THE LAYOUT OF WORKCENTRES IN A JOB SHOP SITUATION

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DECLARATION

No part of the work described in this thesis has been submitted in support of an application for another degree or other qualification of this or any other Institution.

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SUMMARY

This thesis deals with an extended approach to the problems of rearranging the layout of workcentres within an existing job shop to suit a change in manufacturing conditions.

Initially these problems are identified as:

1. The need to utilise an adequate representation of facilities and layout area.
2. The need to consider subjective and quantitative factors at a detailed level.
3. The influence of the overall manufacturing system on the arrangement of workcentres.
4. Whether in reality the benefits claimed of a layout arrangement are in practice obtained during the life span of the layout.

To investigate these problems a two stage approach is suggested dealing firstly with the creation of static layout designs and secondly with the dynamic simulation of layout changeovers.

The static layout model utilises materials movement as

a quantitative criterion in an interactive designer-heuristic approach which firstly locates pregrouped sets of workcentres and secondly locates individual workcentres within the areas allocated to each set.

Having created an initial and a final layout arrangement an interactive simulation model is proposed for evaluating the changeover from initial to final layout under varying conditions. Features of the simulation model include:

1. A more complex but realistic evaluation of materials movement cost.
2. The use of both workcentre relocation and materials movement costs.
3. The use of a parallel present value financial analysis to account for the influence of time on costs.
4. An inbuilt automatic changeover heuristic.

A computerised suite of programs is then introduced to include these models, giving consideration to the best possible combination of equipment and program for the design process.

Finally a number of the new parameters introduced are examined using an industrial test case and conclusions drawn on their behaviour, with test results presented to support these conclusions.

ACKNOWLEDGMENTS

In an undertaking of this size and duration there is a need to recognise the support and encouragement generously given by a number of sources.

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1. INTRODUCTION

The increasing rate of technological innovation and product obsolescence, combined with the rising cost of financing industrial investment has contributed to the need to examine more closely present quantitative facility layout techniques and to consider whether the benefits of the layout designs produced are in practice obtained during the life of the layout arrangement.

The majority of present quantitative methods are concerned with obtaining an arrangement of facilities that will give an "optimal" value for a selected criterion, the most common criterion being materials movement. In practice the benefits of this "optimal" or "sub-optimal" solution must be related to a number of other factors, particularly:

1. The capital cost involved in introducing the new layout design
2. The manner in which the new layout design is introduced
3. The relationship between layout design and manufacturing system design, where plant layout is not an independent problem but a contributor to a larger design task.

This work is concerned with the development of an extended layout philosophy to relate the static layout design problem to the subsequent introduction of the new layout for one particular type of industrial production, with the objective of assessing the financial contribution of the layout changeover to the overall manufacturing system.

Traditionally production has been organised into three layout types, product layout, process layout and fixed position layout, depending upon the influence of product quantity and variety. With the introduction of group technology, originating from the work of Mitrofanov (43), a new set of layout types were added to the more traditional plant designs, namely the group technology cell, the group technology flow line and the group technology machine centre. The interaction between product, production system and type of layout is illustrated in Figure 1.

Extensive design procedures have been developed for use in continuous. and mass/flow manufacturing systems, for example assembly line balancing techniques. Requiring extensive capital outlay, the sequence of manufacture dictates much of the layout procedure and restricts the number of potentially available solutions. Jobbing production alternatively is the least predictable form of production since by definition each product is on a one-off basis and the life span of a layout may be equal only to the duration of product manufacture. Under these circumstances plant layout may be either fixed position for small products or highly mobile as in the case of shipbuilding.

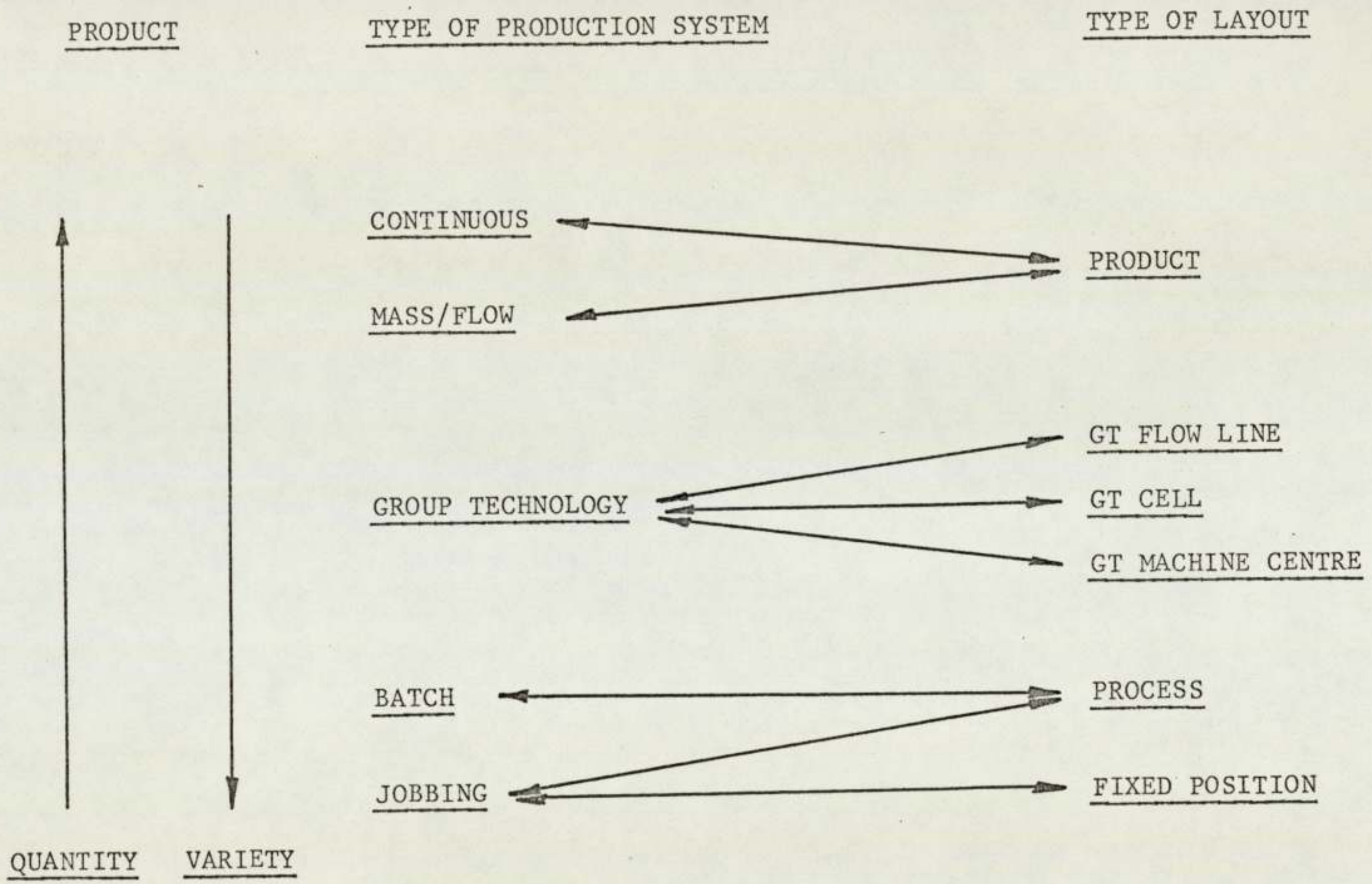


FIG 1 INTERACTION BETWEEN PRODUCT, SYSTEM AND LAYOUT

(after Sawyer)

unpublished

It is within the middle ground between mass and jobbing production systems that the greatest scope for potential improvement of quantitative facility techniques lies and it is this area of manufacture, accounting for an estimated two-thirds of industrial production, that is examined in this thesis.

Referred to as the job shop or batch production situation and consisting of the processing of intermittent work batches, a number of factors influence the choice of layout solution approach and the overall effectiveness of a layout design. These considerations fall within four groupings:

1. The extent of layout change
2. Manufacturing system considerations
3. Dynamic parameters
4. Subjective layout considerations.

Moore (45) and Muther (47) described four potential levels of layout change, each of which may apply in the job shop situation, as:

a. Building a completely new production area
b. Moving into an existing building
c. Rearrangement of an existing layout design
d. Minor changes in plant layout.

Leaving aside minor changes, which are associated more with machine-tool replacement than with accommodating changes in production program, there remains three problem levels. Within these three problems the designer is required to consider different degrees of physical restriction. In building a new plant area only the facility shapes initially form the physical restrictions whereas in the rearrangement of an existing layout both building and workcentre restrictions will affect the problem.

Considering physical restrictions as a set of limitations determined by each individual problem a further difference between the three types of layout is the relationship between capital investment and layout cost, expressed in terms of materials movement and illustrated in Figure 2. Taking only those costs associated with creating the job shop under the three conditions and assuming that all three final layouts are the same, thus having the same materials movement cost, it can be seen that the importance of achieving an "optimal" layout based upon materials movement becomes less significant as capital expenditure increases.

If the objective of job shop manufacture is a corporate one of obtaining the best possible financial return from an efficient layout then the true contribution of plant layout is a function of both the materials movement cost of a layout design and the capital expenditure required to install the layout.

Within the context of this work the third case, i.e. the rearrangement of an existing job shop, has been chosen

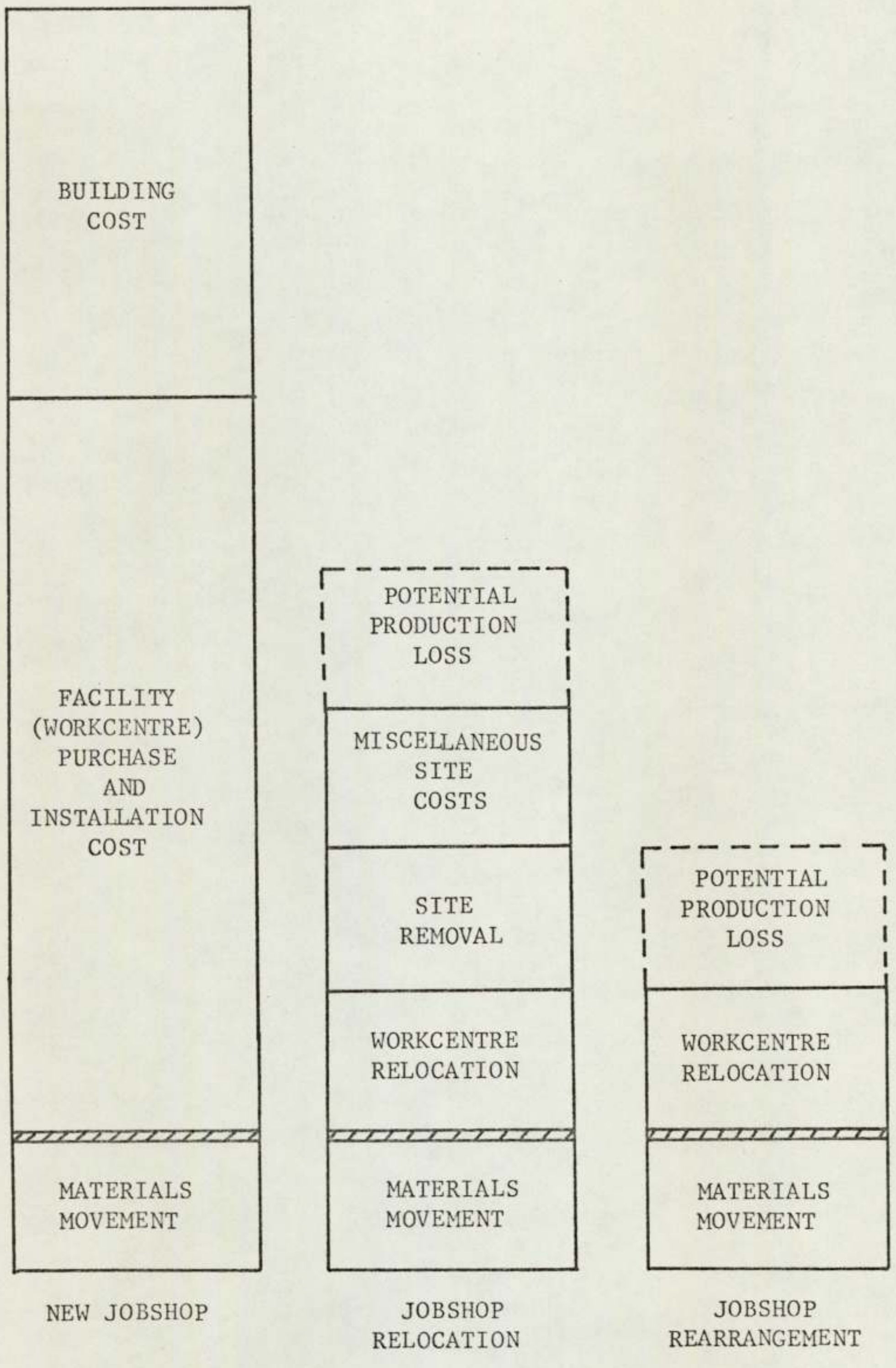


FIG 2 COMPARATIVE CAPITAL AND LAYOUT COSTS

for examination for two reasons. Firstly this problem has the lowest ratio between capital cost and layout cost and therefore the effects of a layout design are more relevant. Secondly the two alternative problem formulations may be accommodated with only a minor change to capital cost calculations.

The concept of a corporate strategy applied to job shop layout is not confined to financial considerations. Plant layout is an integral part of the design of a manufacturing system and has a two-directional relationship with other aspects of this manufacturing system. Clearly a poor layout will be detrimental to production control, materials movement, production scheduling and a number of other factors. Of more importance to job shop layout is the influence that these areas of manufacturing system design have on layout techniques. The majority of present layout techniques are concerned with minimising materials movement, expressed as the product of distance and quantity. In a job shop situation this criterion used singularly and in a direct manner may lead to disorganised production units. Whilst materials movement is an important factor in layout evaluation a modification in its use applicable to job shop layout will be introduced at a later stage.

As discussed earlier the true contribution of plant layout is a function of both the layout cost and the capital cost of introducing the layout. In practice both of these quantities are affected by the dynamic nature of manufacturing production. Two forms of dynamic variation are relevant to the problem examined:

1. Production variation
2. Layout variation.

The normal practice in formulating the layout problem is to average the total production and to utilise the mean values, a practice which is continued within this work. Where variation is excessive enough to influence layout efficiency then the use of specific simulation models presents a better solution approach.

Layout variation is concerned with the manner in which layout changes occur. Where a change in production program is required a number of alternative layout decisions are possible. The first alternative is to make no layout change. Assuming this results in inefficient production, and this may not be the case, the disadvantages incurred may be less than either the disruption to an existing layout caused by a change or alternatively the cost of constructing a new job shop.

Where a new layout is to be created this may be achieved by the introduction of the new design in one time period. This allows the maximum benefit to be obtained from the new design and minimises the potential disruption period. Where an existing layout is involved this form of introduction would require the halting of production and consequently there would be an added loss. Alternatively the new layout design can be introduced over a period of time, allowing continuity of production in any existing layout. A gradual changeover of layouts enables the capital expenditure involved to be spread over a period of time and although the changeover takes longer a gradual change allows the manufacturing system better opportunity to adapt to the changes. Clearly a major influence on the way in which a layout change is to be introduced will be the expected life span of the layout. The longer the life span the greater the period over which capital outlay may be returned and the longer the time available for introducing layout changes.

The effect of life span and other dynamic parameters on the expected benefits of a layout design will be examined as part of the extended layout philosophy.

The factors so far discussed have been concerned with the quantitative evaluation of layout projects. A realistic job shop situation however is a combination of subjective and quantitative factors, both of which are essential in designing an efficient layout. The close proximity of facilities in the job shop amplifies the effect of subjective considerations and compounds the ill-structured nature of the problem. An example of this is closeness desirability (47), used as the main alternative to materials movement as a quantitative layout criterion.

The basis of closeness desirability is a chart of graded ratings expressing how desirable it is to locate two facilities as neighbours. In a job shop situation the effect of facilities on one another extends further than immediate neighbours and can be altered by the use of partitioning, thus becoming too complex to use on a quantitative basis.

The detailed discussion of the many subjective influences is beyond the scope of this work, differing for each individual problem. It is however necessary to allow within any design philosophy the ability to take into account subjective considerations, particularly in the close proximity of a job shop situation. The point in the design procedure at which this subjective consideration is given will be discussed further at a later stage.

Within this introduction a number of influences have been identified that affect the design of job shop manufacturing areas and the evaluation of the contribution to the overall project of the layout design. In the generalised job shop situation two problems can be identified for investigation:

1. Static layout design
2. Dynamic layout changeover.

Initially one special formulation of each of the two problems are examined with regard to the rearrangement of an existing layout to meet the requirements of a new production program and at a later stage the possibility of adapting the approach to other related problems is discussed.

2. REVIEW OF EXISTING LAYOUT METHODS

To undertake a review of all the published work concerned with plant layout problems does in itself constitute a major task and has already resulted in a number of literature surveys and technique reviews, most notably those of El-Rayah and Hollier (18),Moore (45),Lee (31), Stewart, Teicholz and Lee (60) and Francis and White (21).

A number of these methods are not directly applicable to job shop layout i.e. a problem concerned with locating physically independent facilities in a continuous layout space and therefore have not been included. In particular assignment problems related to the placing of facilities in fixed locations have been omitted from the review. However for completeness a number of references to assignment techniques have been included in the bibliography.

