs

2.10.2 EXTRACT MATERIALS AND PLANT COSTS

DESCRIPTION: For each major job, take materials and plant costs from invoices. Cost stores allocation sheets from invoices.

INPUTS: materials and plant invoices, stores allocation sheets

OUTPUTS: plant and materials cost sheet

2.10.3 PRODUCE COST/VALUE BREAKDOWN

DESCRIPTION: Total costs for each resource. Combine totals to derive contract cost and evaluate margin based on latest valuation.

INPUTS: labour and subcon costs, plant and materials costs, interim claim, final account

OUTPUTS: cost/value breakdown

2.10.4 COST WORKMANS SHEETS

DESCRIPTION: For small jobs, cost operatives description of work (includes hours and materials used) from invoices and allocation sheets.

INPUTS: workmans sheets, labour unit costs, materials and plant invoices, stores allocation sheets

OUTPUTS: costed workmans sheets

2.10.5 UPDATE INVOICE SUMMARY

DESCRIPTION: Record total cost, final contract sum, and margin achieved for each small job.

INPUTS: costed workmans sheets, final accounts

OUTPUTS: invoice summary sheet

2.10.6 COMPARE TURNOVER WITH FORECAST

DESCRIPTION: Compare monthly turnover and margin with the forecast and estimated overheads. Amend bidding strategy if necessary.

INPUTS: invoice summary sheet, cost/value breakdown, turnover forecast

OUTPUTS: over/under recovery of overheads

CASE STUDY OF FIRM D

TYPE OF FIRM: Limited Company

LOCATION: Malton, N. Yks.

APPROXIMATE TURNOVER: # 1,000,000

WORKFORCE;

	DIRECTLY EMPLOYED	LABOUR-ONLY SUBCONTRACTORS	TOTAL
LABOURERS	8	0	8
JOINERS	30	14	44
BRICKLAYERS	10	5	15
PLASTERERS	1	0	1
DRIVER	1	0	1
TOTAL	50	19	69

FULL-TIME STAFF: 8 **PART-TIME STAFF**: 0

COMPUTER USAGE: One microcomputer, but no applications decided for it.

HISTORY: Established in 1947, the company was purchased by its present owners in 1972. In 1985 the firm moved to new premises on a small industrial estate, where a joiner's workshop and a small yard are also situated. Since 1984 it had enjoyed a sustained expansion of its business, due, it was claimed, to its proficiency in high quality joinerwork. This had earned the company a profitable reputation with some of the major breweries in the region.

TYPE OF WORK: The firm tendered for work in the range # 2,000 - # 500,000, with an average value of about # 20,000.

The greater part of the firm's work was in refurbishments of public houses. On these contracts a high priority was attached to the rapid completion of the work, and this often required large numbers of operatives working extended hours in relatively confined conditions. Periods allowed for the preparation of tenders were also characteristically short. Some repair and maintenance and new work was taken on, but there was no design-and-build or speculative work.

The company was very busy and at the time of the investigation had seventeen jobs ongoing with a further eight due to commence shortly.

Being located in a rural area the firm's sites were often at some distance from its yard and offices.

MANAGEMENT ORGANISATION: Estimating was divided between the estimating director, the quantity surveyor, and a consultant estimator.

The provision and direction of the workforce, and the assessment of daily materials requirements was undertaken by the firm's two contract managers. All matters relating to the surveying of the work, ordering of major materials, and payment of subcontractors and suppliers were the responsibility of the quantity surveyor. In consultation with the managing director he would also draft the contract programme. The managing director had responsibility for the surveying of the smaller contracts.

Trades foremen, and on the bigger sites, site managers were appointed to supervise the work and requisition materials. Clerical staff undertook general administrative duties and prepared costing reports which were further analysed by the managing director.

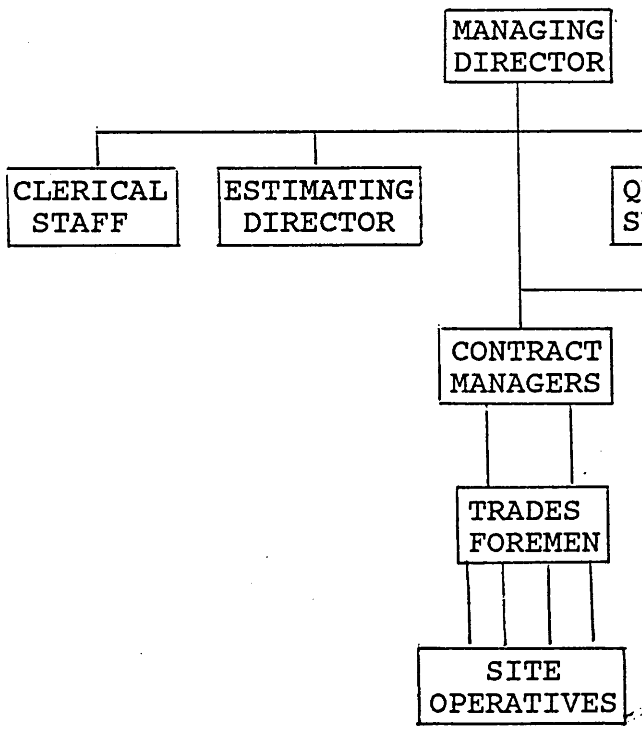
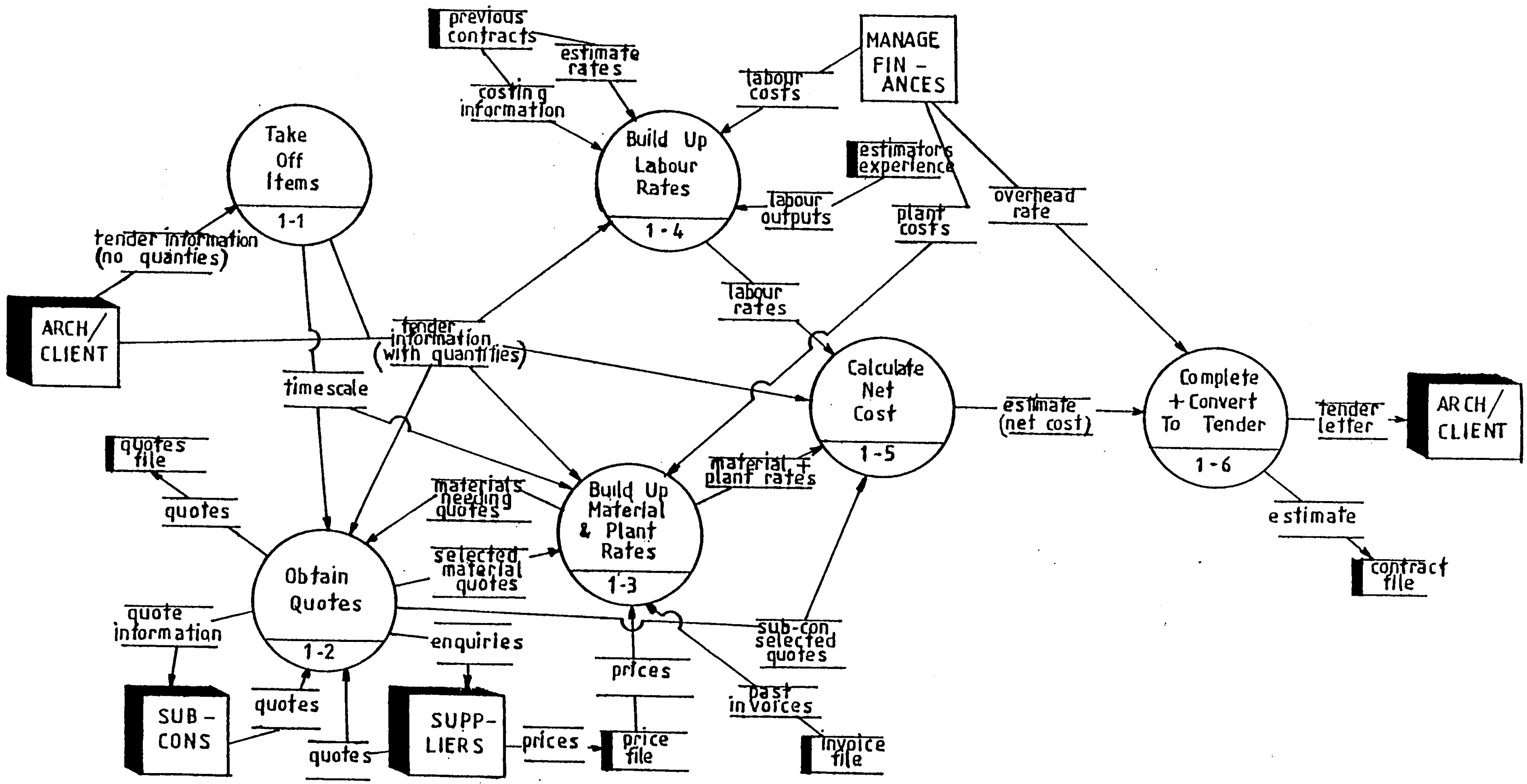


Figure A4.1 MANAGEMENT ORGANISATION - FIRM D



1. PRODUCE TENDER

Figure A4.2.