Within the context of this review four approaches to plant layout will be examined with regard to job shop manufacturing:

1. Qualitative and systematic layout planning
2. Mathematical and schematic methods
3. Computerised layout programs
4. Dynamic plant layout

The first three of these approaches reflect the stages through which plant layout theory has evolved since the appearance of the first text books on the subject and are consistent with the introduction of two powerful tools in systems analysis i.e. operations research techniques and the digital computer.

2.1. Qualitative and Systematic Layout Planning

Qualitative plant layout

The initial approach to plant layout theory consisted of a detailed discussion of the many qualitative factors influencing a layout design. Mallick and Gaudreau (39) in defining plant layout give an indication of the all-embracing nature of this approach:

> "Plant layout is the master plan that integrates the factory grounds, buildings, floors, departments, machine-tools, processing equipment, manufacturing methods, materials handling equipment, service facilities, flow of production, utilisation of labour and shipment of finished products into a united machine of which management itself is the operator".

Covering the complete range of layout problems in detail, qualitative layout utilises the flow of material as a basis for arrangement. Providing a series of reference examples for layout engineers qualitative layout lacks both a systematic method and quantitative analysis.

This detailed treatment however has proved useful in presenting a breakdown of the numerous subjective considerations and their interaction which affects job shop layout, an essential part of an efficient layout solution technique. The complex nature of the flow, or materials movement, in a job shop however does not produce a dominant product, thus limiting the usefulness of flow planning.

Systematic layout planning

Muther (47) (48) reorganised the early qualitative approach into a systematic solution procedure based upon a combination of flow considerations and qualitative factors.

Systematic layout planning improved upon qualitative approaches by the use of a variety of empirical charts for evaluating layout decisions and introduced closeness desirability as a layout criterion.

Qualitative and systematic layout planning were both concerned with the examination of the total problem and therefore did not easily accommodate rigid solution procedures or evaluation by a single quantitative criterion. Muther, whilst stressing that flow was not the only consideration in plant layout, used flow of materials as the basis of systematic planning.

Materials movement, as the one criterion that can be directly related to the positioning of facilities, provides a means of quantitatively evaluating layout designs and this relationship between movement value and layout pattern has provided the basis for the majority of quantitative layout techniques.

2.2. Mathematical and Schematic Methods

With the introduction of mathematical and schematic techniques, ranging from semi-systematic spiral analysis to precise mathematical formulations of the plant layout problem a fundamental change in approach occurred.

Qualitative and systematic layout planning were concerned with the total problem but lacked a quantitative basis. To overcome this the problem definition is considerably reduced to one single criterion, in the majority of cases a form of materials movement, on the basis that after the solution is obtained then the layout can be modified to suit practical requirements. The methods examined in this grouping are:

Spiral analysis
Sequence analysis
Straight line analysis
Straight line sequence demand
Travel charting
Single facility layout techniques
Multiple facility layout techniques.

Sequence analysis, introduced by Buffa (10) and spiral analysis (53) are two similar semi-systematic techniques. Using an analysis of production sequence for the dominant products a two dimensional diagram is determined with facilities represented by circles, from which is evolved a block plan. Both spiral analysis, based on percentage volume and sequence analysis using numbers of loads become unemployable for all but a small number of facilities and, combined with the inherent variation in possible solutions, these techniques are unsuitable for use in a job shop situation.

Straight line analysis has the objective of arranging facilities in a straight line to reduce materials movement, using parallel product lines arranged in percentage volume order to minimise backtracking. Bannester (8) introduced a further modification to straight line analysis, formulating a problem with a single straight line along which equally spaced facilities have to be arranged in order. In a similar manner to Noy (50) the average position of each facility along the line is determined and facilities are placed in this order. This problem was modified by Singleton (59) to allow for uneven production sequences, and Hollier (26) later discounted optimality claims by Singleton, producing a series of solution methods for various movement criteria. The nature of job shop production with diverse production sequences and two dimensional layout limits the usefulness of straight line techniques.

Travel charting is potentially of greater use as a means of displaying movement data than as a layout technique. Introduced by Levy (35) utilising an "X" to indicate inter-facility movement the chart was modified by Cameron (13) to include batch quantities and Llewelyn (36) to include the product of batch quantities and distance. The use of travel charts as a layout technique is based upon inspection of elements in relation to minimising total movement and backtracking. For straight line production excessive movement is indicated by the distance away from the main diagonal. For a two dimensional problem inspection of the largest numerical value may yield a possible improvement although this is not guaranteed due to the changing distance values involved.

In general schematic techniques can only be applied to limited size problems and whilst some physical representation is achieved these techniques have only limited potential for use in job shop layout.

Considering materials movement, expressed as the product of distance and quantity, as the sole criterion and reducing physical representation of facilities to a set of points then it is possible to formulate a number of mathematical and semi-mathematical solutions to facility layout. These solutions fall into two groups, single facility location where optimal solutions can be easily found, and multiple facility location where considerable limitations exist.

Single facility layout, analogous to warehouse or plant location, can be defined as the location of one new facility with respect to an existing set of facilities. Initial solution approaches, examining the straight line distance case, utilised semi-mathematical electrical or mechanical analogues, some of which were capable of including a limited amount of non-linear movement. Bindschedler and Moore (9) extended mathematically the analogue concept to produce iso-cost or level curves representing levels of cost in a similar manner to height levels on a contour map. Developing the concept for both straight line and Euclidean distances Moore and Mariner (46) computerised the technique to enable calculation of values for weighted distance cases. Although not directly a mathematical placement method, iso-cost diagrams enable easy selection of low cost sites and are particularly useful where the minimal position is not feasable. The mathematical determination of the optimal position using Euclidean distances was formulated by Francis (19) who extended the proof to the two facility case and the determination of the slope of the level curve at a given point.

The location of more than one facility with respect to existing facilities has led to a number of mathematical formulations, in particular those of Francis (20), Cabot, Francis and Stary (12), Wesolowsky and Love (62), Love and Kraemer (38), and Seppala (57). Two cases of multi-facility layout problem exist. Where there is no relationship between new facilities then the problem takes on a linear appearance and may be solved optimally. In the case of relationships existing between new facilities the problem takes on a quadratic appearance where solution is more difficult as shown in the following example.

Wesolowsky and Love, discussing their optimal method determined the number of restraints required as:

$$n(2m+n-1)$$

and the number of linear variables to be:

$$4mn+2n^2$$

where m = number of existing machines

n = number of new machines.

For a problem involving thirty existing and ten new machines mathematical solutions by this technique would involve consideration of 690 restraints and 1400 equations, a task that is too time consuming for even a computer.

Clearly whilst the optimal location of one single facility is possible by mathematical techniques the computation involved grows exponentially with increasing numbers of facilities having a quadratic relationship, ruling out their use for realistic size problems. In addition the representation of facilities by a set of points will require considerable adjustment of layouts to suit the practical requirements of workcentres or departments. Wesolowsky and Love indicated that new facilities were frequently located on top of existing machines using the solution method described.

In general both schematic and mathematical techniques have proved to be limited to problems with small numbers of facilities, mathematical techniques by virtue of the high computational cost and schematic techniques, as discussed by El-Rayah and Hollier (18), because of the trial and error procedure adopted.

2.3. Computerised Layout Programs

Because of the need to manipulate considerable amounts of layout information and the extensive number of calculations necessary for the quantitative evaluation of layout designs increasing interest has been shown in the use of computers for plant layout. This interest, as shown by Moore (45) has come from a variety of disciplines, each examining facility layout problems from alternative perspectives.

Within the confines of examining those programs of possible use for the layout of a job shop area on a quantitative basis, an important question has to be answered:

> "Are present quantitative programs
> of use for practical problems, and
> if not how might they be improved

by experience gained from alternative layout perspectives?"

Moore's review concluded that much work remains in improving the computers ability to evaluate solutions with an eye towards the practical problems. This usefulness is affected by four areas of program construction:

1. The representation of facilities and layout area
2. The ability to take into account subjective factors
3. The evaluation criteria
4. The heuristic technique employed in the program.

An examination of a number of quantitative programs, listed in Table 1. will show the influence of these four areas.

The representation of facilities and layout area

The physical requirements of facilities, in the form of shape and size, and layout areas are the major non-linear influence on the facility layout problem and affect the extent of modification required to change computer designs into practical layout plans. The type of physical representation adopted by a program will determine the level of problem that can be examined, the number of calculations required to locate and check facilities, the

PROGRAM	INTRODUCTION DATE	MAXIMUM FACILITIES	REFERENCE
CRAFT	1961	40	(6) (7) (61)
WHITEHEAD AND ELDARS * +	1964	55^{θ}	(1) (52) (63)
ALDEP	1966	63	(56)
CORELAP ++	1966	45	(33) (44)
HINTZMAN *	1967	11^{θ}	(22)
RMA COMP1	1970	50	(49)
SPLAF(LSP)	1970	50	(64) (65)
PLANET	1972	99	(4) (5)
MUSTLAP	1972	122^{θ}	(41) (42) (55)
PLANT	1972	40	(40)
PREP	1973	99	(3)

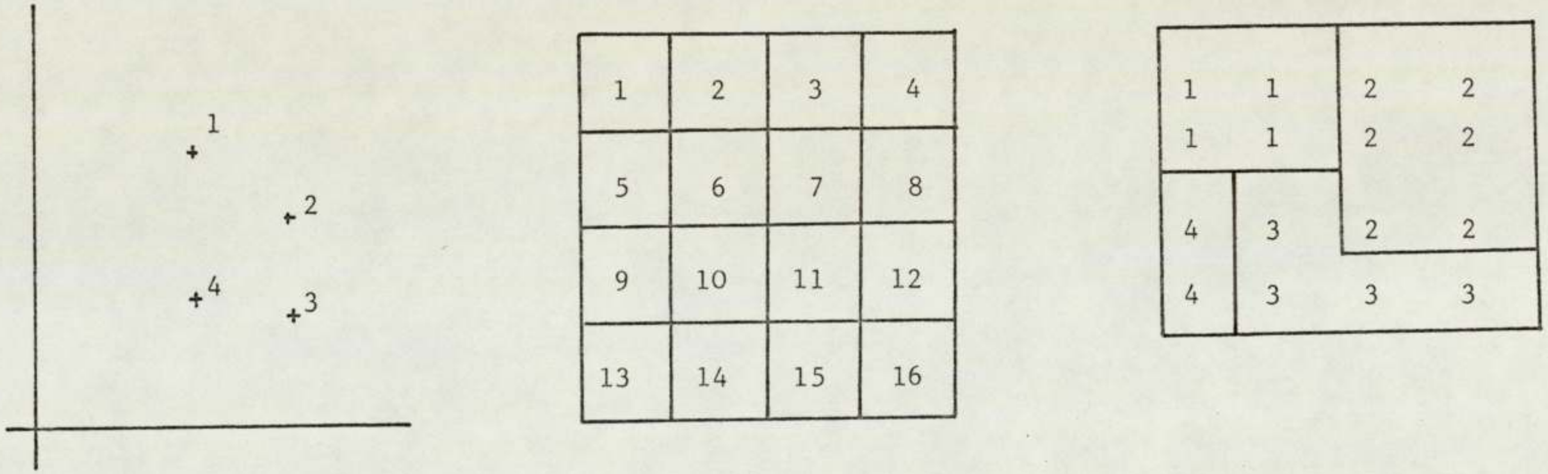
+	Revised 1970	*	Authors name
++	Revised 1971	θ	Largest known example

TABLE 1 QUANTITATIVE LAYOUT PROGRAMS

type of computer hardware peripherals required and construction of software programs.

Table 2. and Figure 3. illustrate the three forms of representation in use with the majority of quantitative programs. Point representation has been utilised by Hintzman (22) to locate facilities within feasible areas. The use of point representation neglects the physical shape and size of facilities completely and therefore potentially requires the greatest subsequent modification. Unit area representation in a similar manner ignores practical facility requirements and is utilised on the basis that each facility can be placed in each unit area. Using unit areas reduces the problem to one similar to an allocation problem, where facilities have to be allocated to known locations. Unit areas potentially are wasteful in shape, requiring block units equal in size to the largest facility. PLANT partially overcame this limitation by using very high relationship values to attract together groups of unit blocks to form proportional block areas, the most frequently used type of representation.

This combination of a matrix representing the layout area and proportional blocks of matrix locations has been used in the initial program CRAFT through to the program PREP with a number of modifications depending upon the problem formulation. Programs designed for layout without building restrictions utilise a large matrix, for example



a) Point Representation

b) Unit Area Representation

c) Proportional Block Area Representation

FIG 3 ILLUSTRATION OF COMPUTER FACILITY REPRESENTATION

PROGRAM	AREA REPRESENTATION	FACILITY REPRESENTATION
CRAFT	MATRIX	PBA
WHITEHEAD AND ELDARS	MATRIX	PBA
ALDEP	MATRIX	PBA
CORELAP	MATRIX	PBA
HINTZMAN	CO-ORDINATE	POINT
RMA COMP1	MATRIX	SQUARE PBA
SPLAF(LSP)	MATRIX	PBA
PLANET	MATRIX	PBA
MUSTLAP	MATRIX	RECTANGULAR PBA
PLANT	MATRIX	UNIT AREA
PREP	MATRIX	PBA

PBA Proportional block area

TABLE 2 PROGRAM AREA AND FACILITY REPRESENTATION

PLANET has a matrix large enough not to interfere with the possible boundaries of each layout problem. A rectangular building can be introduced by limiting the matrix dimensions as in CRAFT and further modification to the outline can be achieved by the use of dummy fixed facilities as used in SPLAF or ALDEP.

Within these areas has to be arranged the total number of facility blocks. CRAFT, which starts with an initial layout and exchanges pairs of facilities showed a clear tendency for block areas to change shape on exchange and in some cases to assume impractical outlines. SPLAF and PLANET both used special techniques to limit unreasonable shapes, SPLAF utilised an oscillating method and PLANET made use of a spiral technique. Whilst the shape of facilities obtained from PLANET were reasonable, due to the unrestricted perimeter area available SPLAF facilities still leave room for improvement.

At this stage an important distinction becomes clear regarding the usefulness of the majority of layout programs using matrix representation. Whilst these programs are useful for the layout of departments within a factory, their inability to maintain a fixed shape and the restriction of orthogonal placing raises a serious doubt as to their usefulness for the layout of workcentres within a department.

The set of programs based upon MUSTLAP have potentially the most advanced matrix system. Facilities are represented by proportional rectangular blocks where the shape is fixed. In addition the layout area, although still a matrix system, can include non-production areas and a traffic system with directional flow.

Eastman (17) however casts a doubt on the usefulness of a representation based upon a simple array:

> "The limitations of the array are self evident. Its dimensional accuracy is determined by the size of the domain. Greater accuracy requires more domains in the representation and thus increases memory requirements. As operations must act on one domain at a time any increase in accuracy requires a large increase in computing time. Also all domains must be of square or rectangular shape. Thus irregular forms can only be approximated."

To a certain extent the use of matrix representation is related to the historical development of computer systems. Early computers utilised line printers as the main output device on which matrix diagrams could be easily reproduced. The introduction of graph plotters required time consuming off-line operation, reducing the speed with which results could be obtained. Only two computer programs, CDULP (28) and ALDEP have made direct use of graph plotting devices and the appropriate drawing programs have been written for data presentation only.

Contrast the use of block diagrams with recent advances in architectural design. Whilst architectural programs are concerned more with aesthetic factors than with quantitative analysis a quick responding, highly accurate representation has been achieved by the use of visual display units linked to the computer. Amongst computer graphic techniques are IMAGE (29), SOMI (2), the COMPROPLAN (32) set of programs and programs developed at the Computer Aided Design Centre, Cambridge (34).

The use of visual display devices, an example of which is illustrated in Figure 4. is now a well tried and tested technique, with commercially maintained programs available from leading computer companies. A potential area for advancing quantitative layout programs lies in the use of these devices to replace present limited block diagrams. Apart from the necessary changes regarding equipment this would allow the use of an accurate contour representation, necessary for the layout of workcentres in a job shop situation, and for the inclusion of columns, traffic routes, offices and workcentres at any orientation. If the intention is to propose the eventual development of such a

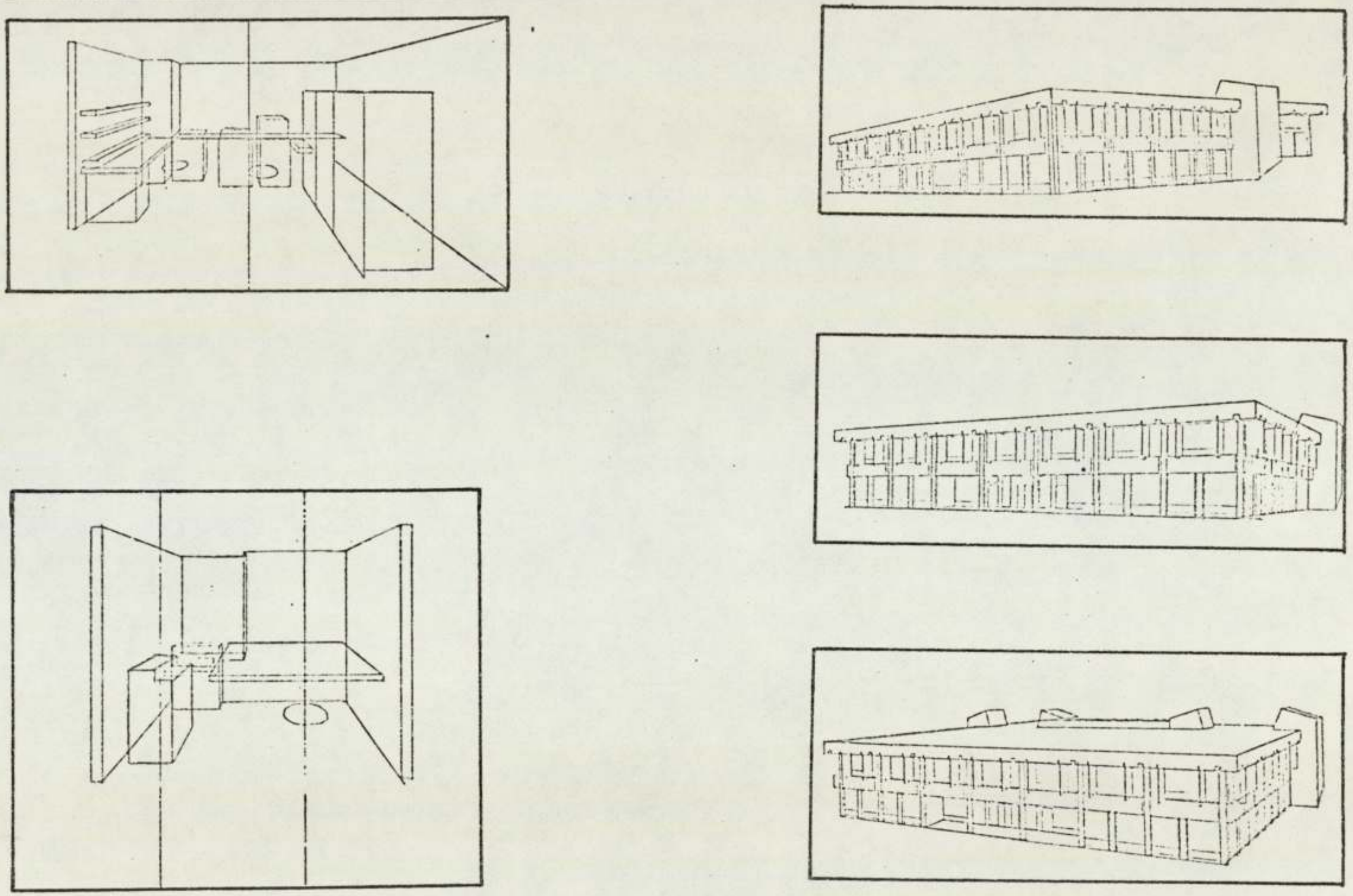


FIG 4 ILLUSTRATION OF VISUAL DISPLAY IMAGES

(After Stewart Teicholz Lee)

system, as is the case within this research, then the use of a contour or outline representation should be adopted. The effect of a more complex but accurate representation on layout heuristics and computation levels will be discussed at a later stage.

Subjective factors

The ill-structured nature of the job shop layout problem, with the need to consider both subjective factors and quantitative analysis, places an important emphasis on the relationship between designer and computer program. No present computer program is capable of producing final layout designs without this relationship, which is achieved in one of two ways:

1. Manipulating input data and examining program outputs
2. Interactively during the design process.

The first of these two approaches, of which CRAFT and ALDEP are examples, is based upon a "black box" principle with problem information entered at one end and layout solutions resulting at the other. Subjective consideration is given by adjusting the input information and re-running the program or by directly modifying a solution. Using this approach however has a number of limitations. Firstly, in a complex problem it is necessary for the designer not only to obtain a solution layout, but also to understand how the solution is obtained in order that the problem be fully understood. Because of the variation in potential problems, using such a rigid solution technique may not yield the best possible layout answer. Secondly where a change has to be made in say the location of a facility this change should be made at the time of allocating the facility in question, rather than at the beginning or end of a solution run on the computer.

In order to obtain a better control over the program technique a number of interactive layout programs have been developed, including PREP, PLANT and a modified version of CORELAP (CORELAP 8). Interactive programs have a greater potential use to layout engineers than more rigid programs. With the designer able to make changes at the time they are required, the amount of eventual layout modification must be reduced and the final layout design will have been produced under the constant supervision of the design team, an advantage in making computer layout programs acceptable to management. Moore (45) summarises the usefulness of an interactive program by saying:

> "This capability permits the user to interrupt during execution of the program to assist the heuristic with counsel and advice. It is these interactive programs which permit the complementary talents of man and the computer to assist one another."

Evaluation criteria

With any problem it is necessary to define the criteria by which alternative solutions can be comparatively evaluated. In manufacturing layout problems the most common criteria are materials movement and closeness desirability.

Materials movement is defined as the sum of the weighted movement distances i.e.

$$\sum_{i=1}^{n} \sum_{j=1}^{n} D_{ij} W_{ij}$$

Where n = number of facilities

D_{ij} = distance from facility i to facility j

W_{ij} = weighted movement from facility i to facility j.

In an industrial problem the movement will relate to the production program but in a more general formulation of the problem this movement could relate to the processing of paperwork or the activity of staff, as used in the design of hospital suites. Weighting in its simplest form may be the number of batches to be moved, as used for example in CRAFT, or may be translated by multiplying by relevant constants into a financial cost per unit distance. The distance used is defined as either the straight line distance from facility centroid to facility centroid or the equivalent Cartesian distance on the basis that

Cartesian distances approximated movement along aisles or traffic systems.

A number of points concerning materials movement as a criterion are however open to discussion. This discussion is related to both the concept of materials movement as a criterion and to the technical details of the weighted models used. Firstly the examination of any layout problem is in practice a prediction of future or revised events and consequently in the eventual real situation when the layout becomes operational materials movement is susceptible to possible deviation. In the job shop case particularly, with the complex movement patterns involved, product movement may not move as predicted and in addition the correct materials movement equipment may not be used. In using materials movement as a criterion it is therefore necessary to be confident that the eventual layout will behave as predicted.

Technical criticisms of present movement models relate to determining the actual distance and to the directly proportional weighting factors. In a realistic situation the cost of moving a production batch consists of a fixed cost for raising and lowering a load and a variable cost proportional to distance, with a gradient related to the type of movement equipment. Over a long distance this added non-linearity may be insignificant but in the case of a job shop, where distances are relatively shorter, neglecting this fixed cost may introduce significant errors. The assumption that either straight line distances or Cartesian distances represent actual distances is largely applicable for the layout of departments. At the job shop level movements encounter a large number of obstructions and routing problems; potential sources of error. A balance however has to be achieved between accuracy and computational cost for evaluating layouts involves a large number of calculations, a relationship that is examined further for the evaluation model used in this research.

Whilst however these criticisims of a strictly linear weighted distance criterion exist one important factor makes materials movement the most useful of the criteria so far developed. Using an evaluation criterion that is proportional to distance enables layout changes to be reflected in the value of materials movement. In any problem the more non-linear the relationship between decisions and resulting values the more difficult it becomes to propose better solutions.

The alternative approach to materials movement is closeness desirability. Developed originally by Muther (47), closeness desirability is a subjective expression of how close one facility is required to another. These ratings which range from absolutely necessary to undesirable have been used in some form in ALDEP, CORELAP, RMA COMP1 and the early program of Whitehead and Eldars. The normal process for using closeness desirability consisted of searching each perimeter for immediate neighbours and where two were found the closeness rating was added to the total score. The difficulty of using this technique in a job shop situation where immediate neighbours may not be in close contact, and where in a realistic problem closeness desirability influences which spread over more than close neighbours can be altered by inexpensive barriers has already been discussed. Further to this the use of closeness desirability suffers from two drawbacks. Firstly even with the use of numerical values instead of alphabetical characters the criterion is still essentially qualitative and is concerned more with the subjective requirements of a layout than with quantitative analysis. Secondly, in an industrial environment where cost is important closeness desirability suffers from the limitation that it is not possible to convert ratings to financial terms. For these reasons charts based on closeness desirability are potentially more useful as a means of storing subjective decisions than as a basis for layout evaluation.

Heuristic technique

The basic component of each layout program is the technique on which layout designs are produced. Because of the complex nature of plant layout problems these techniques are heuristic in nature and fall into two groups, improvement programs and construction programs. Improvement programs interchange facilities in an existing layout to improve criteria values, whilst construction programs which are generally for new layout designs place facilities on the layout area in a selected order.

Heuristics for improvement programs generally involve evaluating the best possible exchange according to a definite rule. For example CRAFT considers all pairs of neighbouring facilities and selects the exchange which will give the highest saving. A number of modifications including exchanging any pair of facilities and exchanging sets of three or more facilities has been examined on a simplified fixed location problem and a useful modification to the original CRAFT procedure has been introduced by Hitchings (24) (25). Called Terminal Sampling Procedure (TSP) this modification proved computationally more efficient than the original CRAFT system by the use of bias sampling to detect dominant relationships.

Construction program heuristics have developed along two lines, one group concerned with placing facilities one at a time in a manner similar to the growth of a crystal, and a second group which constructs the entire plan in one attempt and the resulting arrangement is then moulded to suit practical requirements. PLANET is an example of the first group where facilities are selected in order of any of three heuristics and placed at the minimal position on the outline. A useful heuristic in this connection is the biased sampling approach, used by ALDEP, SPLAF (LSP) and Terminal Sampling Procedure.

The second group is illustrated by RMA COMP1 where firstly a small matrix of facility centres are developed, then expanded to allow proportional block areas which are later moulded to the layout problem. An interesting development in this field is the use of graph theory to design layouts. Seppanen and Moore (58) illustrated the approach where facilities are represented by nodes and relationships by branches, developing a heuristic based upon the spanning tree and using closeness desirability as a criterion. At present graph theory techniques become complex to handle with larger numbers of relationships in a similar manner to early schematic methods and are subject to a degree of variation at the point where graphs are converted to drawings. Carrie (14) using a graph theory approach utilised proportional area circles to represent a machine tools shape and area requirement to reduce this variability in the graph to drawing stage. In computer program form an extensive use of graph theory has been made by Krejcirik (30), where in a slightly restricted problem formulation with the objective of finding the optimal arrangement of facilities along a communication corridor graph theory is used under a number of layout conditions.

Examining the merits of individual layout heuristics is made difficult by their dependence upon varying physical representations and individual progam constructions. In addition test cases may be affected by the question of flow dominance within the product data. Vollman (61) maintained that in the case of highly dominant flow involving small problems common sense results could be as good as those obtained by CRAFT. The effect of dominance on layout cost and layout improvement has yet to be examined in greater detail.

The review so far has dealt with the development of layout techniques for solving an essentially "static" formulation of the problem. Before discussing the dynamic aspects of layout projects a number of important conclusions can be drawn from present approaches:

1. Solving practical layout problems requires consideration of both quantitative and subjective factors.
2. The usefulness of schematic techniques and mathematical optimisation approaches are limited by the size of problem they can handle.
3. The use of computerised heuristics presents the best basis for solving layout problems, combining the computational abilities of computers with the reduced extent of search inherent in heuristic methods.
4. Present computer programs for quantitative examination of the layout of facilities are restricted by poor physical representation. Advances in the use of computer graphics, most noticeable in architectural design programs, present an area for improvement particularly with regard to the more rigid requirements in the layout of workcentres

in a job shop.

5. The use of a single criterion for layout of facilities by present quantitative programs does not adequately reflect the requirements of the manufacturing system as a whole. The minimisation of materials movement for example may increase production control costs by a greater amount than any movement savings. In a job shop situation this is particularly true and may therefore require modification of present criteria.

2.4. Dynamic Plant Layout

Within the wide range of possible facility layout problems the dynamic examination of plant layout designs has received relatively little attention. The predominant formulation of facility layout problems on a "static" basis requires the acceptance of a number of assumptions that in reality may not be true. In particular assumptions regarding the benefits to be obtained from individual layout designs require further investigation.

A number of aspects of the operation of manufacturing systems have been examined on a dynamic basis either by detailed simulation of individual industrial cases or by the more general simulation of particular system functions, for example scheduling rules in job shop manufacture. Whilst however simulation methods are now well established few applications of these techniques for examining the actual implementation of layout changes and the consequent effect of this change on layout criteria exist.

Discussing dynamic layout changes from a point of view of determining when layout arrangements become redundant, Hitchings (23) stated that layout changes occur in three distinct ways:

1. Complete replacement of a layout in one attempt
2. The partial relayout of a section of the manufacturing area at a time.
3. A completely phased relayout, removing individual items to minimise disruption.

In an industrial test case the difference between these three types of change may be difficult to detect and may in practice change from one type to another in any one project. The three types are an expression of the rate at which a layout change is implemented, a rate which is subject not only to variation but also may in any one case be suspended for a number of periods throughout a project life span. As a result of this wide variety of possible layout changes a simulation model approach for examining the dynamic layout changeover would help evaluate layout decisions.

A problem exists however in determining and quantifying the cost involved in making layout changes. The mathematical model developed by Hitchings involved five costs determined on a daily rate basis; overhead charges, hire charges, lost productive labour charges, the cost of effecting changes and the cost of lost production. As a result of the generally limited state of industrial information however determining costs on a daily basis may not be possible with any degree of accuracy, a problem generally encountered with detailed models of manufacturing situations.

The objective of Hitchings model was to provide a means of assessing on a continuous basis the efficiency of a layout design. Where the problem is defined as determining the financial return on a projected layout change for a given life span, then daily costs can be replaced where required by more accurate lump sum values allowing the relationship between layout design benefits and layout changeover costs to be examined under a variety of conditions.

Clearly whilst static problem formulations have received considerable attention, examining dynamic changeover has not, and there exists the need to develop a philosophy linking the two. Moore (45) discussing this relationship states:

> "Relatively little work has been done on the relayout of an existing facility. It would be extremely useful to have computer aids to examine the inefficiencies of

> existing layouts. Such a program would need to examine the cost of moving and installation, recommend what machines should be moved, and where machines should be moved, and what machines should not be moved. This would be an extremely useful program. To the best of this writers knowledge, no such program exists."

Within this thesis one such philosophy is developed with regard to a job shop situation and subsequently tested on an illustrative example.

3. THE JOB SHOP LAYOUT PROBLEM

- A TWO STAGE PHILOSOPHY

The approach adopted for the examination of job shop layout problems has been developed from a number of important observations discussed in the review of techniques and summarised in the following points:

1. The large variation in individual job shop problems and the combined influence of quantitative and qualitative factors suggest that an interactive technique, designed to assist the layout designer on a quantitative basis is potentially more useful than a rigid solution procedure.
2. The actual layout arrangement of workcentres is influenced by the requirements of the manufacturing system, in particular with regard to production control and work scheduling. In consequence the use of one single objective alone, for example materials movement, may result in an overall loss of efficiency rather than an improvement.
3. The benefits obtained from a layout design are related to the dynamic life span of the project and the static layout arrangement. Benefits obtained from an improved arrangement may be reduced or lost by the manner in which the changeover occurs.
4. The large quantity of data and calculations

involved in assessing plant layout problems necessitate the use of computers. Recent advances in computer equipment and software programs have yet to be fully utilised by industrial engineers examining quantitative layout problems.

In order to present a useful extension into job shop design encompassing these points an interactive-heuristic approach has been developed to examine three independent but related problems:

1. Static layout design
2. Dynamic layout changeover
3. The development of a computer system for the above models.

The static layout design stage and the subsequent modelling of various layout changeovers form a natural continuation of investigation which can utilise the same basic information structure on a progressive basis from one stage to the next. This logical extension of static layout design using a computerised approach firstly creates a new layout arrangement and then examines how this design may be introduced and the effect of the introduction procedure on the results claimed for the design.

Investigating the rearrangement of an existing job shop employing a discrete materials movement policy i.e. movement in batches by the use of hand or powered trucks which is the most common form of movement in a job shop, the relocation problem involves three major variables, the existing layout area termed job shop, the facilities which have to be reorganised within this area and which are termed workcentres and the production program which indicates the dynamic manufacturing output that will take place within the layout area.

Job shop, workcentres and production program

Figure 5. illustrates a representative job shop area. Each job shop is defined as a combination of three factors, the job shop outline, non-participation areas and the traffic system.