PROCESS DESCRIPTIONS FOR FIRM D

1 PRODUCE TENDER

1.1 TAKE OFF ITEMS

DESCRIPTION: Take quantities off drawings against specification items where feasible. Otherwise describe and quantify work as operations or BOQ type items as appropriate. If not provided by client, decide approximate timescale for the work.

INPUTS: tender information (no quantities)

OUTPUTS: tender information (with quantities), approx. timescale

1,2 OBTAIN QUOTES

DESCRIPTION: Assemble and despatch tender information and required site commencement date to selected subcontractors. Receive quotes and select for inclusion in tender. Extract specification descriptions and quantities for materials enquiries. Review and select suppliers prices.

INPUTS: tender information, materials needing quotes, quotes, approximate timescale

OUTPUTS: quote information, enquiries, selected material quotes, selected subcon quotes

1.3 BUILD UP MATERIALS AND PLANT RATES

DESCRIPTION: Determine major materials requiring quotes. Check past invoices for prices when quotes are unavailable. Take prices for materials required in small quantities from builders' merchants' price lists. Build up rates for major items of plant.

INPUTS: tender information, selected materials quotes. past invoices, prices, plant costs

OUTPUTS: materials needing quotes, material and plant rates

1.4 BUILD UP LABOUR RATES

DESCRIPTION: If job is similar to previous contract, extract labour rates from this source. Amend rates according to results of costing exercise. Otherwise use labour outputs based on personal experience.

INPUTS: tender information, costing information, previous estimate rates, labour costs, labour outputs

OUTPUTS: labour rates

1.5 CALCULATE NET COST

DESCRIPTION: Extend and total direct costs.

INPUTS: labour rates, materials and plant rates, tender information, selected subcon quotes

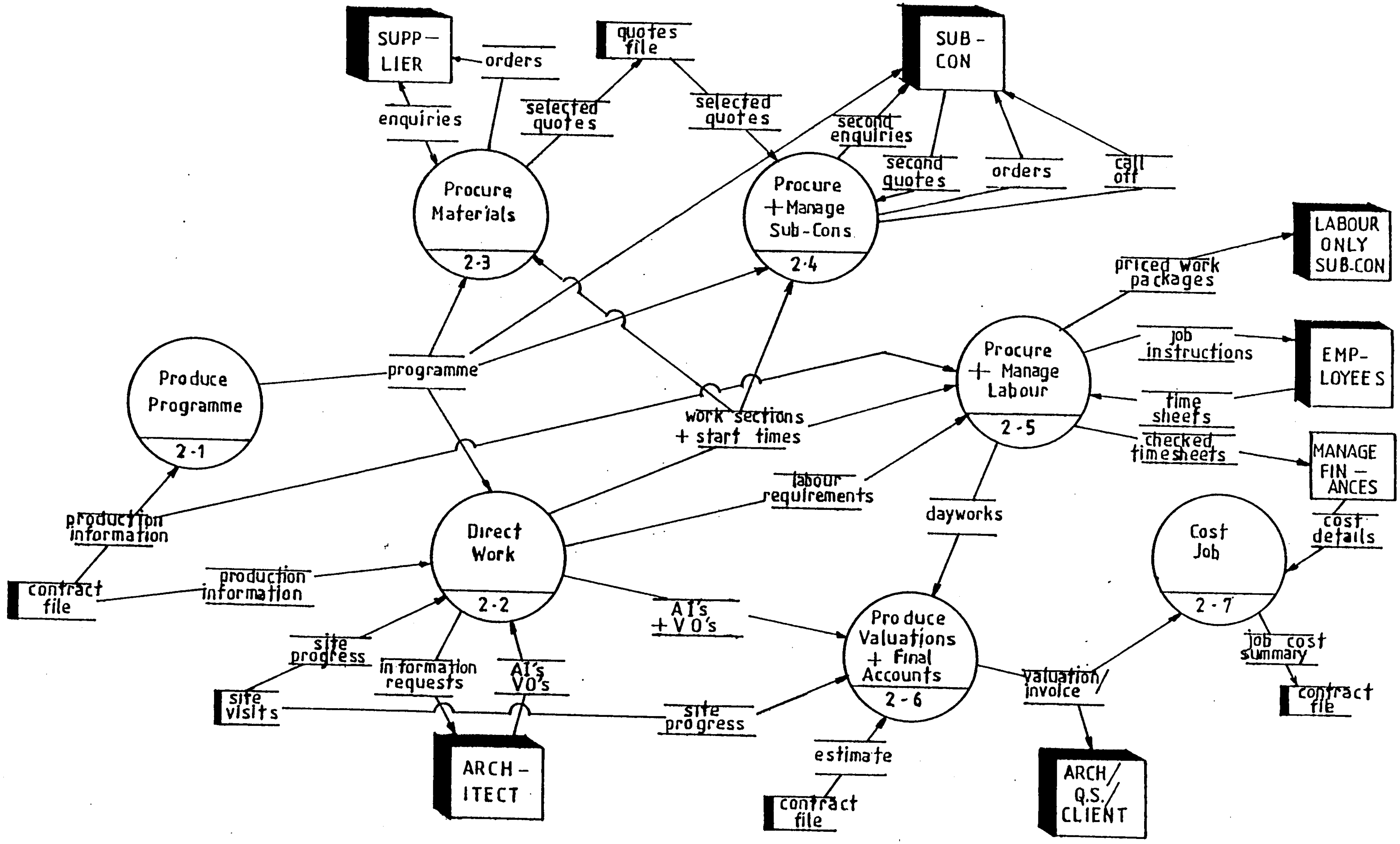
OUTPUTS: estimate (net cost)

1.6 COMPLETE AND CONVERT TO TENDER

DESCRIPTION: Calculate previous years overheads as % of sales figure. Apply % to net cost and add in. Add margin for profit. Prepare summary of overheads for inclusion with tender. Prepare and issue tender letter.

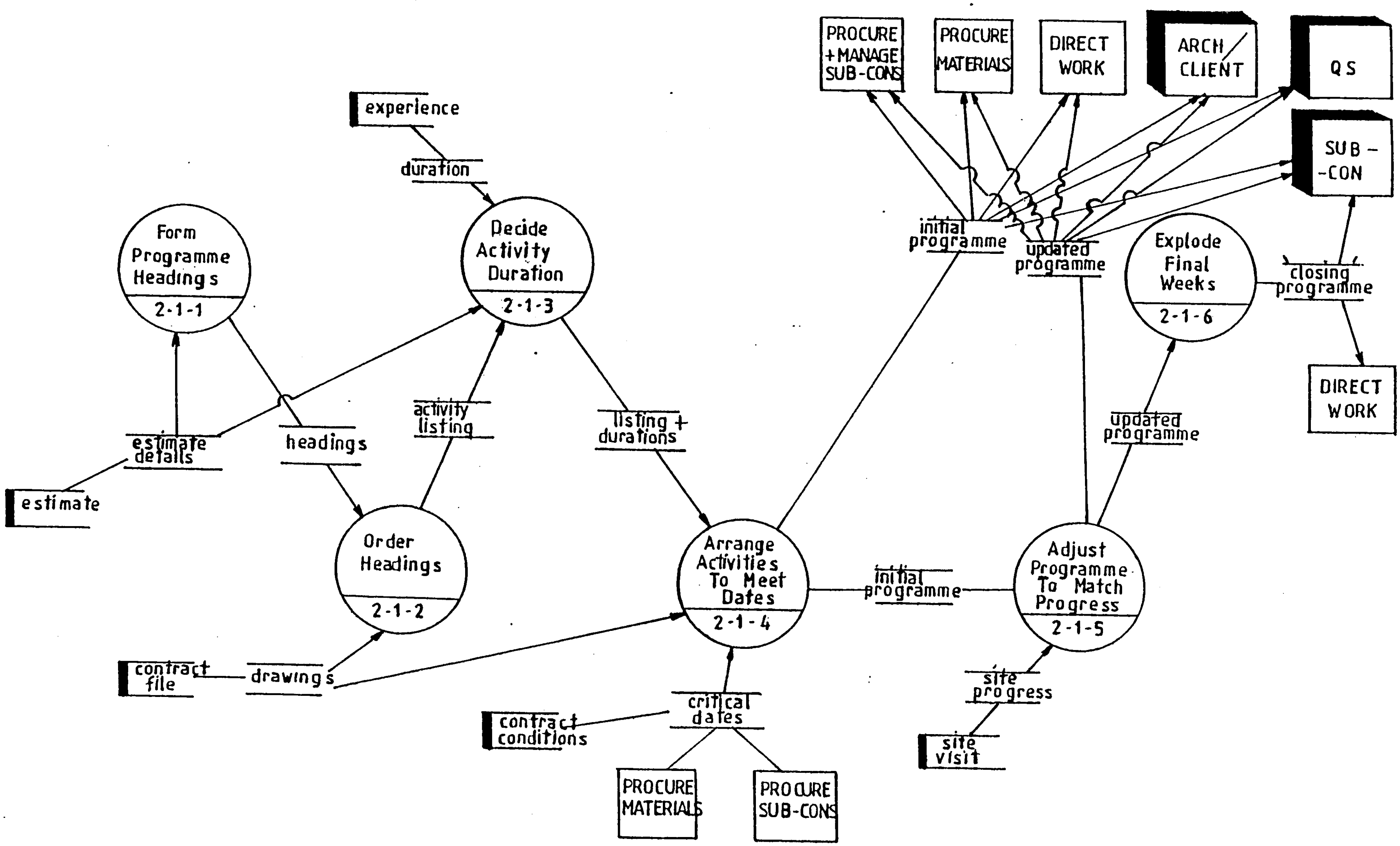
INPUTS: estimate (net cost), overhead rate

OUTPUTS: tender letter, estimate (summary)



2. MANAGE PRODUCTION

Figure A4.3.



2-1 PRODUCE PROGRAMME

Figure A4.4.

2 MANAGE PRODUCTION

2.1 PRODUCE PROGRAMME

2.1.1 FORM PROGRAMME HEADINGS

DESCRIPTION: Take headings from BOQ or specification descriptions, where appropriate.

INPUTS: estimate details

OUTPUTS: headings

2.1.2 ORDER HEADINGS

DESCRIPTION: List headings in approximate chronological order.

INPUTS: headings, drawings

OUTPUTS: activity listing

2.1.3 DECIDE ACTIVITY DURATION

DESCRIPTION: Estimate durations from experience.

INPUTS: activity listing, estimate details, durations

OUTPUTS: listing and durations

2.1.4 ARRANGE ACTIVITIES TO MEET DATES

DESCRIPTION: Ascertain contract start and finish dates and any agreed supplier delivery dates or subcon commencement dates. Arrange activities on bar chart to meet these dates, and to allow for physical dependencies between them.

INPUTS: listing and durations, drawings, critical dates

OUTPUTS: initial programme

2.1.5 ADJUST PROGRAMME TO MATCH PROGRESS

DESCRIPTION: Towards end of contract, or in event of a major difference between planned and actual progress, revise programme to reflect actual progress.

INPUTS: initial programme, site progress

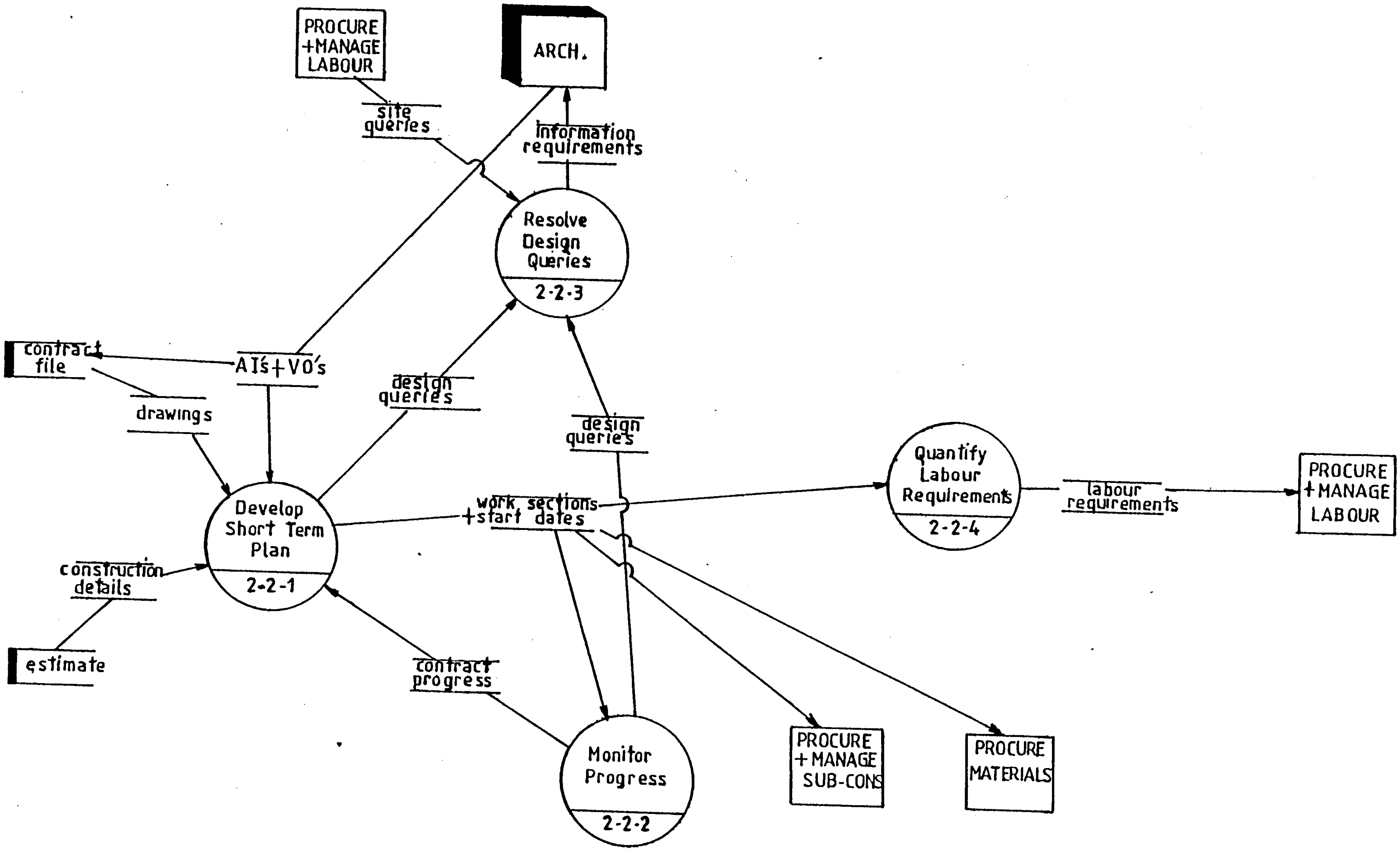
OUTPUTS: updated programme

2.1.6 EXPLODE FINAL WEEKS

DESCRIPTION: Break activities down into their constituent operations. Estimate duration of each. Consider precise dependencies between operations, and produce new chart to smaller time unit.

INPUTS: updated programme

OUTPUTS: closing programme



2-2 DIRECT WORK

Figure A4.5.

2.2 DIRECT WORK

2.2.1 DEVELOP SHORT TERM PLAN

DESCRIPTION: Study drawings to decide which operations will follow on from current operations. Check that the necessary production information is available.

INPUTS: drawings, construction details, architect's instructions and variations, contract progress

OUTPUTS: design queries, work sections and their start dates

2.2.2 MONITOR PROGRESS

DESCRIPTION: Check that the work is being carried out as planned.

INPUTS: work sections and start dates

OUTPUTS: contract progress, design queries

2.2.3 RESOLVE DESIGN QUERIES

DESCRIPTION: Receive queries from site and make requests for further information from the architect.