The outline forms the boundary of the problem within which all workcentres have to be located. This outline is not necessarily of a fixed geometric shape and will consist of a series of boundary lines determined by a combination of building constraints and area requirements. The continuous area formed by this boundary must be sufficient to enable the rearrangement of workcentres. The ratio of total workcentre area to the nett layout area available is an early indicator of the potential complexity of a problem. A high ratio indicates that more difficulty will be encountered with placing workcentres in the restricted area and the subsequent relocation of facilities will require consideration of the availability of final locations. In practice, whilst there is no theoretical limitation on the job shop outline, the boundary of the layout area will conform to the

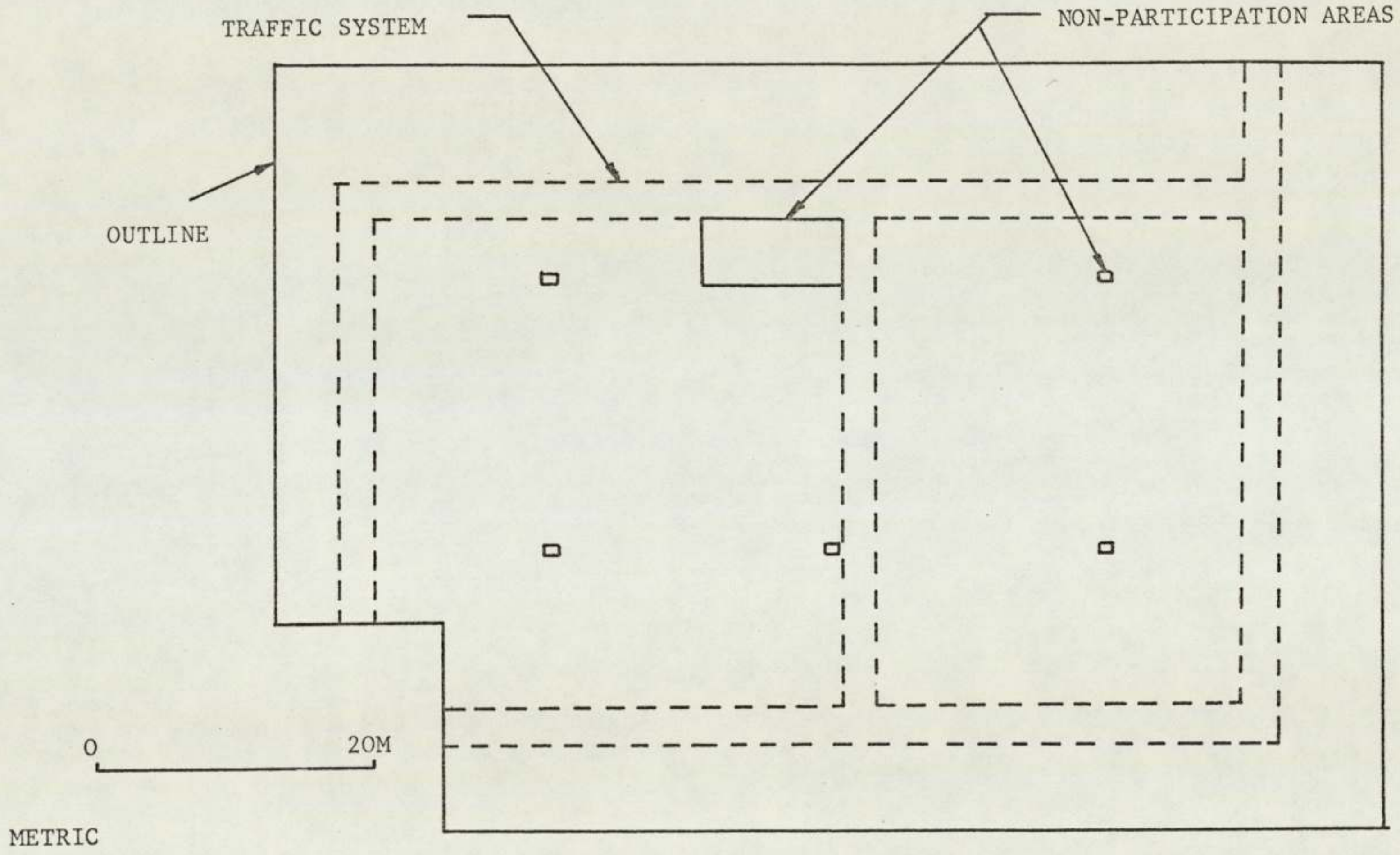


FIG 5 ILLUSTRATION JOB SHOP AREA

practical requirements of a manufacturing environment.

Non-participation areas represent the main internal obstructions found within job shop areas and include columns, lift shafts, offices and space allocated to workcentres unrelated to the project under consideration. The influence of non-participation areas is two fold. Firstly the nett layout area available for workcentre layout is reduced and secondly the amount of calculation involved in placing workcentres is increased. The fixed nature of the shape and size of a workcentre combined with the variety of possible non-participation shapes requires extensive calculation to detect interference.

The relationship between outline and non-participation areas has to be carefully examined in each test case for it is possible to isolate a section of the job shop by the use of non-participation areas. To avoid the possibility of this occurring those non-participation areas close to the outline are merged with the perimeter to present a modified problem outline. In a similar manner non-participation areas in close proximity to each other are merged.

Traffic systems exist in all organised manufacturing areas where the discrete movement of product batches takes place. The most common form is a series of connected aisles laid aside for movement of personnel and products without restriction on route or direction. The design of a traffic system however is partially a function of the location of the workcentres the system serves and therefore a prefixed traffic system may to some extent prejudge a layout solution. To allow for this the design procedure proposed allows for either a predesigned traffic network or the gradual introduction of aisles by repetetive design attempts. Where a traffic system is included however the effect is to reduce the nett area available and to increase the number of positional checks for new workcentre locations as with non-participation areas.

Each individual job shop layout problem therefore is considered to be the layout of workcentres in an area determined by a potentially irregular outline and inside of which there may be both a traffic system and a set of non-participation areas.

This job shop specification is an attempt to reflect more realistically the type of area that would be encountered in a practical problem. In common with other representations used in quantitative layout techniques this representation considers the actual space available to be uniform in nature. The assumption is made that workcentres can be placed in any available location, and that the influence of height restrictions, service facilities, foundations and other factors remain equal throughout the area. With the use of an interactive design procedure there remains however the option to overrule impractical decisions.

Within the layout area has to be placed the workcentres, a term used to describe those facilities specified in the movement sequences of each product listed in the production program. Two types of workcentre are used within this definition, one type based upon the conventional machine tool and a second "dummy" type used to represent unusual points in the product movement sequence.

The conventional workcentre, illustrated in Figure 6. includes a machine tool, work in progress and space for operator and maintenance. Whilst there exists a small degree of flexibility within the resulting shape the convention has been adopted that shapes are rigid and that no other facility or obstruction can be accommodated within the shape.

Dummy workcentres are used to represent points in the production sequence that are not actual production machine tools, for example the points of interchange with the remainder of the factory i.e. the positions at which products enter or leave the job shop area. Alternatively dummy workcentres can be used to represent the entry point to internal storage areas. Where dummy workcentres are required in a project a small radius circle is placed at the appropriate point.

Finally the production program is the third major variable within the job shop layout situation. The production represents the expected dynamic manufacturing activity that will occur during each time period on an averaged basis, as discussed in earlier chapters. This program is based upon

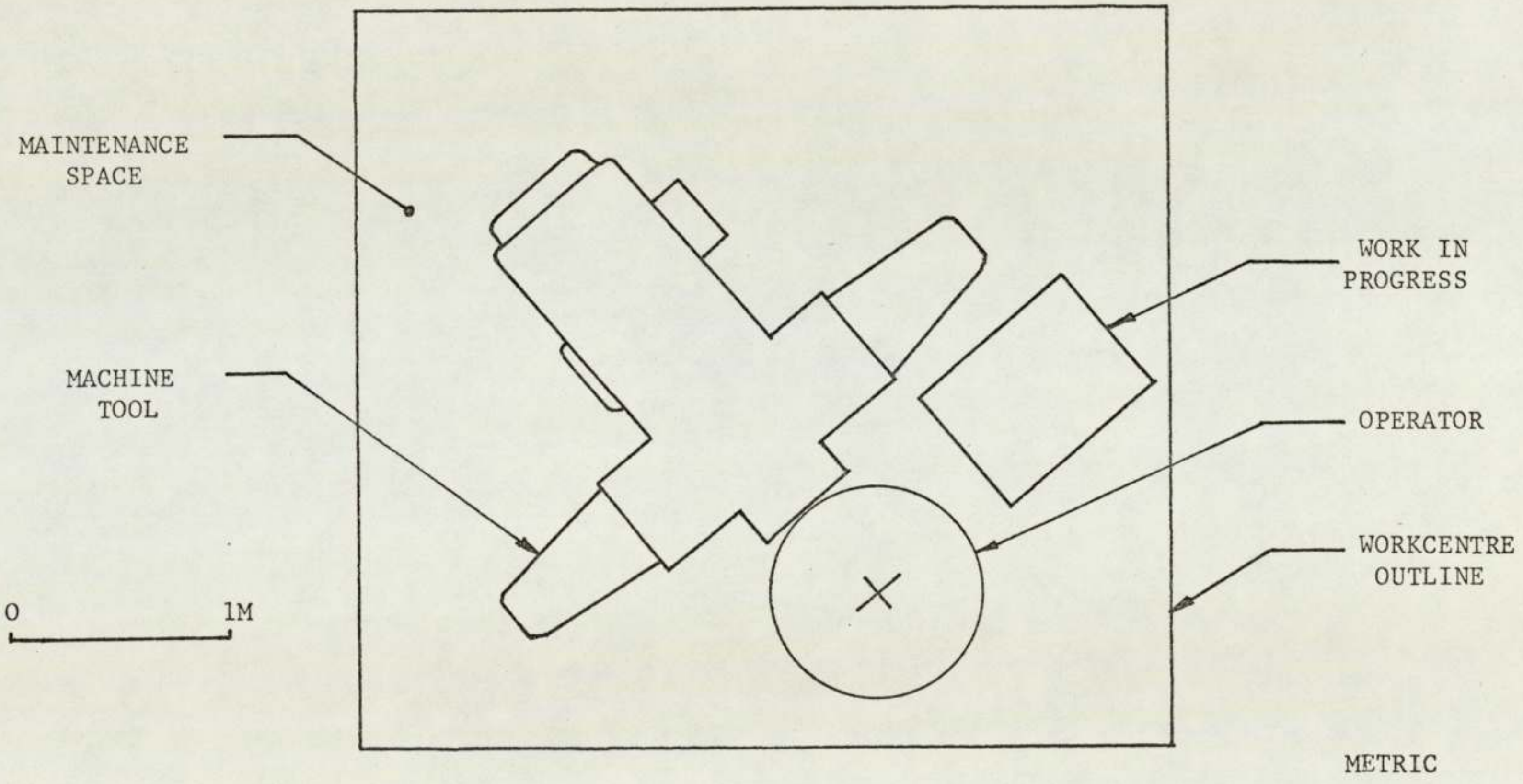


FIG 6 ILLUSTRATION WORKCENTRE LAYOUT

forecasts derived from present or projected output and job allocations determined to meet the requirement of production efficiency.

The role of plant layout as part of the overall manufacturing system is a point worthy of emphasis. Layout area, workcentres and production program have to be determined before the layout project begins as part of the manufacturing system design and will therefore influence layout problems. At the job shop level further restrictions exist on the number of possible workcentre arrangements, restrictions resulting from the need to organise production in an efficient manner. The result of manufacturing system considerations therefore is to raise questions about the suitability of using one single criterion in isolation to determine layout arrangements.

Continuing from this point the two design stages of static layout arrangement and dynamic layout changeover along with the design of a computer system to encompass these models are examined in the light of practical job shop requirements. Using a combination of materials movement and workcentre relocation costs as quantitative criteria two interactive, heuristic procedures will be proposed and investigated.

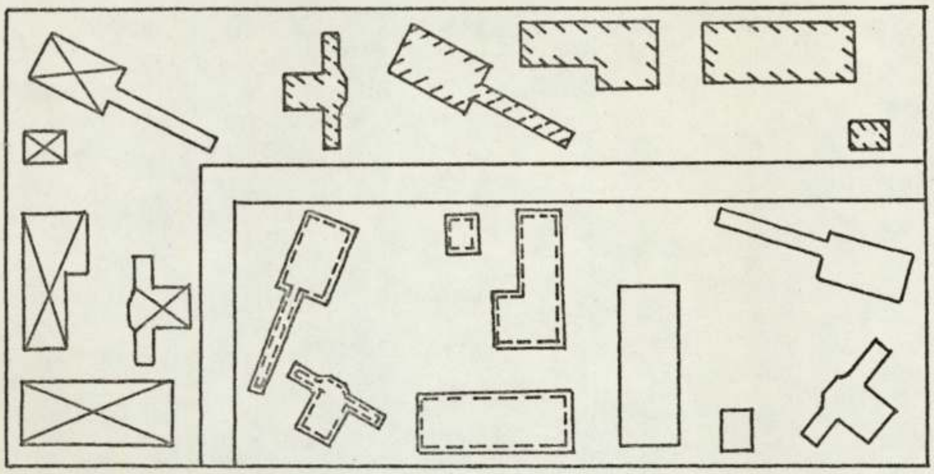
4. STATIC LAYOUT DESIGN

The initial stage in the reorganisation of a manufacturing job shop and the subsequent examination of the effects of this reorganisation is to create a new layout design to suit the requirements of the production program using a quantitative layout criterion.

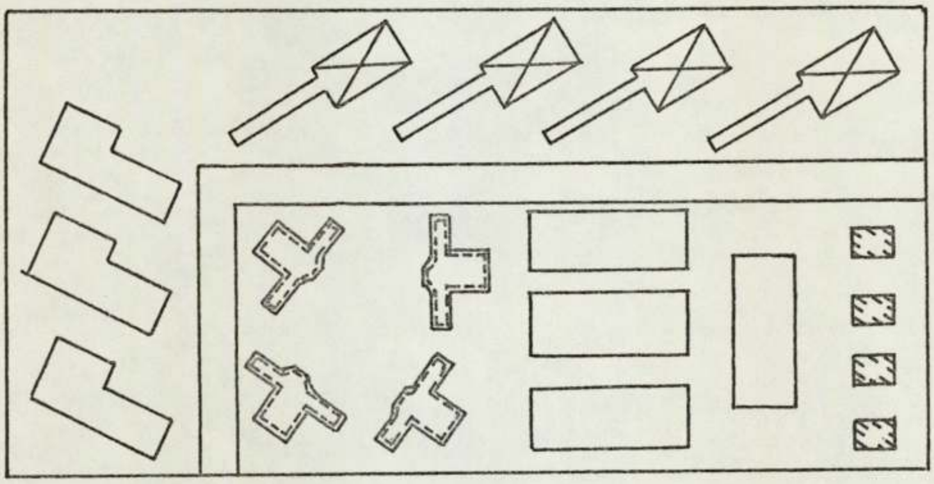
The most useful criterion available for determining the relative arrangement of facilities is materials movement cost because of the relationship between facility positions and materials movement distances. For this reason the minimisation of materials movement has been adopted as the objective in the static design stage with one important modification, necessary in practical layout situations at the job shop level.

This modification is concerned with the need to maintain organised control over the complex manufacturing nature of the job shop during its life span, achieved by the pregrouping of workcentres. The reasons for pregrouping workcentres can be illustrated by examing the three fundamental types of layout design - group technology layout, process layout and product layout as shown in Figure 7.

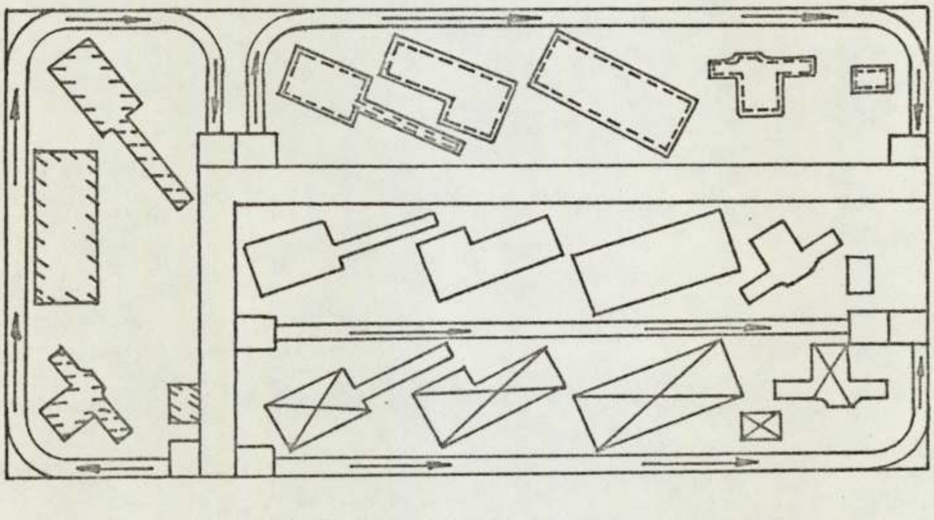
The strongest case for pregrouping workcentres is derived from group technology concepts and is related to production scheduling and organisation. Based upon an analysis of the manufacturing program by the use of a classification



(A) GROUP TECHNOLOGY LAYOUT



(B) PROCESS LAYOUT



(C) PRODUCT LAYOUT

FIG 7. ILLUSTRATION OF PREGROUPED WORKCENTRES system (51) or production flow analysis (11) to detect component or manufacturing similarities, a set of cells, each cell containing a number of workcentres some of which may be the same and together capable of producing a family or range of components,is derived. The result is normally an improvement in work in progress levels, machine setting times, machine efficiency, labour utilisation and throughput time. With the clearly defined independent production groups an effective control over manufacture is obtained as a result of the self disciplinary nature of group technology cells and the reduced amount of progressive work movement required.

Pregrouping also exists in process layouts, where groups are selected on a basis of workcentre function. Within a process layout products are organised to move through the production area according to manufacturing requirements with effective production control being based upon the groups of similar workcentres. The major drawback with process layout is the inherent time consuming routing problem of each product. In a similar manner product layout simplifies the organisation of manufacture by subdividing the total number of workcentres into groups associated with individual product ranges and uses these groups for production control.

Consider therefore the difference between the layout of departments within a factory, the problem level examined by the majority of present quantitative programs, and the layout of workcentres within a department resulting from organisational and administration requirements. In departmental arrangement the relative interaction between departments is more clearly defined by both physical and management barriers. With workcentre arrangement this interaction is more difficult to distinguish and without some form of pregrouping restriction to enable effective production control and organisation, the relative location of facilities merely to minimise a materials movement criterion will result in a considerable decline in production efficiency.

To give adequate consideration to the organisational requirements of job shop manufacture the objective of the static layout design problem has been defined as follows:

> "To determine an efficient layout of workcentres in an existing area, using materials movement cost as an initial quantitative criterion, subject to the restrictions imposed by both subjective considerations and the desire to maintain, as far as is practical, the close proximity of workcentre groups determined by the new production program."