INPUTS: site queries, design queries

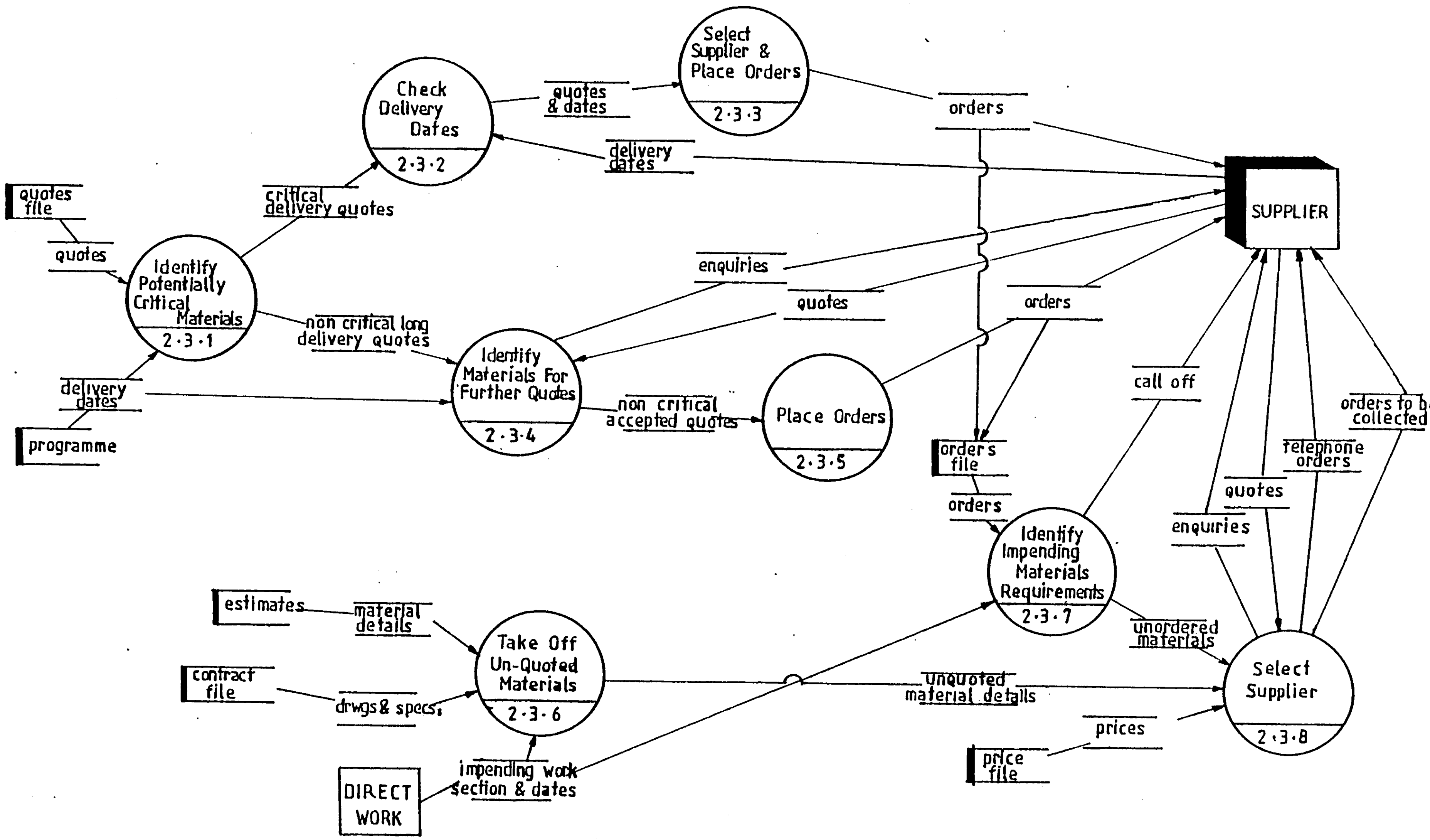
OUTPUTS: information requirements

2.2.4 QUANTIFY LABOUR REQUIREMENTS

DESCRIPTION: Determine the number of men required for each trade over the next week and consider labour allocation alternatives.

INPUTS: work sections and start dates

OUTPUTS: labour requirements



2·3 PROCURE MATERIALS

Figure A4.6.

2.3 PROCURE MATERIALS

2.3.1 IDENTIFY POTENTIALLY CRITICAL MATERIALS

DESCRIPTION: Decide which materials must be ordered immediately in order to meet programme requirements.

INPUTS: quotes, programme delivery dates

OUTPUTS: 'critical' delivery quotes, 'non-critical' delivery quotes

2.3.2 CHECK DELIVERY DATES

DESCRIPTION: Check when delivery of materials can be made by supplier, and that price remains as quoted.

INPUTS: 'critical' delivery quotes, delivery dates

OUTPUTS: quotes and dates

2.3.3 SELECT SUPPLIER AND PLACE ORDER

DESCRIPTION: Select supplier and issue order including required delivery date.

INPUTS: quotes and dates

OUTPUTS: orders

2.3.4 IDENTIFY MATERIALS FOR FURTHER QUOTES

DESCRIPTION: Decide which materials of those not in need of immediate ordering, might benefit from further quotes. Receive quotes (inc. delivery), review and select.

INPUTS: 'non-critical' long delivery quotes, quotes (new)

OUTPUTS: supplier enquiries, 'non-critical' accepted quotes

2.3.5 PLACE ORDERS

DESCRIPTION: Prepare and send out orders to selected suppliers for 'non-critical' materials.

INPUTS: 'non-critical' accepted quotes

OUTPUTS: orders

2.3.6 TAKE OFF UNQUOTED MATERIALS

DESCRIPTION: In advance of their need on site, take off all materials for which no quote was sought at tender stage.

INPUTS: materials details, drawings and specification, work sections and dates

OUTPUTS: unquoted materials details

2.3.7 IDENTIFY IMPENDING MATERIALS REQUIREMENTS

DESCRIPTION: Identify all materials required to complete work sections startind shortly. Call off those on order.

INPUTS: impending work sections and dates, orders

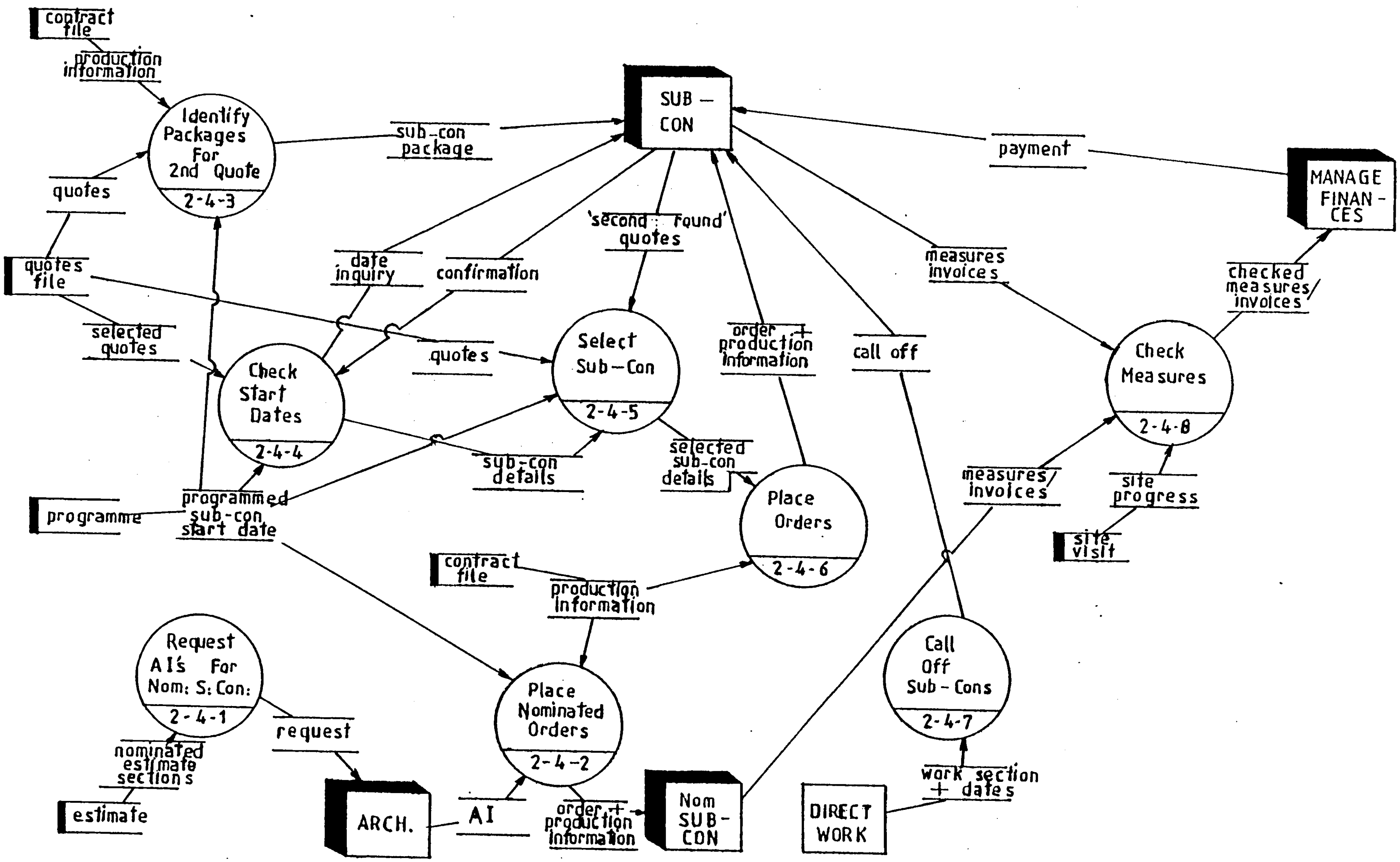
OUTPUTS: unordered materials, call off

2.3.8 SELECT SUPPLIER

DESCRIPTION: Make enquiries and receive quotes for previously unquoted material shortly before they are required on site. Place orders. List orders and unordered items to be collected from merchant by firm's operatives.

INPUTS: unordered materials, unquoted materials details, prices, quotes

OUTPUTS: enquiries, telephone orders, orders to be collected



2-4 PROCURE & MANAGE SUBCONTRACTORS.

Figure A4.7.

2.4 PROCURE AND MANAGE SUBCONTRACTORS

2.4.1 REQUEST AI'S FOR NOMINATED SUBCONTRACTORS

DESCRIPTION: Request notification to place orders for nominated subcontractors.

INPUTS: nominated estimate sections

OUTPUTS: request

2.4.2 PLACE NOMINATED ORDERS

DESCRIPTION: Assemble necessary production information. Take subcontractor start date from programme. Prepare formal order and send all to subcontractor.

INPUTS: AI, programmed subcon start date, production information

OUTPUTS: order, production information

2.4.3 IDENTIFY PACKAGES FOR SECOND QUOTE

DESCRIPTION: If there is sufficient time, send relevant production information including programmed start date to other subcontractors for further quotes.

INPUTS: quotes, programmed subcon start date, production information

OUTPUTS: subcon package

2.4.4 CHECK START DATES

DESCRIPTION: Check or negotiate commencement dates with subcontractors whose quotes were included in estimate.

INPUTS: selected quotes, programmed subcon date, confirmation

OUTPUTS: date enquiry, subcon details

2.4.5 SELECT SUBCONTRACTOR

DESCRIPTION: Review and make final choice of subcontractors on basis of price and ability to meet programme.

INPUTS: subcon details, quotes (tender), quotes (second round), programmed subcon start dates

OUTPUTS: selected subcon details

2.4.6 PLACE ORDER

DESCRIPTION: Prepare and send order with any outstanding production information.

INPUTS: selected subcon details, production information

OUTPUTS: order, production information

2.4.7 CALL OFF SUBCONTRACTORS

DESCRIPTION: Identify subcontractors due to start shortly. Decide precise date of arrival on site and confirm this with the subcontractor.

INPUTS: work sections and dates

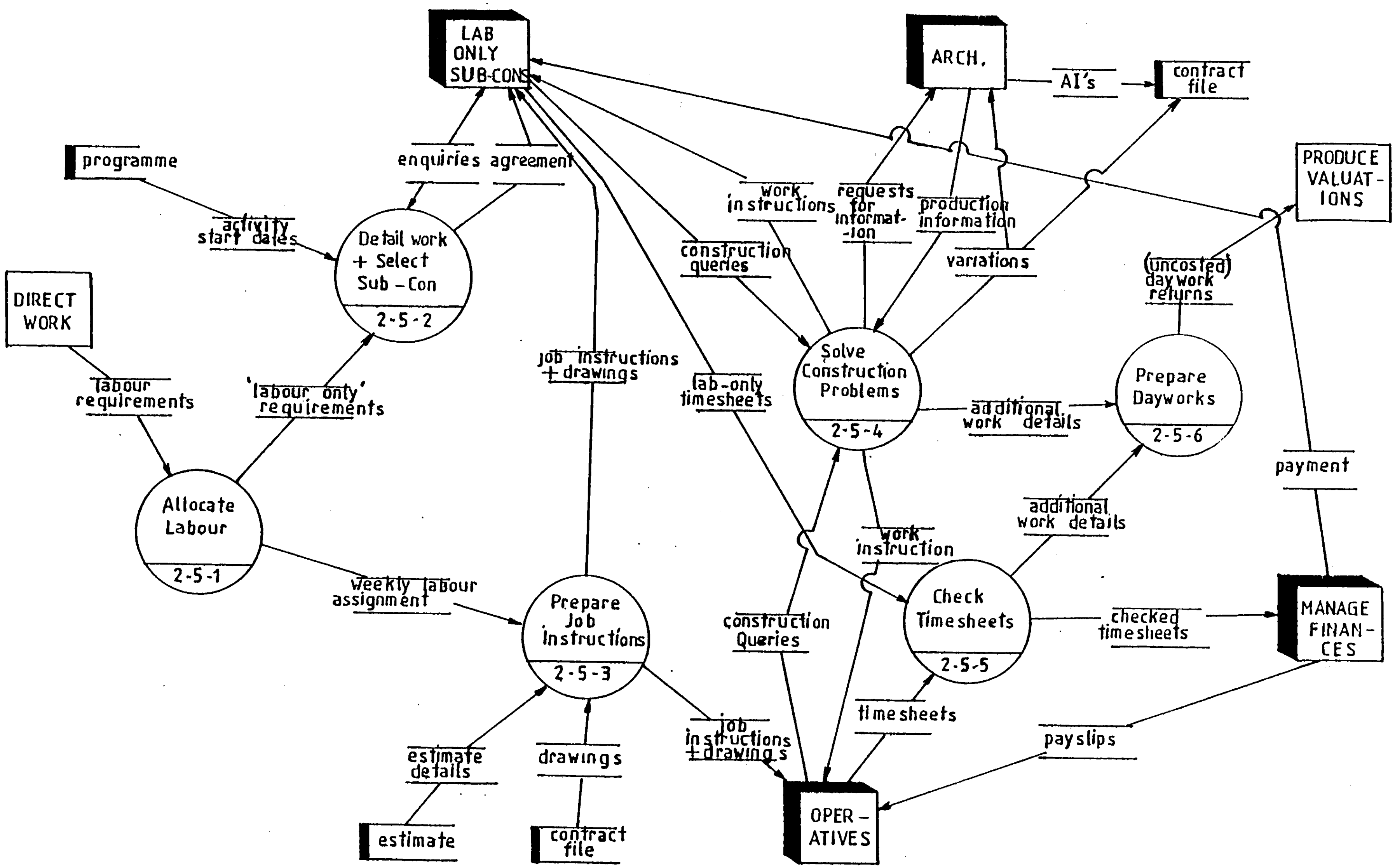
OUTPUTS: call off

2.4.8 CHECK MEASURES

DESCRIPTION: Verify accuracy of valuation received from subcontractor.

INPUTS: measures, invoices, site progress

OUTPUTS: checked measures and invoices



2-5 PROCURE & MANAGE LABOUR.

Figure A4.8.

2.5 PROCURE AND MANAGE LABOUR

2.5.1 ALLOCATE LABOUR

DESCRIPTION: At weekly meetings determine operations for following week to be carried out by each individual or gang. Assess future labour demand and determine the assignment of directly employed labour to major activities. Derive labour-only subcontractor requirements.

INPUTS: labour requirements (for each contract)

OUTPUTS: labour assignments, labour-only requirements

2.5.2 DETAIL WORK AND SELECT (LAB-ONLY) SUBCONTRACTORS

DESCRIPTION: Define details of work to be carried out by labour-only subcontractors. Negotiate pay rates and start dates with subcontractors and reach agreement.

INPUTS: labour-only requirements, activity start dates

OUTPUTS: enquiries, agreement

2.5.3 PREPARE JOB INSTRUCTIONS

DESCRIPTION: From specification, estimate and drawings, establish detail of work to be carried out. Communicate this to appropriate operatives and labour-only subcontractors, as and when necessary.