The advantages in terms of production efficiency are sufficient to make the formation of the new workcentre cells more important than simply improving upon the materials movement cost of the initial layout. It is not necessarily the case that projects will yield a positive project return in terms of the evaluation model, for although the most efficient materials movement arrangement will be sought the cell grouping condition may result in the final layout having a greater materials movement cost than the initial layout, in the event of which the loss in terms of the layout evaluation will have to be considered against the overall project costs. Within the relocation of workcentres the following conditions apply to facilities:

1. Each workcentre must be located within the defined layout area and should not violate non-participation areas, traffic routes or workcentres already placed.
2. Each workcentre must belong to one predetermined group of facilities, referred to as workcentre cells. The term cell, adopted from group technology practice, is used to describe any general set of workcentres and is not restricted to group technology applications only.
3. Workcentres may be either fixed or movable in nature and there must exist at least one fixed workcentre in the layout. Dummy workcentres, related to specific input and output points of the job shop, facilities too expensive to move and facilities restricted by the designer, normally will provide at least one fixed workcentre.

4.1. A Model for Job Shop Rearrangement

The static layout design model presented at this point has been designed to utilise the existence of workcentre cells in a two part heuristic procedure. Initially each cell is located within the layout area using proportional circular areas to represent cells and on completion the cell diagram is then used as a basis for positioning individual workcentres. The solution procedure is not a rigid technique producing specific layout arrangements but is designed to work on an interactive-heuristic basis. The large number of possible solutions, the complex effect of physical shapes and the restrictions caused by fixed workcentres has led to the selection of a heuristic approach in common with the majority of present programs, whilst interactive capability will account for subjective considerations and reduce the amount of computation at a detailed level. The model proceeds through the following steps:

Cell layout

1. For each cell the total workcentre area, the number of fixed workcentres and the total number of workcentres is determined.
2. Using the production program a matrix of cell movement costs is compiled. The matrix values are the sum of the product quantity (batches) X variable movement cost (cost per unit distance).
3. Each cell is allocated a placement priority determined by descending values of total

external movement cost. Although not yet multiplied by the appropriate distances these cost figures represent the extent of cell interaction.

4. All cells containing workcentres that are all fixed in nature are eliminated from the placement list and the cell centre is taken as the averaged Cartesian co-ordinate of the workcentres, with the cell represented by a circle of radius $\sqrt{\text{CELL AREA /2.}}$* This operation will normally place single workcentre cells representing input and output points.
5. Select the highest priority unplaced cell that contains at least one fixed workcentre and determine the average X and Y co-ordinate value of the fixed workcentres. Represent this cell by a circle of radius $\sqrt{\text{CELL AREA /2.}}$* Where no more cells containing fixed workcentres remain go to step 10.
6. Check that the cell centre is inside the layout area and outside any traffic route or non-participation area. In addition check if the cell circle being placed overlaps any of the previously located cells. Proceed to step 8 if one of these tests fails.

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* Selected to allow workcentre adjustment in cell areas

7. If the cell location passes each test the designer is asked to approve the location. Where approval is given the cell circle is placed and the procedure returns to step 5 or 10 appropriately.
8. Where the location is not suitable then the designer is given the opportunity to change locations, the procedure giving a movement guide of cost values for each direction. For a new location change, the cell centre co-ordinates are updated and the procedure returns to step 6.
9. Where the designer decides not to move, each location radiating at two* metre intervals and forty five* degree spacing is tested up to ten* metres radius in minimum cost order. Each location that passes the positional tests of step 6 is put forward for approval by the designer and if approved the cell is placed and the procedure returns to step 5 or 10 appropriately. Should the designer not approve a location then the process continues through the forty possible locations. When these are exhausted the procedure returns to step 8, indicating that a move is essential.

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* Arbitrarily selected to limit the number of locations examined in the immediate neighbourhood area.

10. Selecting the highest priority cell containing no fixed workcentres and starting from a position outside the layout outline determine the minimal materials movement cost position between the candidate cell and those cells already placed. The case of adding one additional facility to an existing layout can be solved to give the minimal value by the use of a search technique. This position is then adopted as the cell centre and the procedure goes through steps 6 to 9 before returning. When all the cells containing no fixed workcentres have been located the quantitative cell location stage is complete.

Workcentre layout

11. On completion of the cell layout stage the next operation in the design approach is to manually place each workcentre within the cell areas as far as is practical.

This manual procedure has been adopted for the second layout stage for a number of reasons at this point in the philosophy development. Firstly the placing of individual workcentres within a cell area will have a less significant effect on materials movement cost because of the reduction in the number of possible workcentre locations achieved by the cell layout stage. In addition any procedure for locating individual workcentres will save considerable calculation requirements if the designer performs the task of checking the suitability of a particular position, especially at this detailed level. The question of which tasks can be best performed by the designer and which tasks can be best performed by heuristic procedures is discussed in greater detail in the development of a computer based system.

There is also the question of whether the small movement distances involved inside cells actually contribute to the materials movement cost. Within a job shop, particularly one producing small size components, movement over short distances may be undertaken by production operatives and will not involve materials movement personnel or equipment. The limiting distance between local movement undertaken by operatives and departmental movement undertaken by materials movement personnel is examined as a parameter in the dynamic changeover simulation.

During the static layout design stage either the straight line distance, used where no traffic system exists, or the Cartesian distance, where a traffic network has been included, is employed as an approximation to actual distances.

4.2. A Theoretical Example

To illustrate the static layout model consider the theoretical example shown in Figure 8. and Table 3. The problem starts with the initial layout and the new production program consisting of twelve products with a variable mat-

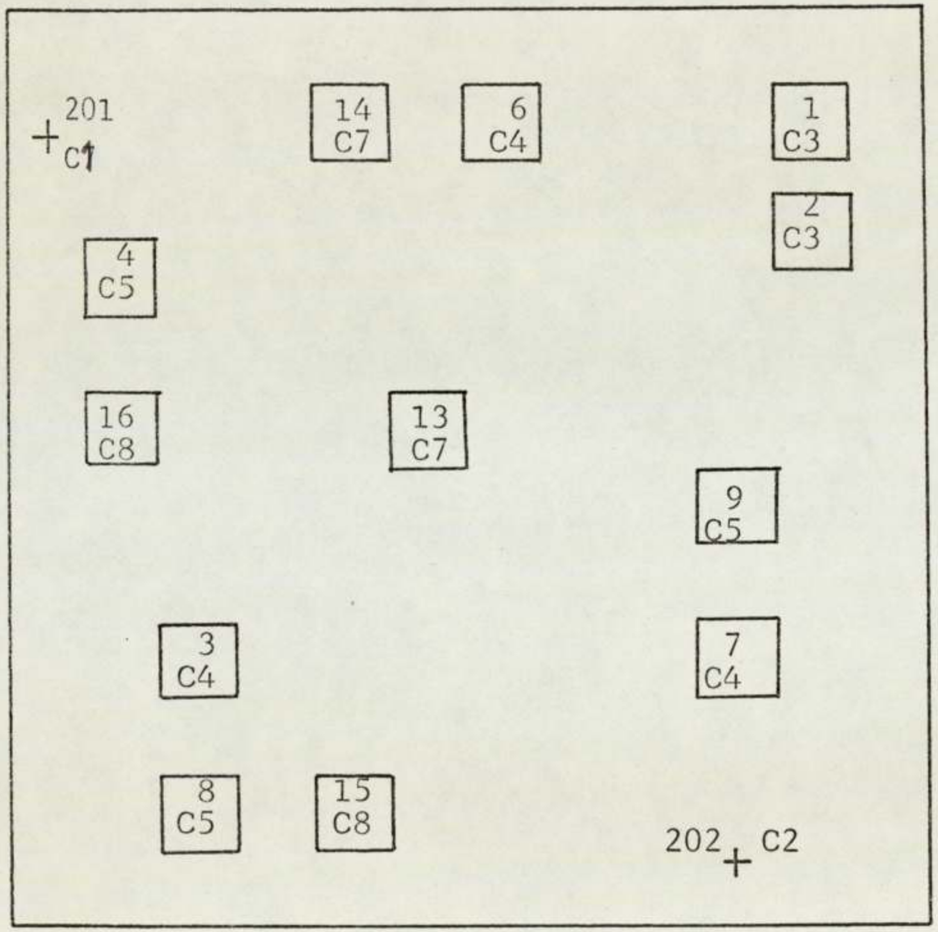


FIG 8 INITIAL LAYOUT OF STATIC DESIGN EXAMPLE

PRODUCT	BATCHES	PV	WORKCENTRE SEQUENCE
1	100	.002	201 15 16 1 202
2	120	.002	201 3 6 7 2 202
3	140	.002	201 4 8 9 202
4	60	.002	201 10 11 4 12 202
5	80	.002	201 13 14 202
6	10	.002	201 1 13 14 202
7	200	.002	201 2 12 11 10 202
8	40	.002	201 1 9 8 4 202
9	80	.002	201 2 6 7 3 202
10	200	.002	201 10 11 12 202
11	20	.002	201 13 14 202
12	20	.002	201 15 16 202

PV = Product movement cost per unit distance

TABLE 3. PRODUCTION PROGRAM FOR STATIC DESIGN EXAMPLE

0 5M

METRIC

erials movement of .002 units per batch-metre each. In addition each workcentre is preassigned to a workcentre cell for efficient machine utilisation and manufacturing production, with the cells indicated on the initial layout Figure 8.

This pregrouping of workcentres is an indication of the two directional relationship between facility layout and manufacturing system design. The forms of pregrouping have been discussed earlier in this chapter and in practice before starting a layout project manufacturing system design will have selected the workcentres on which each product is to be manufactured (product workcentre sequence) and then will have grouped these workcentres to enable more efficient production control.

The first stage, corresponding to step 2, is to calculate the cell movement matrix (Table 4) and to order each cell using decreasing external movement cost as the priority rule. To assist the cell layout heuristic the cell area, number of fixed workcentres and total number of workcentres in each cell is also calculated (Table 5).

Scanning the list of cells, cells 1 to 3 contain all fixed workcentres and therefore all these facilities will occupy the same position in the final layout as in the initial layout. Consequently these cells are placed in the diagram and the candidate table ammended (Figure 9 and Table 6). This stage corresponds to step 4 and provides the first located cells with which to calculate materials movement

	1	2	3	4	5	6	7	8	
1	-	0.00	0.66	0.24	0.28	0.52	0.20	0.24	
2	0.00	-	0.44	0.16	0.36	0.92	0.22	0.04	
3	0.66	0.44	-	0.40	0.08	0.40	0.02	0.20	
4	0.24	0.16	0.40	-	0.00	0.00	0.00	0.00	
5	0.28	0.36	0.08	0.00	-	0.24	0.00	0.00	
6	0.52	0.92	0.40	0.00	0.24	-	0.00	0.00	
7	0.20	0.22	0.02	0.00	0.00	0.00	-	0.00	
8	0.24	0.04	0.20	0.00	0.00	0.00	0.00	-	
	2.14	2.14	2.20	0.80	0.96	2.08	0.44	0.48	TOTAL
	2	3	1	6	5	4	8	7	ORDER

TABLE 4. INTER-CELL MOVEMENT COSTS AND PRIORITY

CELL	AREA	NO FXD	TOTAL NO
1	0.0	1	1
2	0.0	1	1
3	8.0	2	2
4	12.0	0	3
5	12.0	1	3
6	12.0	0	3
7	8.0	0	2
8	8.0	0	2

TABLE 5. CELL WORKCENTRE DATA

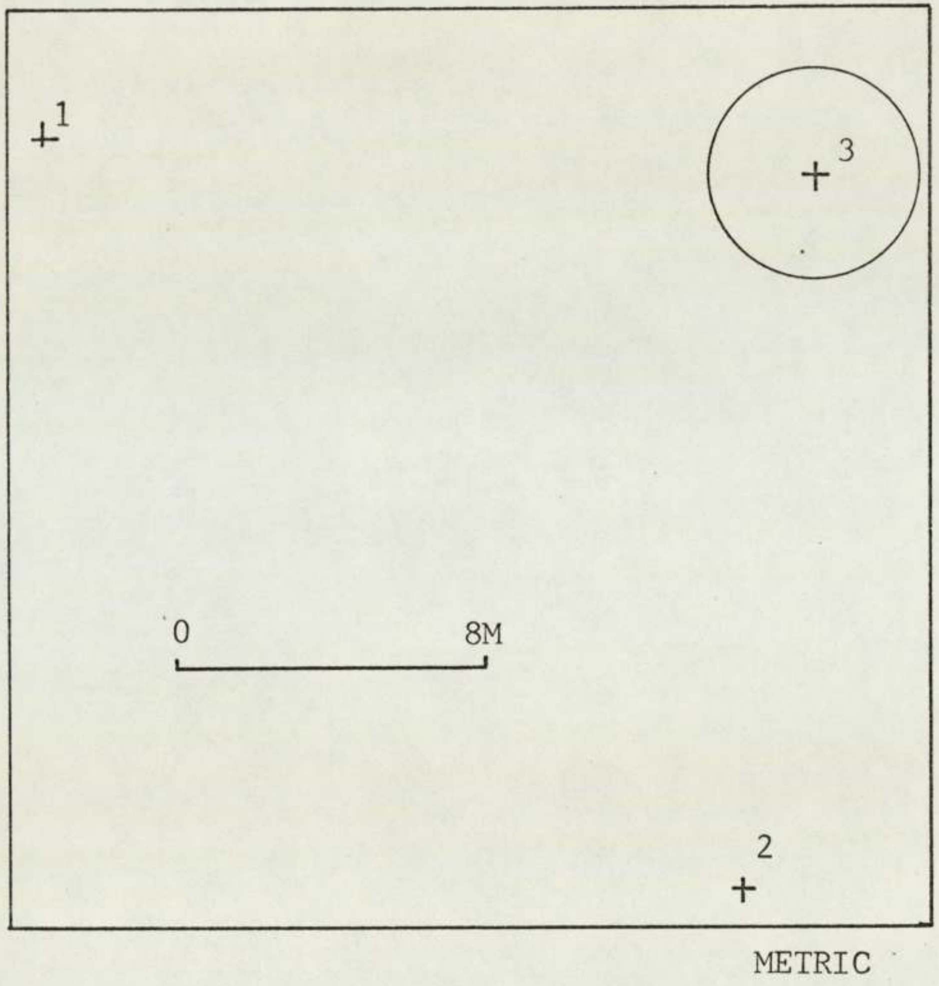


FIG 9 CELL DIAGRAM WITH TOTALLY FIXED CELLS

CELL	INITIAL STAGE	STAGE 1	STAGE 2
1	2	0	0
2	3	0	0
3	1	0	0
4	6	6	6
5	5	5	0
6	4	4	4
7	8	8	8
8	7	7	7

TABLE 6. CHANGE IN CELL PRIORITY THROUGHOUT LAYOUT

Stage 1 - After placing total fixed cells
Stage 2 - After placing part fixed cells

cost.

The next group of cells to be located are those containing at least one fixed workcentre but not in the group of completely fixed cells. Within the example cell 5 falls in this category. The cell contains one fixed workcentre and therefore the possible number of cell locations is restricted if workcentres are to be maintained in close proximity, this being the reason that cells containing a partial degree of fixed workcentres are given priority over free cells. The location for cell 5, coinciding with co-ordinates of the one fixed workcentre, does not fail any of the positional tests and therefore is placed at the fixed workcentre co-ordinates, allowing the remaining workcentres to be grouped around the fixed facility. This completes the partially fixed cells, corresponding to step 5 and the resultant layout is shown in Figure 10.