INPUTS: labour assignments, estimate details, drawings

OUTPUTS: job instructions, drawings

2.5.4 SOLVE CONSTRUCTION PROBLEMS

DESCRIPTION: Respond to queries from workforce. Request and receive further information from architect and pass this on to workforce. Confirm variations to architect. Make record of additional work carried out by workforce.

INPUTS: construction queries, production information

OUTPUTS: work instructions, requests for information, variations, additional work details

2.5.5 CHECK TIMESHEETS

DESCRIPTION: Check timesheets are correct. Take note of any additional work carried out.

INPUTS: timesheets

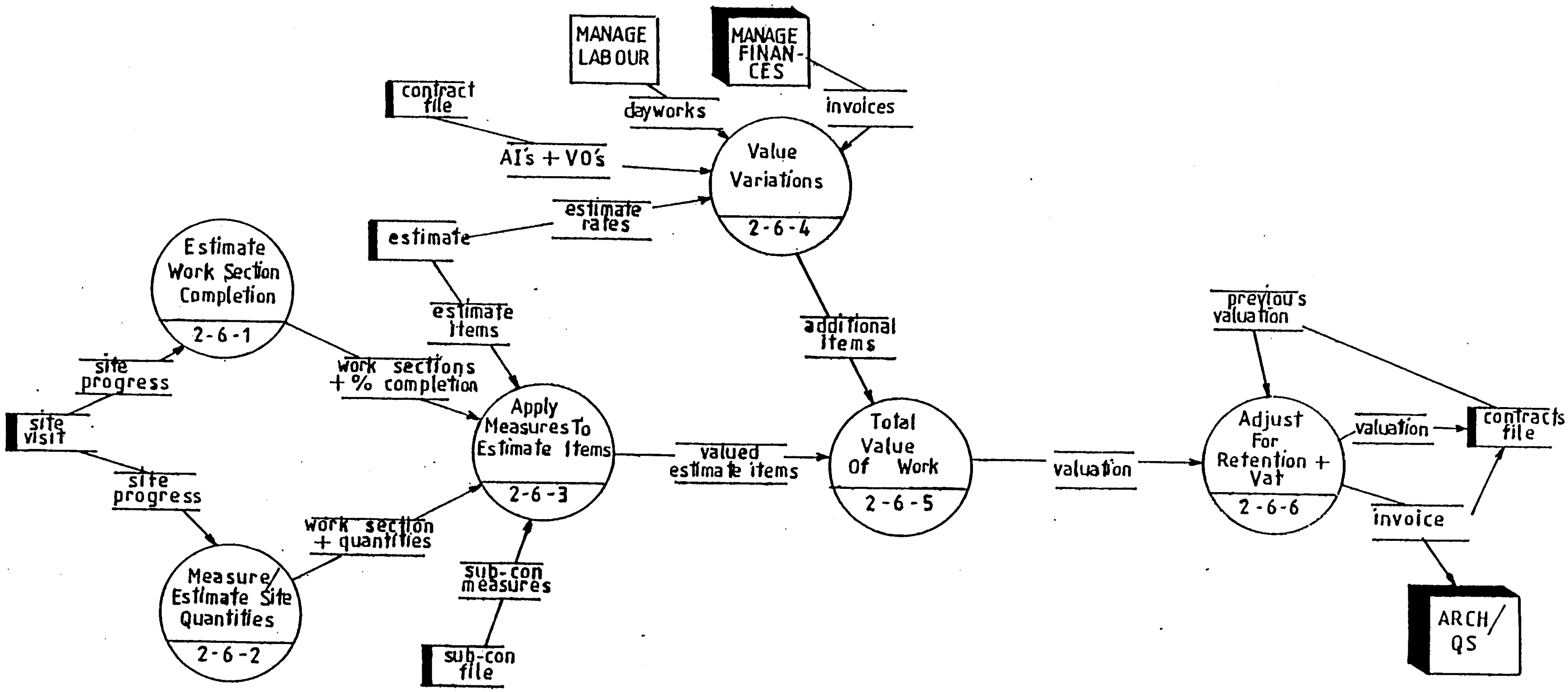
OUTPUTS: checked timesheets, additional work details

2.5.6 PREPARE DAYWORKS

DESCRIPTION: Make record of men, plant and materials utilised on work not estimated for at tender stage or priced as an instruction.

INPUTS: additional work details

OUTPUTS: daywork returns



2–6 PRODUCE VALUATIONS & FINAL ACCOUNTS.

Figure A4.9.

2.6 PRODUCE VALUATIONS AND FINAL ACCOUNTS

2.6.1 ESTIMATE WORK SECTION COMPLETION

DESCRIPTION: From site inspection, estimate the percentage completion of major sections of the work.

INPUTS: site progress

OUTPUTS: work sections and % completion

2.6.2 MEASURE/ESTIMATE SITE QUANTITIES

DESCRIPTION: Estimate, or take measurements and calculate quantities of work completed.

INPUTS: site progress

OUTPUTS: work sections and quantities

2.6.3 APPLY MEASURES TO ESTIMATE ITEMS

DESCRIPTION: For those items on which progress has been made since previous valuation, determine new completion from quantity or percentage of the work section to which they belong. Thus determine item values. Enter subcontractor valuations after allowing for main contractor's profit.

INPUTS: work sections and % completion, work sections and quantities, estimate items, subcon measures

OUTPUTS: valued estimate items

2.6.4 VALUE VARIATIONS

DESCRIPTION: Apply estimate rates to additional items described in architect's instructions where this is the agreed method. Otherwise apply labour rates to manhours recorded on dayworks sheets. Apply materials rates derived from invoices to material quantities used. Match costed dayworks to architect's instructions.

INPUTS: AIs, VOs, dayworks, invoices, estimate rates

OUTPUTS: additional items and values

2.6.5 TOTAL VALUE OF WORK

DESCRIPTION: Subtotal and total value of work comleted to date of valuation.