The remaining cells (cells 4,6,7 and 8) have no restrictions and are termed free cells. Considering each cell in order of priority (6,4,8 then 7) the first requirement is to find and examine the minimal cost position. A number of techniques for finding this minimum exist, the one utilised in the computer programs later developed is based upon a hill-climbing procedure. For cell 6, the first free cell to be located, the minimal position is at X=14.7 and Y=9.2 with a materials movement value of 22.8. With the position being acceptable the cell is located and the next cell, cell 4, is examined. In this case the minimal position at X=21.0

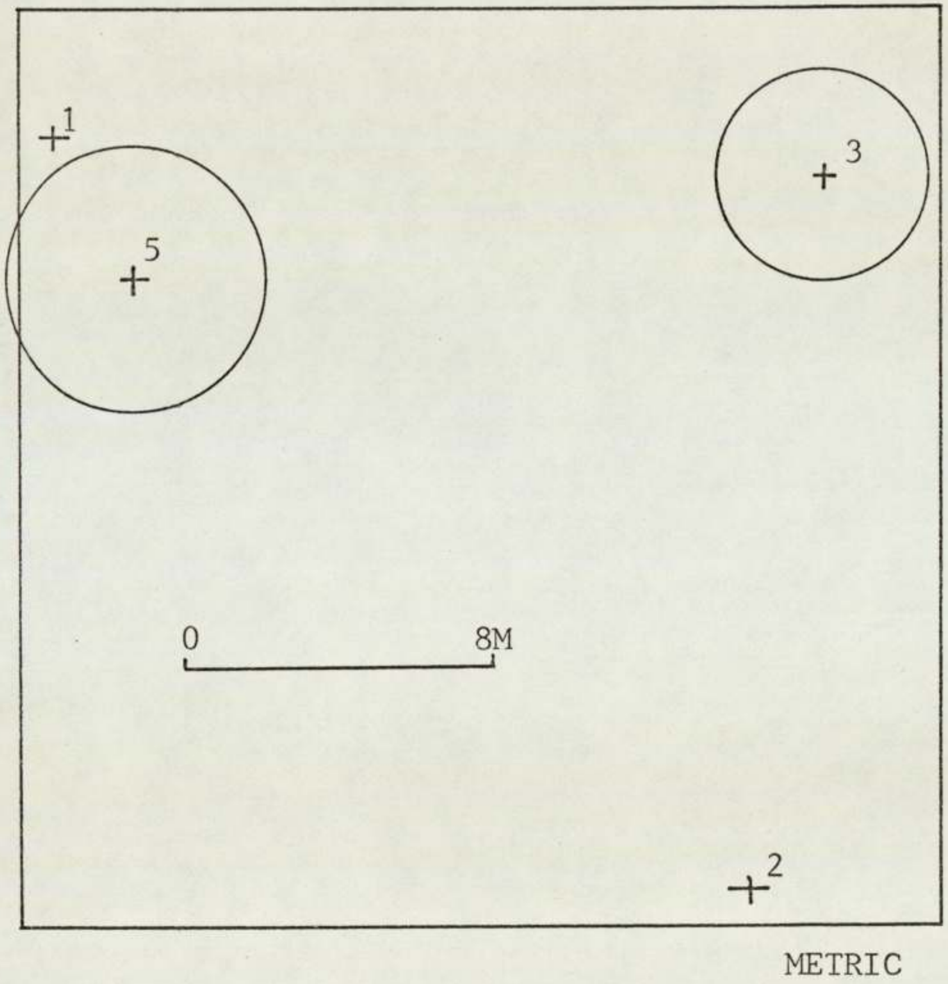


FIG 10 CELL DIAGRAM WITH PART FIXED CELLS

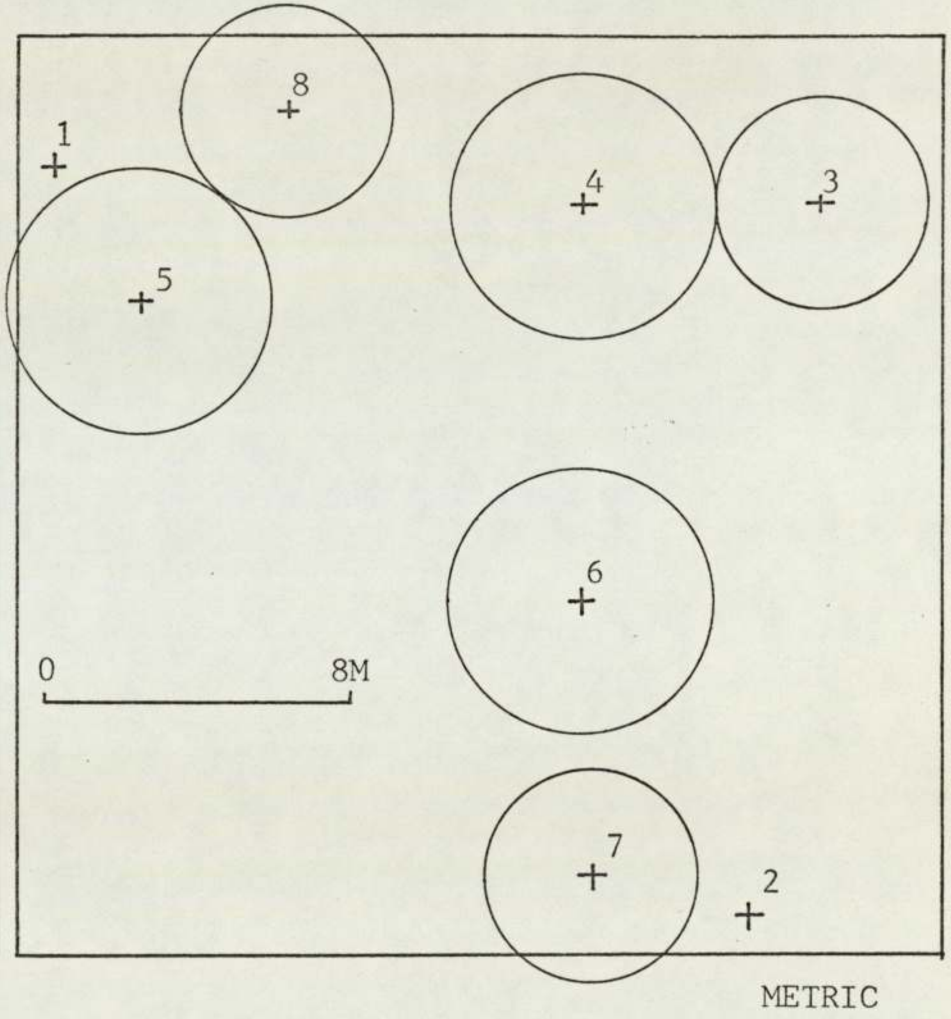


FIG 11 FINAL CELL DIAGRAM

and Y=19.5, giving a movement value of 7.8, is on top of cell 3 and will therefore fail the position tests, moving on to step 8 of the layout model. Considering the most effective direction to move to be towards cell 1, the location of cell 4 is moved to X=14.7 and Y=19.5, where with a movement value of 8.9 the result is an increase of 14% for the cell. In a similar manner the two remaining cells are initially located at 1.3, 20.9 and 19.0, 1.0 respectively and after failing positional tests were relocated at 7.0, 22.0 and 15.0, 2.0 respectively, resulting in movement value increases of 3% and 2.6%. The final cell diagram is shown in Figure 11.

Using the cell diagram as a basis for layout individual workcentres are located around cell positions to give the final layout diagram illustrated in Figure 12.

Experience at this stage of the process indicated that the ratio:

$$\frac{\text{Total workcentre area}}{\text{Nett available layout area}}$$

influences the ease with which workcentres can be placed. In the illustrating example the ratio is relatively low at 0.08, at which level a heuristic procedure for placing workcentres in their final position might work. As the ratio rises to a level more commonly found in practical problems (approximately 0.5) the placing of workcentres becomes extremely difficult for automatic procedures and would still require manual adjustment by the designer.

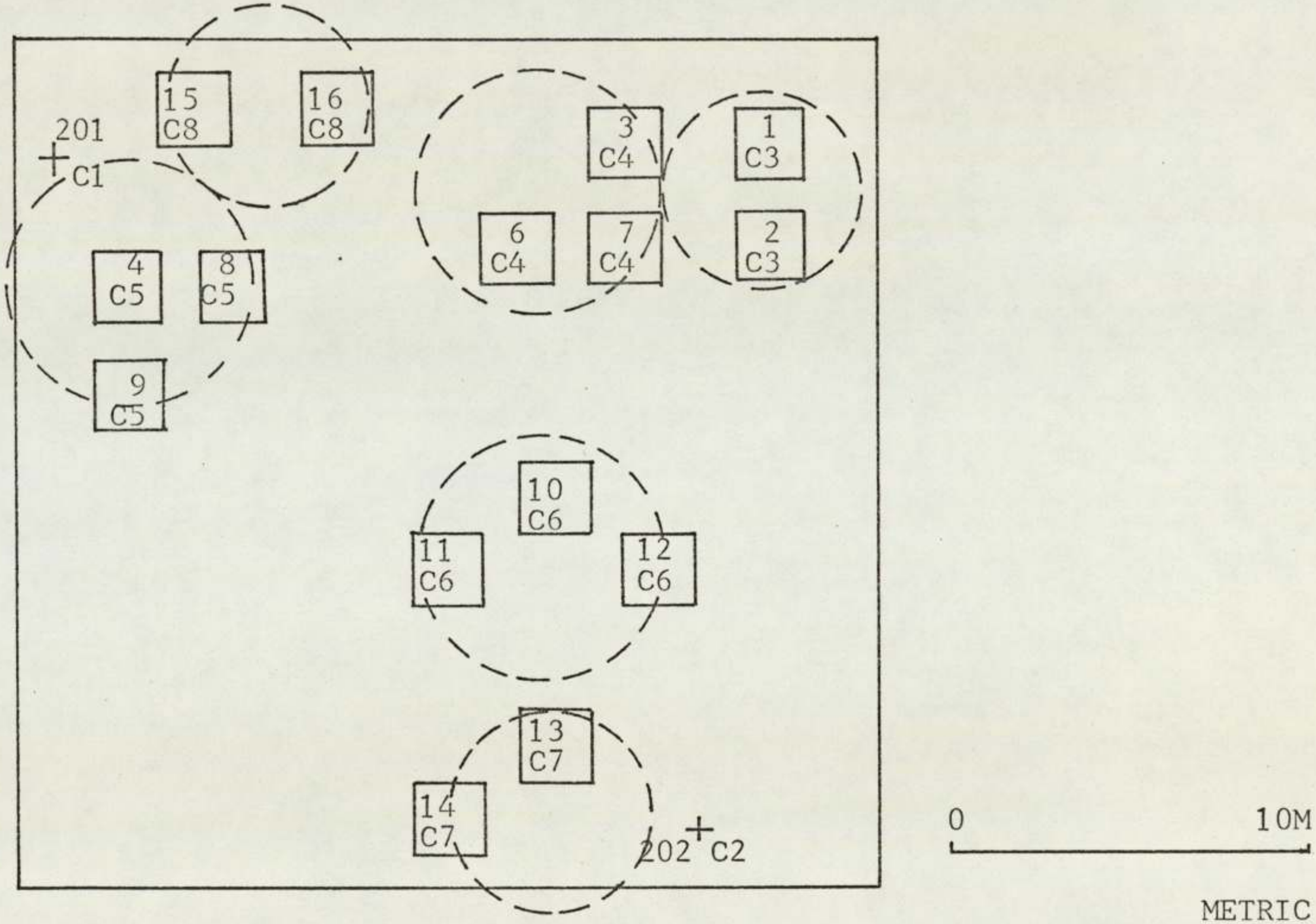


FIG 12 FINAL WORKCENTRE LAYOUT FOR THEORETICAL EXAMPLE

The layout model presented to examine the static design stage therefore is not in itself a complete process producing final layouts. The procedure in practice combines the skill and judgement of a layout designer with a quantitative heuristic, placing cells of pregrouped workcentres in order of locational difficulty and movement interaction in an initial stage and then manually inserting workcentres, an approach which allows all the advantages of interactive design to be obtained during the actual design process.

At the beginning of the static layout design stage there is in existence an original layout and a new production program. At the end of the layout design stage there should exist an original layout and a new layout to meet the requirements of the production program.

Considering the overall philosophy proposed in Chapter 3, with the two layout arrangements in existence the next stage is to examine the dynamic change from initial to final layout.

5. DYNAMIC LAYOUT CHANGEOVER

The changeover from an initial design to a new arrangement may be performed in a variety of alternative approaches ranging from the complete relocation of facilities in one move to the gradual change of single facilities throughout the expected life span of the layout design.

To examine this transition period in a job shop environment the second stage of the layout approach presents a simulation model which determines the financial contribution of a particular changeover to the cost of the overall manufacturing system. The model is developed by first examining the nature of materials movement cost in a job shop and then secondly to include this cost in a two part evaluation criterion, relating the change in materials movement cost throughout the lifetime of the project to the cost of relocating workcentres at the various stages.

5.1. Materials Movement Cost

Materials movement cost consists of a combination of two factors, the distance over which the material is required to move and the function which converts this distance into a cost incurred by the layout.

During the static layout design stage an approximation in the form of straight line or Cartesian co-ordinate distance dependent upon the existence of a traffic system is used to estimate movement distance. Whilst this is acceptable during the static design stage where the problem involves a degree of approximation, when it is necessary to obtain the actual movement cost the use of this approximation, particularly in a job shop must be examined further.

This examination involves analysing movement distances for the two possible job shop cases, firstly where no traffic system exists and secondly where a traffic system is in use. Using random generation techniques sixteen workcentre locations were selected for each of five job shop areas taken from industrial situations, the locations and layout diagrams are shown in Appendix A. The nett result of using sixteen workcentre locations is to generate one hundred and twenty movement combinations in each of the five diagrams.

No traffic system case

The object of examining a number of techniques is to obtain a distance measuring procedure which balances accuracy against computational requirement. At one extreme certain techniques may be easy to calculate but the accuracy may be too low whilst at the other extreme highly accurate techniques may require too much calculation to be of use. Four methods of distance measurement in the no traffic system case, illustrated in Figure 13, are put forward for examination:

N1	Straight line distance
N2	Cartesian co-ordinate distance
N3	Modified periphery method
N4	Total combinations method.

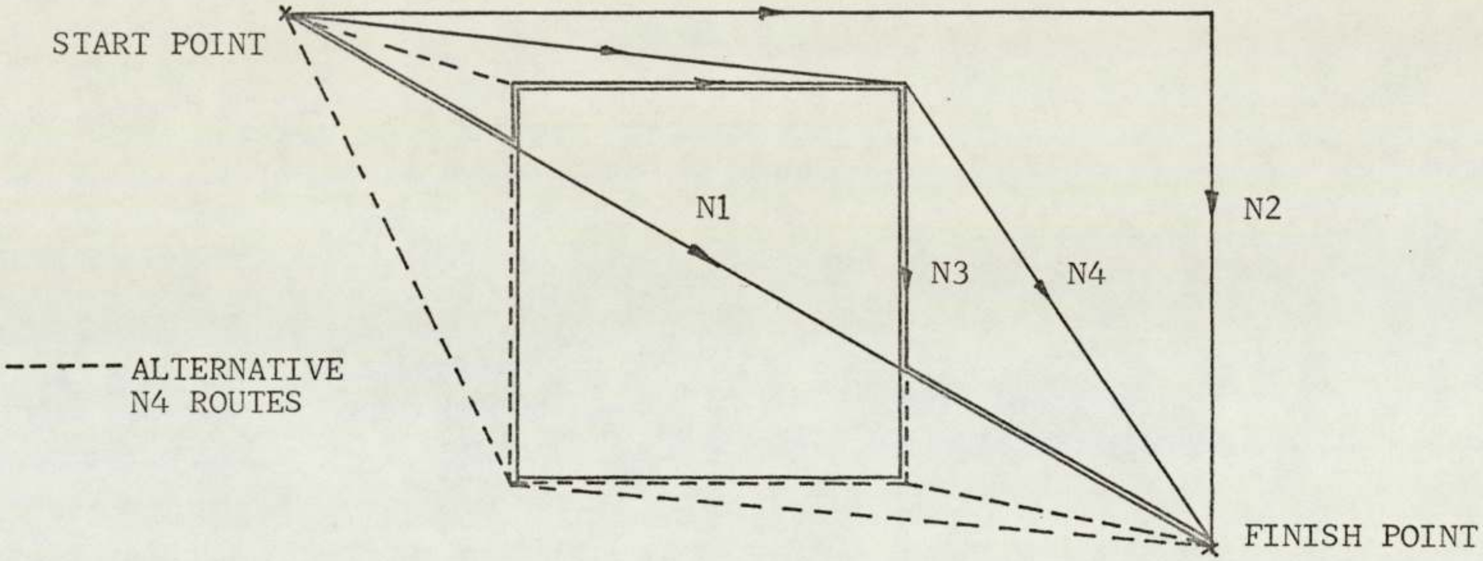


FIG 13 ILLUSTRATION OF MOVEMENT DISTANCE METHODS N1 TO N4

The first two methods are straight forward distance calculations ignoring obstructions. The third technique (N3) includes obstructions by calculating the smallest distance around the obstruction and deducting the wasted distance travelled through the obstruction. The fourth technique sets up a network of points linking the start and finish of a journey and including all obstruction points. For example where the straight line is interrupted by a rectangular obstruction the number of network points grows to six. In turn the resulting fifteen (n x (n-1)/2) links are also checked for obstructions and the list of points increased until no more obstructions are found. Eliminating those straight line links that are blocked the shortest straight line path from the initial to the final destination point is determined. This fourth technique determines the actual shortest distance from one point to another in the job shop and therefore has been adopted as the true distance.

The number of calculations required by each technique is influenced by the method used to detect obstructions and also by the actual number of obstructions encountered in the exercise. The first two techniques, N1 and N2, which ignore obstructions require one calculation for each distance examined. Technique N3 required ten calculations approximately to check each straight line against each obstruction line and an additional twenty calculations for each interference found. The final technique N4 is proportionately larger with ten calculations required to check each obstruction line against each of the movement path lines. The relationship between accuracy and and the number of calculations necessary is shown in Figure 14.

Examining Figure 14 it can be seen that whilst method N4 produced the most accurate results the number of calculations required excludes the use of this method for job shop problems. From the graph the best combination of accuracy and computational efficiency is method N1, the straight line distance method, where the average error from actual distance over six hundred measurements was 4.6%.

Therefore in layout projects involving no organised traffic system materials movement will be assumed to move in a straight line, an assumption giving the best combination of reasonable accuracy and relative computational efficiency.

Traffic route case

The majority of organised job shops have an arranged traffic system capable of accommodating all the materials movement equipment in use and allowing transport in any direction. In a similar manner to the no traffic route case four methods of distance measurement are put forward for examination:

T1 Straight line distance
T2 Cartesian co-ordinate distance
T3 Traffic route method without obstruction check
T4 Traffic route method with obstruction check.