INPUTS: valued estimate items, additional items

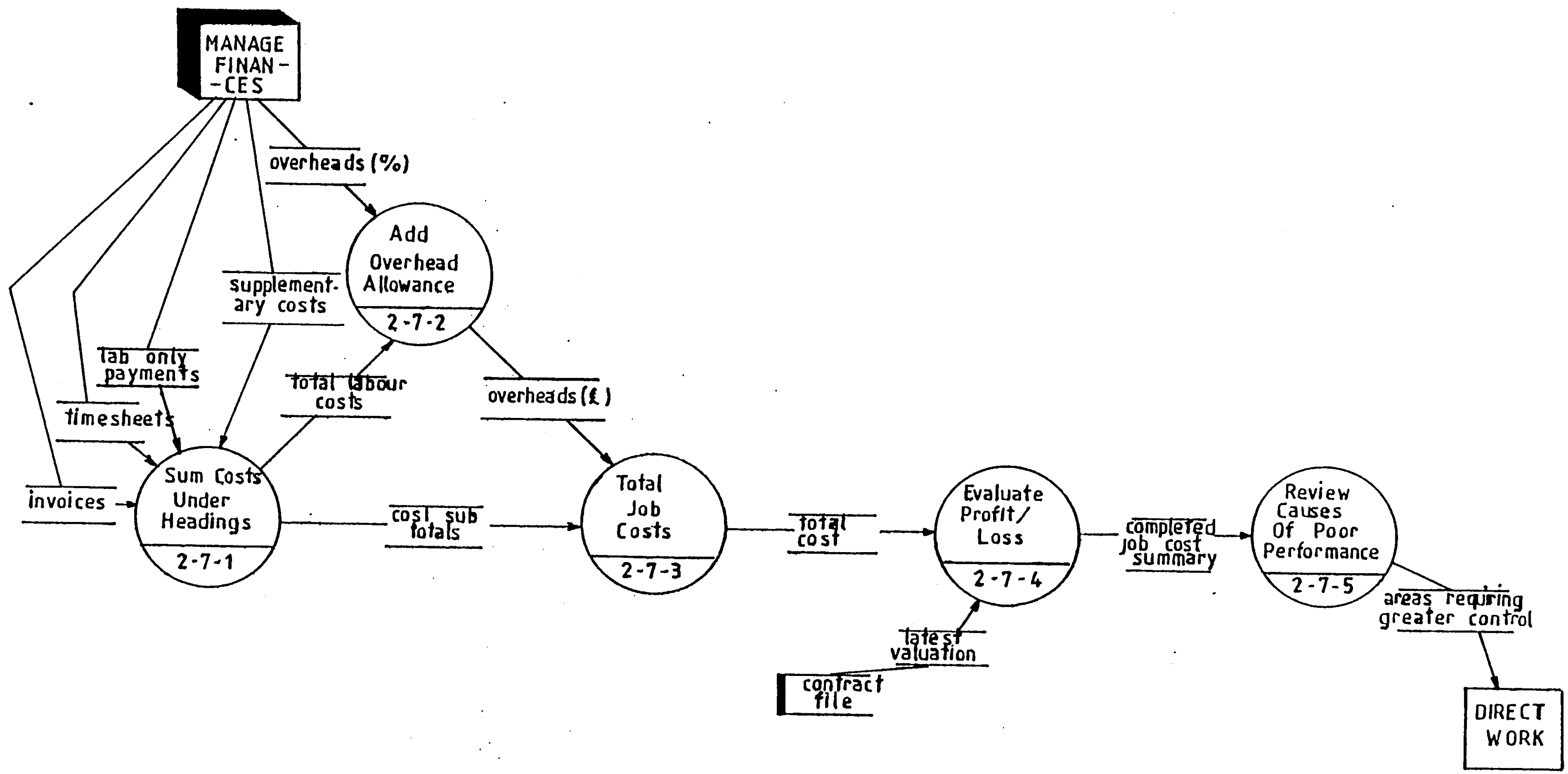
OUTPUTS: valuation

2.6.6 ADJUST FOR RETENTION AND VAT

DESCRIPTION: Subtract figure for retention and previous payments. Add VAT. Submit breakdown of valuation in as much detail as required by QS.

INPUTS: valuation, previous valuation

OUTPUTS: valuation, invoice



2-7 COST JOB

Figure A4.10.

2.7 COST JOB

2.7.1 SUM COSTS UNDER HEADINGS

DESCRIPTION: Assign costs to contracts under resource headings and subtotal.

INPUTS: invoices, timesheets, labour-only payments, supplementary costs

OUTPUTS: cost subtotals (materials, plant), total labour costs

2.7.2 ADD OVERHEAD ALLOWANCE

DESCRIPTION: Calculate overheads as % of total labour cost.

INPUTS: total labour cost, overheads recovery rate

OUTPUTS: overheads

2.7.3 TOTAL JOB COST

DESCRIPTION: Calculate total cost of contract for period reviewed.

INPUTS: cost subtotals, overheads

OUTPUTS: total cost

2.7.4 EVALUATE PROFIT/LOSS

DESCRIPTION: Extract value of work completed over costing period for each resource heading. Calculate differences between cost and value and hence evaluate overall profit or loss.

INPUTS: total costs, latest valuation

OUTPUTS: completed job cost summary

2.7.5 REVIEW CAUSES OF POOR PERFORMANCE

DESCRIPTION: If a significant loss is discovered, examine records to determine source of loss.

INPUTS: completed job cost summary

OUTPUTS: areas requiring greater control

ACTIVITY DESCRIPTIONS:

- ACTIVITY CODE
- ACTIVITY DESCRIPTION

ACTIVITY DETAILS:

- ACTIVITY CODE
- ACTIVITY DESCRIPTION
- ACTIVITY INTERRUPT INDICATOR
- [WORK CONTENT or DURATION]

ACTIVITY PROGRESS REPORT:

- CONTRACT NAME
- PROGRESS REPORT DATE
- * ACTIVITY PROGRESS DETAILS: *
    - (ACTIVITY CODE)
    - ACTIVITY DESCRIPTION
    - PROGRESS

ACTIVITY RELATIONSHIPS:

- ACTIVITY CODE 1
- ACTIVITY CODE 2
- LINK TYPE
- [LEAD or LAG]

ACTUAL TARGET MANHOURS:

- CONTRACT REFERENCE
- ACTIVITY CODE
- TARGET CODE
- ACTUAL MANHOURS TO DATE

AVAILABLE LABOUR:

- TRADE
- NUMBER OF MEN
- CALENDAR NAME

AVAILABLE PERSONNEL:

- OPERATIVE NAME
- TRADE
- CALENDAR NAME

BASIC RATE OF PAY:

- TRADE
- BASIC RATE

BONUS PAID TO DATE:

- CONTRACT REFERENCE
- ACTIVITY CODE
- TARGET CODE
- BONUS PAID

BONUS PAYMENT:

- CONTRACT REFERENCE
- ACTIVITY CODE
- TARGET CODE
- PAYMENT

CONTRACT DETAILS:

- CONTRACT REFERENCE
- CONTRACT NAME
- RETENTION

CONTRACT NAME:

- CONTRACT REFERENCE
- CONTRACT NAME

CONTRACT PARTICULARS:

- CONTRACT REFERENCE
- CONTRACT NAME
- (CONTRACT COMMENCEMENT)
- (CONTRACT COMPLETION DATE)
- (CONTRACT PERIOD)
- (RETENTION)

CONTRACT PROGRAMME INFORMATION:

- CONTRACT REFERENCE
- (CONTRACT COMMENCEMENT)
- (CONTRACT COMPLETION DATE)
- (CONTRACT PERIOD)

CONTROL REPORT:

- CONTRACT NAME
- DATE
- * ANALYSIS OF HOURS: *
    - ACTIVITY DESCRIPTION
    - * TARGET HOURS COMPARISON: *
        - TARGET DESCRIPTION
        - * OPERATIVE NAMES *
        - STANDARD TARGET MANHOURS
        - ESTIMATE TARGET MANHOURS
        - PLANNED TARGET MANHOURS
        - ACTUAL TARGET MANHOURS
        - * OPERATION DETAILS: *
            - TRADE
            - NUMBER
            - OPERATION DESCRIPTION
            - QUANTITY
            - UNIT
            - STANDARD OUTPUT
            - STANDARD MANHOURS
            - ESTIMATE OUTPUT
            - ESTIMATE MANHOURS

COST INFORMATION:

- CONTRACT REFERENCE
- TOTAL LABOUR COST
- TOTAL MATERIALS COST
- TOTAL PLANT COST
- TOTAL SUBCONTRACTOR COST
- TOTAL COST
- * OPERATION COST BREAKDOWN: *
    - ESTIMATE REFERENCE CODE
    - QUANTITY
    - OUTPUT
    - (MATERIALS RATE)
    - MATERIALS SUM
    - (PLANT RATE)
    - PLANT SUM
    - (SUBCON RATE)
    - SUBCON SUM
    - LABOUR RATE
    - OPERATION TOTAL COST

DAILY HOURS:

- OPERATIVE NAME
- WEEK BEGINNING DATE
- * DAILY HOURS REPORT: *
    - DAY OF WEEK
    - HOURS

DATAFILE NAMES:

- CONTRACT REFERENCE
- * FILE NAME *

EARLIEST START DATES:

- ACTIVITY CODE
- EARLIEST START DATE

ESTIMATE (AT COST):

- ESTIMATE REFERENCE CODE
- DESCRIPTION
- QUANTITY
- UNIT
- OPERATION TOTAL COST

ESTIMATE DETAILS:

- ESTIMATE REFERENCE CODE
- TRADE
- NUMBER
- DESCRIPTION
- QUANTITY
- ESTIMATE OUTPUT
- RESOURCE COSTS:
    - ([MATERIALS RATE or MATERIALS SUM])
    - ([PLANT RATE or PLANT SUM])
    - ([SUBCON RATE or SUBCON SUM])
    - HOURLY LABOUR RATE

ESTIMATE OPERATIONS:

- ESTIMATE REFERENCE CODE
- QUANTITY
- ESTIMATE OUTPUT

ESTIMATE (REVIEW) DETAILS:

- **ESTIMATE DETAILS**

  (except no resource costs)

INTEGRATED ACTIVITY RELATIONSHIPS:

- CONTRACT REFERENCE
- **ACTIVITY RELATIONSHIP**

INTEGRATED EARLIEST START DATES:

- CONTRACT REFERENCE
- **EARLIEST START DATES**

INTEGRATED LABOUR ASSIGNMENTS:

- CONTRACT REFERENCE
- **LABOUR ASSIGNMENTS**

INTEGRATED PROGRAMMES:

- CONTRACT REFERENCE
- **PROGRAMME**

INTERIM CLAIM:

- CONTRACT NAME
- CERTIFICATE NUMBER
- DATE OF VALUATION
- CLAIM BUILD UP:
    - (GROSS VALUE)
    - (RETENTION)
    - (LAST PAYMENT RECEIVED)
    - (AMOUNT DUE BEFORE TAX)
    - (VAT)
    - TOTAL DUE

ISSUED TARGET REFERENCES:

- CONTRACT REFERENCE
- ACTIVITY CODE
- TARGET CODE
- ISSUE STATUS

LABOUR ASSIGNMENTS:

- ACTIVITY CODE
- [OPERATIVE NAME or DEFAULT REFERENCE]
- ASSIGNMENT TYPE

LABOUR CALENDARS:

- CALENDAR NAME
- * WORKING HOURS: *

    - DATE
    - HOURS AVAILABLE

LABOUR DEMAND:

- [TRADE or OPERATIVE NAME]
- * DAILY DEMAND: *

    - DATE
    - MANHOURS SCHEDULED

LABOUR RATE:

- TRADE
- HOURLY LABOUR RATE for estimating

MARGIN:

- CONTRACT REFERENCE
- MARGIN

MATERIALS FOR QUOTES:

- (ESTIMATE REFERENCE CODE)
- OPERATION DESCRIPTION
- UNIT
- QUANTITY

NEW OPERATION COMPLETIONS:

- **WORK BREAKDOWN**
- OPERATION COMPLETION AT LAST VALUATION
- TARGET PROGRESS

OPERATION COSTS/RATES:

- [ESTIMATE REFERENCE CODE + DESCRIPTION or QUOT DESCRIPTION]
- UNIT
- [RATE or COST]

OPERATION DESCRIPTIONS:

- ESTIMATE REFERENCE CODE
- DESCRIPTION
- UNIT

OPERATION DETAILS:

- **OPERATION DESCRIPTION**
- **OPERATION QUANTITY**
- TRADE

OPERATION MANHOURS:

- ESTIMATE REFERENCE CODE
- OPERATION MANHOURS

OPERATION ORIGIN:

- ESTIMATE REFERENCE CODE
- TRADE
- NUMBER

OPERATION OUTPUTS:

- ESTIMATE REFERENCE CODE
- ESTIMATE OUTPUT

OPERATION QUANTITIES:

- ESTIMATE REFERENCE CODE
- QUANTITY

OPERATION TRADE:

- ESTIMATE REFERENCE CODE
- TRADE

PAYMENT DETAILS:

- ACTIVITY CODE
- TARGET CODE
- TYPE OF INCENTIVE
- (PRICE)
- (PAYBACK RATE)
- (FACTOR)

PLANNED TARGET MANHOURS:

- ACTIVITY CODE
- TARGET CODE
- PLANNED TARGET MANHOURS

PREVIOUS PAYMENT:

- CONTRACT REFERENCE
- CERTIFICATE NUMBER
- VALUATION DATE
- LAST PAYMENT VALUE

PREVIOUS VALUATION OPERATION COMPLETION:

- ESTIMATE REFERENCE CODE
- OPERATION COMPLETION AT LAST VALUATION

PRINTED ESTIMATE:

- CONTRACT NAME
- * ESTIMATE ITEM: *

    - ESTIMATE REFERENCE CODE
    - DESCRIPTION
    - QUANTITY
    - UNIT
    - OPERATION VALUE

- TENDER SUM BEFORE VAT

PROGRAMME:

- CONTRACT COMMENCEMENT DATE
- (CONTRACT COMPLETION DATE)
- * ACTIVITY: *
  - ACTIVITY CODE
  - ACTIVITY DESCRIPTION
  - ACTIVITY START DATE
  - ACTIVITY FINISH DATE
  - (INTERRUPT START DATE)
  - (INTERRUPT FINISH DATE)

PROGRAMME ACTIVITY DETAILS:

- **ACTIVITY DETAILS**

PROGRESS REPORT DATE:

- CONTRACT REFERENCE
- PROGRESS REPORT DATE

RATES + COSTS:

- ESTIMATE REFERENCE CODE
- ([MATERIALS RATE or MATERIALS COST])
- ([PLANT RATE or PLANT COST])
- ([SUBCON RATE or SUBCON COST])

REMAINING ACTIVITY WORK CONTENT:

- ACTIVITY CODE
- [REMAINING MANHOURS or REMAINING DURATION]

REVISED OPERATION COMPLETIONS:

- **NEW OPERATION COMPLETIONS**

  (values adjusted only)

ROGUE OPERATIONS:

- **STANDARD OPERATIONS**

STANDARD DAY:

- CALENDAR NAME
- STANDARD HOURS PER DAY

STANDARD OPERATIONS:

- TRADE
- NUMBER
- STANDARD DESCRIPTION
- STANDARD OUTPUT
- UNIT
- (STANDARD MATERIALS RATE)
- (STANDARD PLANT RATE)
- (STANDARD SUBCON RATE)

STANDARD OUTPUTS:

- ESTIMATE REFERENCE CODE
- DESCRIPTION
- UNIT
- STANDARD OUTPUT

STANDARD RATES:

- ESTIMATE REFERENCE CODE
- OPERATION DESCRIPTION
- UNIT
- (MATERIALS RATE)
- (PLANT RATE)
- (SUBCON RATE)

TARGET DESCRIPTION:

- ACTIVITY CODE
- TARGET CODE
- (TARGET DESCRIPTION)

TARGET PROGRESS:

- ACTIVITY CODE
- TARGET CODE
- TARGET PROGRESS

TARGET PROGRESS REPORT:

- CONTRACT REFERENCE
- CONTRACT NAME
- PROGRESS REPORT DATE
- * ACTIVITY PROGRESS ANALYSIS: *
    - ACTIVITY CODE
    - ACTIVITY DESCRIPTION
    - * TARGET PROGRESS: *
        - TARGET CODE
        - TARGET DESCRIPTION
        - TARGET PROGRESS

TARGET SHEETS:

- CONTRACT REFERENCE
- CONTRACT NAME
- TRADE
- ACTIVITY CODE
- TARGET CODE
- TARGET DESCRIPTION
- (EXTENDED TARGET DESCRIPTION)
- (* CONSTITUENT OPERATION: *)
    - OPERATION DESCRIPTION
    - QUANTITY
    - UNIT
- [FACTORED TARGET MANHOURS or [PRICE or RATE]]

TENDER DOCUMENT:

- **CONTRACT PARTICULARS**
- (TENDER SUM BEFORE VAT)
- (VAT)
- FINAL TENDER SUM
- (NOTES AND CONDITIONS)

TIMESHEETS (BLANK):

- WEEK BEGINNING DATE
- TRADE
- * TARGET: *
    - CONTRACT REFERENCE
    - ACTIVITY CODE
    - TARGET CODE
    - TARGET DESCRIPTION
- * DAY OF WEEK HEADING *

TIMESHEETS (COMPLETED):

- OPERATIVE NAME
- WEEK BEGINNING DATE
- * WORK ITEM HOURS: *
    - [OPERATIVE'S WORK DESCRIPTION or
    - (CONTRACT REFERENCE +
    - ACTIVITY CODE +
    - TARGET CODE +
    - TARGET DESCRIPTION)]
    - * DAILY HOURS REPORT: *
        - DAY OF WEEK
        - HOURS

TIMESHEETS (CHECKED):

- **TIMESHEETS (COMPLETED)**

UNFIXED MATERIALS VALUE:

- CONTRACT REFERENCE
- (UNFIXED MATERIALS VALUE)

VALUATION BREAKDOWN:

- (ACTIVITY DESCRIPTION)
- (ACTIVITY COMPLETION)
- (ACTIVITY VALUE OF WORK COMPLETED)
- (* OPERATION VALUATION: *)
    - ESTIMATE REFERENCE CODE
    - OPERATION DESCRIPTION
    - OPERATION COMPLETION
    - OPERATION VALUE OF WORK COMPLETED

VALUE OF WORK COMPLETED:

- CONTRACT REFERENCE
- VALUE BEFORE UNFIXED MATERIALS ADDED

VARIATION:

- **ESTIMATE OPERATION**

(estimate ref. code assigned identifies operation as variatio

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VARIATION AFFILIATION:

- EXISTING OPERATION ESTIMATE REFERENCE CODE
- VARIATION ESTIMATE REFERENCE CODE

VARIATION WORK BREAKDOWN:

- **WORK BREAKDOWN**

WORK BREAKDOWN:

- ACTIVITY CODE
- TARGET CODE
- ESTIMATE REFERENCE CODE