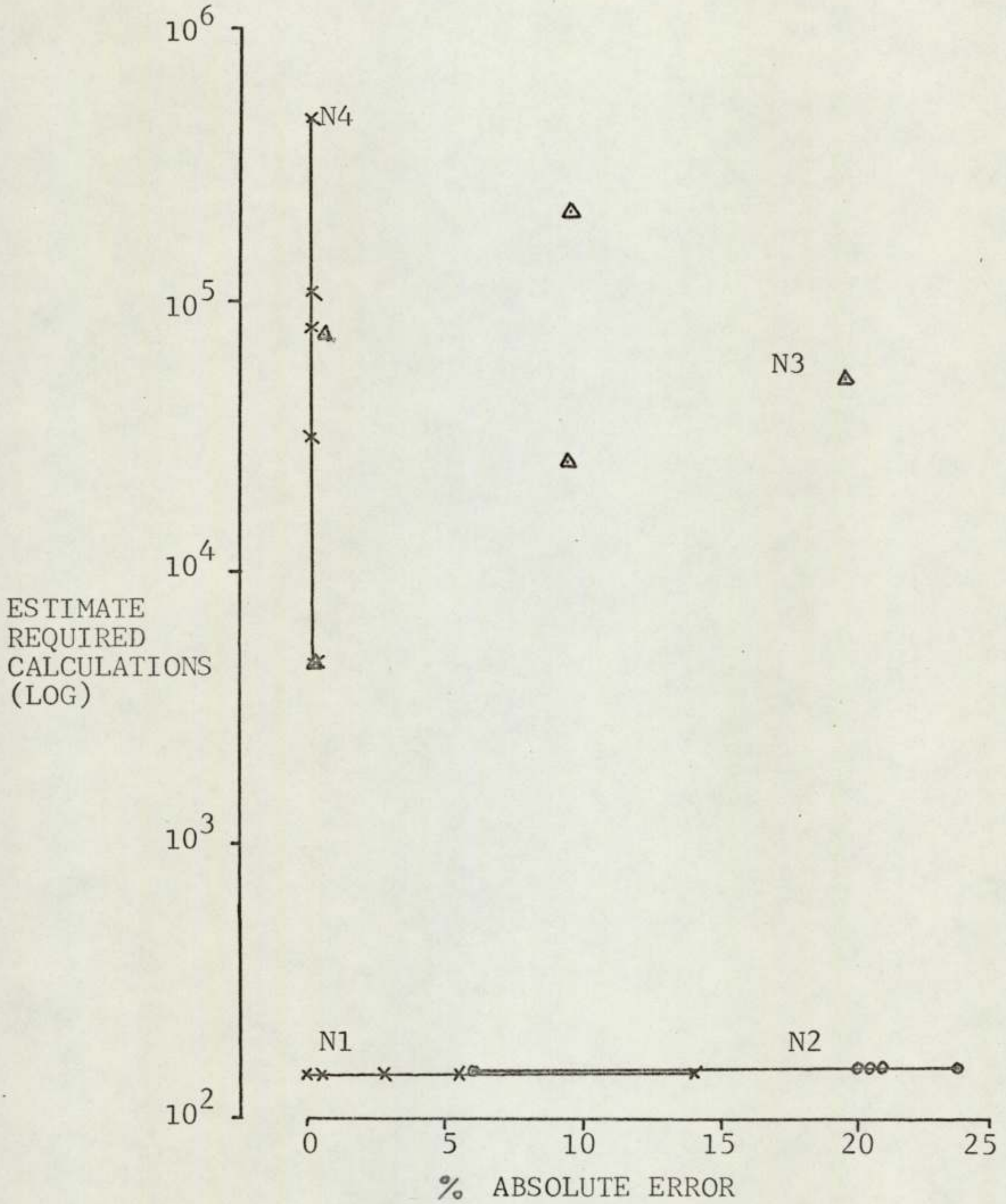


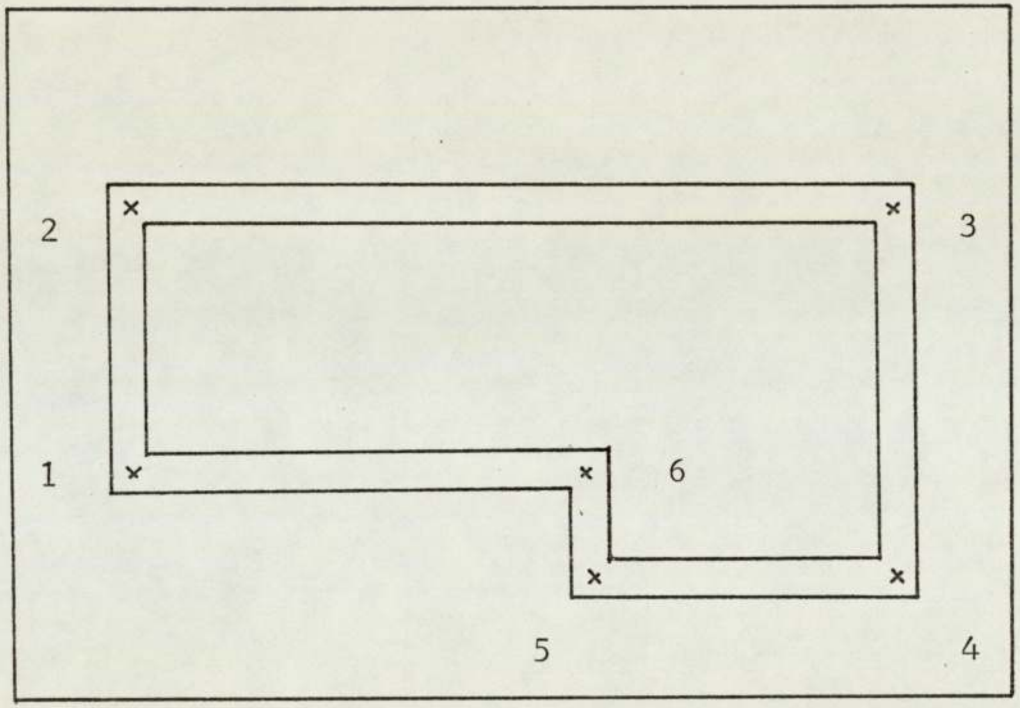
FIG 14 GRAPH OF LOG CALCULATIONS AGAINST ERROR
NO TRAFFIC ROUTE CASE

Methods T1 and T2 again represent the straight line and rectangular co-ordinate distances from workcentre location to workcentre location. Methods T3 and T4 use a modification of the shortest traffic system distance. This modification is related to reducing the number of calculations required to determine movement distances. As a result of the large number of movement calculations that will occur in a layout project, savings can be achieved by calculating in advance certain distances related to the traffic system, distances that will only have to be calculated once.

Considering each traffic system as continuous and numbering each traffic aisle junction, the minimum distance from any one junction to another is determined and recorded for repeated use. Figure 15. illustrates this calculation saving first step for methods T3 and T4.

Having determined the matrix of junction distances the next stage is to determine for each workcentre location the nearest traffic aisle, the distance to the traffic aisle and the distance to each end of the traffic aisle from the point of contact as illustrated in Figure 16. Using the two sets of information the distance from any one facility to another is the minimum of the four possible routes and can be calculated in a relatively short time. Where both facilities are on the same aisle the distance from workcentre A to workcentre B is:

$$\underline{D = C_A + C_B + \text{Absolute } (A_A - A_B)}$$

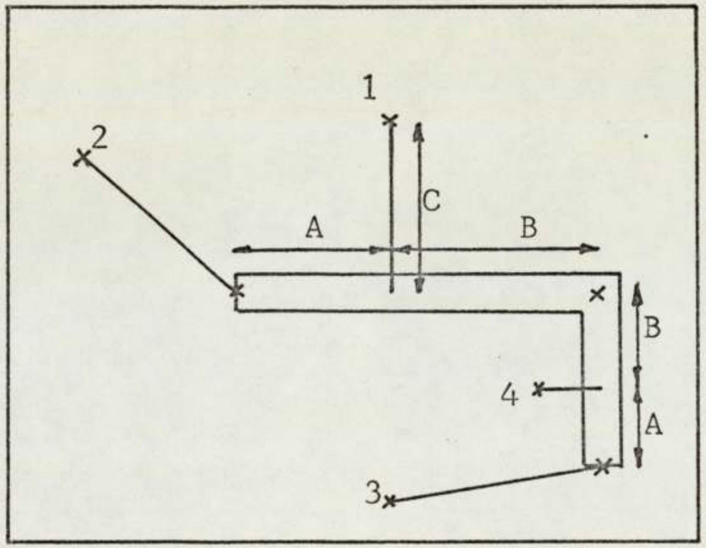


	1	2	3	4	5	6
1	-	14	54	46	30	24
2	14	-	40	60	44	38
3	54	40	-	20	36	42
4	46	60	20	-	16	22
5	30	44	36	16	-	6
6	24	38	42	22	6	-

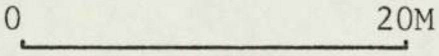
0 20M

METRIC

FIG 15 DETERMINATION OF TRAFFIC ROUTE DISTANCE MATRIX



	A	B	C
1	8.0	11.0	11.0
2	0.0	19.0	11.0
3	0.0	9.0	11.2
4	4.0	5.0	3.0



METRIC

FIG 16 ILLUSTRATION OF WORKCENTRE DISTANCES TO TRAFFIC SYSTEM using the convention adopted on the diagram. For facilities on two different aisles the distance from workcentre to workcentre is the minimum sum of distances using routes including the junctions at each end of the two aisles nearest workcentres. In Figure 16 for example the minimum distance from workcentre 1 to workcentre 4 is:

$$\underline{C_1 + C_4 + B_1 + B_4}$$

which is equal to 30.0 metres.

The difference between techniques T3 and T4 lies in determining the distance C to each traffic aisle. Method T3 uses the uncorrected straight line distance to the nearest aisle ignoring obstructions. Method T4 incorporates a check for obstructions in the two lines from workcentres to traffic aisles and calculates the actual distance in a similar manner to technique N4 where an obstruction is found. The relationship between accuracy and the number of calculations necessary is shown in Figure 17. for the four traffic route techniques.

Examining Figure 17. both the straight line and rectangular co-ordinate distances registered high error values against method T4, taken as the actual distance, indicating a limitation on their use in a job shop model. A major contributor to the high error values, particularly in the case of the rectangular co-ordinate method T2, is the relatively short distance materials travel in a job shop. With a limited movement distance each error becomes more significant than at an inter-departmental level and within the test

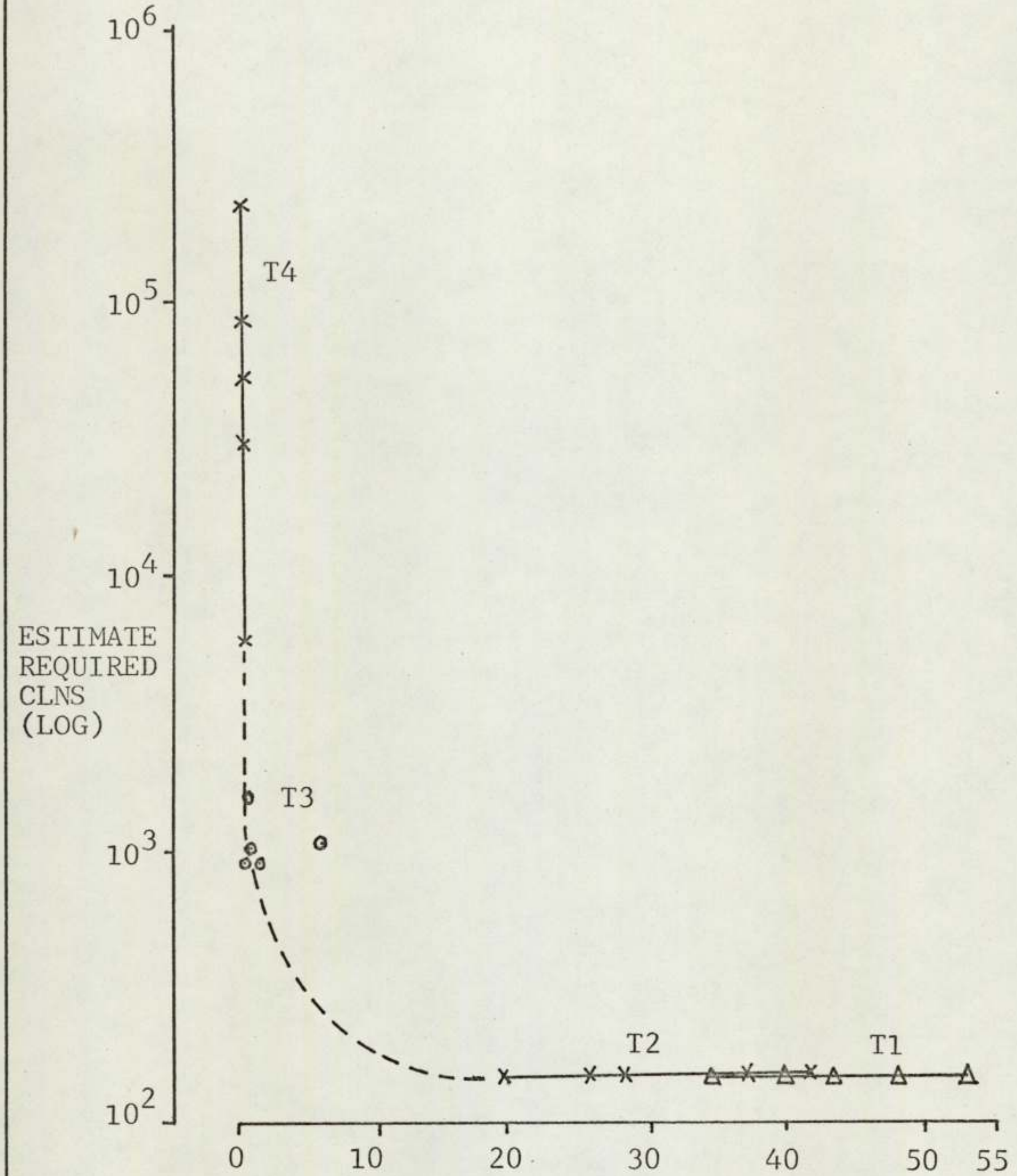


FIG 17 GRAPH OF LOG CALCULATIONS AGAINST ERROR TRAFFIC ROUTE CASE

movements these errors mainly originated in the need to backtrack along aisles. Method T2 therefore, although used in a number of computerised techniques to approximate aisle movement, has not been selected because of inaccuracy at the job shop level.

Alternatively the highly accurate technique T4 again required considerable calculation, estimated at approximately one hundred times the number for methods T1 and T2. From the four methods T3 achieved the best balance between accuracy and computational requirements, needing only ten times the number of T1 and T2 calculations with the greatest error at 6% and an average error over the five test cases of 1.6%. In addition, because of the inclusion of the non-repeating traffic junction calculations the ratio of ten to one between methods T3 and T2 will decrease as the number of distance calculations increases. An explanation of the accuracy of T3 is the relatively small distances moved outside of a traffic aisle and the resulting reduction in the risk of encountering an obstruction.

Therefore in layout projects involving an organised traffic system materials movement will be assumed to move in a manner similar to method T3 giving the best combination of reasonable accuracy and relative computational efficiency.

Within the simulation model it has been necessary to examine in some detail the determination of actual distances moved rather than accepting a simplified approximation because of the importance placed upon materials movement cost. From this point onwards movement distances will be discussed in general terms but within the simulation model the distance will be calculated using the following procedure:

a. Using the straight line distance where no traffic system exists.

b. In the case of a continuous traffic system by -

   1 Calculating a matrix of minimal distances from traffic junction to traffic junction.

   2 For each workcentre determining the nearest aisle, the straight line distance to that aisle and the distance from the contact point to each end of the aisle.

   3 For workcentres on the same aisle take the sum of distances to the aisle and the difference from one end.

   4 For workcentres on differing aisles take the sum of distances to the aisle and the shortest of the four possible connecting routes. The number of routes may be less than four if either aisle has an unconnected end.

Having examined the distances involved in materials movement in a job shop there remains to examine the function relating distance to cost and in particular the influence on this function of two parameters:

1. Fixed movement costs

2. Movement undertaken by machine operatives.

Fixed movement costs

The most common expression of movement cost in use as a quantitative criterion can be stated as:

$$\sum_{i=1}^{n} \sum_{j=1}^{n} D_{ij} W_{ij}$$

where n = number of facilities

D_{ij} = distance from facility i to facility j

W_{ij} = weighted cost value between facility i and facility j.

The function W_{ij} is expressed as the product of cost per unit distance and the number of loads per time period, a relationship used by both Armour (6) and Deisenroth (5) in computerised layout programs. The actual cost of moving a load however is a function of both a fixed cost, required to find and raise a load at the beginning of a journey and to lower and place the load at the end of a journey, and a variable cost proportional to the distance moved. The influence of the fixed cost factor is dependent on the distance involved in moving a particular batch of work. Huffman (27)[*] examining materials movement in a job shop area concluded that 20% or more of the time required for any one trip is taken up by constant portions of the task and that the exact percentage depends upon the distance travelled and may be as high as 80%. A more recent example from Reed (54)[+] gives a

[*] Pages 3 and 4

[+] Pages 8 to 11 inclusive

movement time of .0024 hours for a 15.2 metre (50 ft) run and a fixed lifting time of .0075 hours, giving an approximate ratio of three to one between fixed and variable movement cost.

To allow for the inclusion of this fixed movement cost factor in the job shop situation, where distances are smaller than at an inter-departmental level and consequently the fixed cost will be more important, the following materials movement cost model is used:

1. For each product the cost of moving one batch is determined as a fixed cost per batch (PF) and a distance variable cost per batch (PV).
2. Using the workcentre sequence for each product the cost of internal movement for the total number of batches through workcentres (PQ) is -

   $$\underline{PQ_k \times (PF_k + (D_{ij} \times PV_k))}$$

   where k = product under consideration

   D_{ij} = distance from workcentre i to workcentre j in the product sequence.
3. Summing for all workcentres in a particular product workcentre sequence the movement cost becomes -

   $$\underline{PQ_k \times (n \times PF_k + (PV_k \times \sum_{j=1}^{n-1} D_{j,j+1}))}$$

   where n = number of workcentres in

the production sequence of product k.

4. Summing for all products, the materials movement cost becomes -

$$\sum_{k=1}^{p} PQ_k \text{ X } (n \text{ X } PF_k + (PV_k \text{ X } \sum_{j=1}^{n-1} D_{j,j+1}))$$

where p = number of products.

A product based evaluation of materials movement cost has been adopted because of the difficulty of generating a flow matrix representing inter-facility movement where potentially large numbers of workcentres may be involved. In addition using a product basis also enables the fixed and variable costs to be selected to suit the physical requirements of individual products.

Movement undertaken by machine operatives

The cost function so far developed is a two part distance based equation developed from accepted materials movement theory. In addition one further modification is included derived from the observation of actual materials movement within a job shop.

When facilities are in close proximity as in the case of job shop workcentres, and the physical size of product batches is not excessive then a percentage of materials movement will be undertaken by machine operatives and will therefore not incur a cost against materials movement equipment. This results in a saving of movement cost for those product movements involving small distances.

To give adequate consideration to the possibility of local movement undertaken by workcentre operatives a boundary distance (E) is introduced to differentiate between the two forms of movement. Where the straight line distance between two facilities is less than or equal to E the materials movement incurred between the two facilities is not counted in the total cost. Where the distance exceeds E the cost is included. The consequent effect on materials movement cost is shown in Figure 18, where the cost function has clearly progressed from a directly proportional cost to a non-linear relationship presenting an area for investigation with regard to the possible effect on project return.

Adopting this modified function for use in the simulation model it is still possible to revert to a directly proportional equation or a fixed and variable cost equation by returning either the boundary distance (E) or the fixed costs (PF) to zero. Using a combination of the distance measuring technique and the modified cost function introduced in this section the total materials movement cost at any stage in the dynamic changeover of layout designs can be calculated. Having developed this cost procedure for materials movement, a major important variable in the simulation study, it is now possible to examine the changeover simulation model.

5.2. An Evaluation Model for Simulating Layout Changes

The heuristic technique developed for assessing the

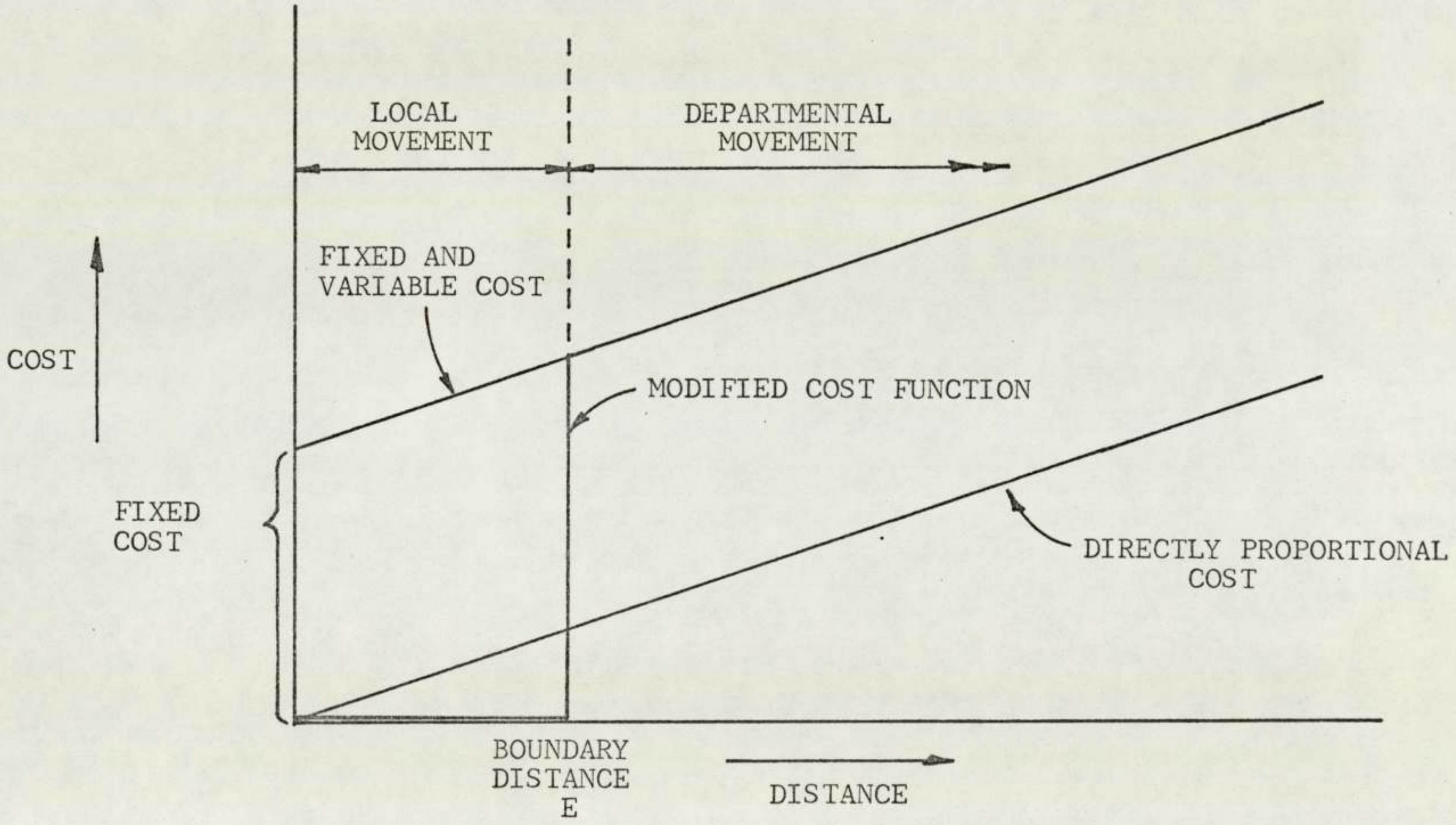


FIG 18 ILLUSTRATION OF MATERIALS MOVEMENT COST FUNCTIONS

materials movement cost of a layout at any period in time can be combined with the cost of relocating individual workcentres to form the basis of an evaluation model for examining layout changes. This two part evaluation relates the running cost of a layout, expressed as materials movement cost, to the basic capital outlay required to change the layout, expressed as workcentre relocation cost. The difficulty of including additional costs other than on a lump sum basis has been discussed in the review of dynamic plant layout methods, the main problem being the determination of cost values with a degree of reliability from available industrial information.

In consequence at this stage the model is restricted to the two cost combination and is used to examine layout changeovers under the following conditions, with the possibility of enlarging the model discussed in the chapter on future work.

1. Workcentres are relocated in the interval between production periods and consequently no loss of production is assumed to occur.
2. During each changeover interval a maximum limit is set upon the number of workcentres that can be relocated (LN). Once this limit has been reached further changes in layout will have to wait for the next available time period.
3. During the changeover process the situation

may arise where a selected workcentre cannot be relocated because the new location is still occupied by other workcentres. To give reasonable account of this additional complication when a workcentre is selected for relocation all workcentres infringing the new position must also be relocated in the same interval. This may result in a "snowballing" situation where to relocate one workcentre it is necessary to relocate a much greater number at the same time. If this number is greater than the number that can be moved in a time period the changeover will halt.

4. No provision has been made for temporary workcentre locations during the changeover.

Consider the following formulation of the evaluation model, illustrated in Figure 19.

Let TP = life span of the new production program

M_0 = materials movement cost per time period of the new production program in the initial layout.

Then the cost of materials movement if no change occurs is:

$$\underline{C_0 = M_0 \text{ X } TP}$$

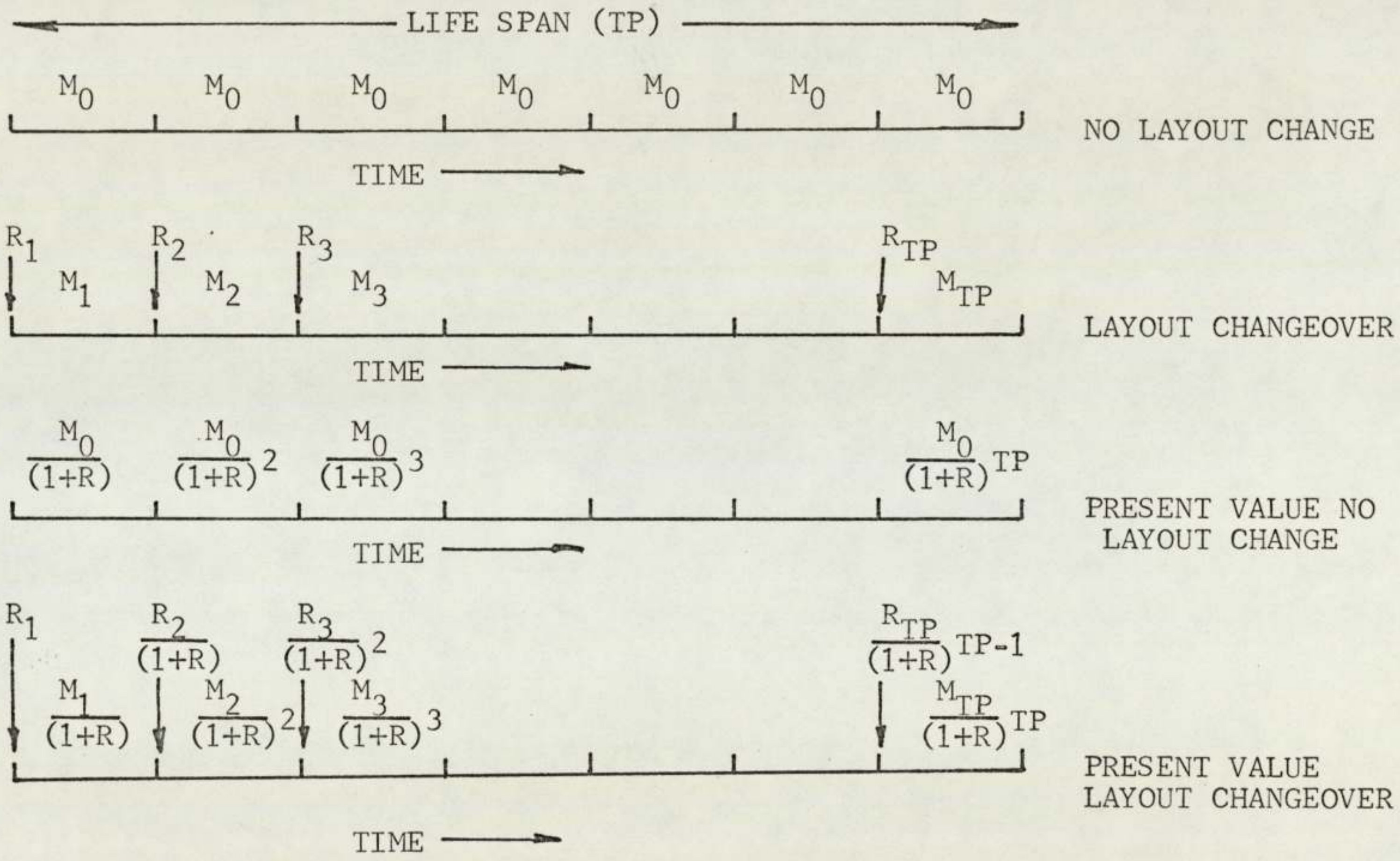


FIG 19 CASH FLOW THROUGHOUT PROJECT LIFE SPAN

Accounting for the changeover from initial to final layout:

Let R_j = total relocation cost of moving the required workcentres at the beginning of time period j.

M_j = materials movement cost for the new production program with the layout arrangement resulting from change R_j.

Then the cost of the new layout can be expressed as:

$$C_{REL} = \sum_{j=1}^{TP} (M_j + R_j)$$

Therefore the contribution towards the reorganisation of the manufacturing system of the layout change is:

$$PRN = C_0 - C_{REL}$$

$$= M_0 \times TP - \sum_{j=1}^{TP} M_j + R_j$$

Within the evaluation model an assessment of certain cash flows throughout the layout life span are used in a financial approach to determine the contribution of a layout changeover to the overall manufacturing system. Where projects extend over a period of time then the influence of changes in the value of money must also be taken into account. There are in existence a number of accountancy methods for this form of project evaluation, including:

Discounted yield method

Payback period technique

Average annual return technique

Nett present value method.

Of the two major methods, discounted yield and nett present value the latter has been selected to present an additional parallel analysis within the evaluation model showing the effect of an expected rate of return on cash flows. The reasons for selecting nett present value are two-fold, firstly the evaluation model is actually concerned with determining a nett contribution to the overall manufacturing system and secondly a major area of interest will be the pattern of actual cash flows throughout the project life span.

Two general examples illustrate present value concepts. In the first example assume that the relocation has been completed in a relatively short period of time and for the remainder of the project life span a certain return per period is expected. Using direct cost values the nett result may be a positive return but allowing for the reduced value of returns when projected back through time the actual nett return may be negative, requiring a decision on which figures are the most important. In the second example the question of capital outlay is examined. Assuming that the objective is to introduce the new layout with a restricted initial capital outlay then by postponing the rearrangement of facilities the eventual relocation cost when projected back to the present may be reduced from an excessive to an acceptable level, allowing the project to be implemented at the cost of a possible loss in materials movement improvement.

The parallel present value analysis is formulated in the following manner:

Let R = expected rate of return per time period

TP = life span of new production program

M_0 = materials movement cost per time period of the new production program in the initial layout.

Accepting the convention of present value analysis that capital transfers occur at the beginning of each period and that continuous costs are taken at the end of a period, the cost of materials movement if no change occurs is:

$$PVC_0 = M_0 \frac{X\ (1 + R)^{TP} - 1}{R\ X\ (1 + R)^{TP}}$$

Considering the changeover from initial to final layout

Let R_j = relocation cost of moving workcentres at the beginning of time period j.

M_j = materials movement cost for the new production program with the layout arrangement resulting from change R_j, a cost which is taken to occur at the end of period j.

Then the cost of relocation for period j is:

$$PVR_j = \frac{R_j}{(1 + R)^{j-1}}$$

Summing over the project life span the present value total relocation cost is:

$$\sum_{j=1}^{TP} \frac{R_j}{(1 + R)^{j-1}}$$

The cost of materials movement for period j is:

$$PVM_j = \frac{M_j}{(1 + R)^j}$$

Summing over the project life span the present value total movement cost is:

$$\sum_{j=1}^{TP} \frac{M_j}{(1 + R)^j}$$

Therefore

$$= \sum_{j=1}^{TP} \left[\frac{M_j}{(1 + R)^j} + \frac{R_j}{(1 + R)^{j-1}} \right]$$

Giving a present value project return of:

$$PVRTN = M_0 \frac{X (1 + R)^{TP} - 1}{R X (1 + R)^{TP}} - \sum_{j=1}^{TP} \left[\frac{M_j}{(1 + R)^j} + \frac{R_j}{(1 + R)^{j-1}} \right]$$

Using this evaluation model the formulation is adaptable enough to cover the entire spectrum of layout changes as discussed earlier and which includes instant layout changeovers, changeovers incomplete at the end of the project lifespan due to a low number of allowable relocations or a short number of time periods and thirdly the range of partial or suspended changeovers found between these two polar cases.

The completion of the evaluation model presents a means of assessing financially any sequence of workcentre relocations, a sequence not necessarily derived to suit financial objectives but also any alternative criteria desired by the layout designer. There remains one task to be included in the dynamic changeover simulation and that is to propose a procedure for relocating workcentres under the model restrictions for use where the designer has no specific sequence of changes.

5.3. Heuristic Procedure for the Relocation of Workcentres

The heuristic proposed for the changeover from the initial to the final layout has two objectives:

1. To assign workcentres in the most financially beneficial manner.
2. To complete cell reorganisation in the minimum time whenever possible.

These two objectives may in practice act in a contradictory manner and illustrate the possible conflict between financial and engineering considerations, a point discussed further in the chapter on future work. In this initial formulation the financial objective has been selected as the main objective and the heuristic procedure selected for sequencing workcentre relocations proceeds through the following steps:

1. A priority rating is given to each cell expressing the order of potential gain which may be obtained by the cell relocation. This potential gain is derived from the function -

$$\underline{(CI_{0,j}+0.5 \text{ X } CE_{0,j})-(CI_{f,j}+0.5 \text{ X } CE_{f,j}+CR_j)}$$

where $CI_{0,j}$ = internal materials movement cost of cell j in the initial layout arrangement.

$CE_{0,j}$ = external materials movement cost of cell j in the initial layout arrangement.

$CI_{f,j}$ = internal materials movement cost of cell j in the final layout.

$CE_{f,j}$ = external materials movement cost of cell j in the final layout.

CR_{j} = the sum of relocation costs for all workcentres in cell j requiring repositioning.

2. Each workcentre is given the priorty rating attributed to its cell. This will result in the introduction of individual cells in a shorter period, reducing disruption.
3. Scanning the list of candidate workcentres the next workcentre with the minimum priority number is selected for relocating.
4. For this workcentre the total number of workcentre moves necessary for relocating the candidate facility is calculated and if combined with the number of relocations already allocated for the time period the limiting number of moves has not been exceeded then all the workcentres associated with the candidate facility are relocated and eliminated from the move list. Where the number of required moves exceeds the limiting number the

heuristic returns to step 3.

5. When the limiting number has been reached or no more workcentres can be relocated without exceeding this number the relocation is complete for the time period.
6. When all workcentres are relocated or no more may be relocated due to a small limiting number the procedure is complete.

A guide to the relocation heuristic is provided in the following example. The problem involves relocating twelve workcentres that are grouped in six cells and have materials movement costs and relocation costs as shown in Table 7. The potential gain values and consequential cell priorities are shown and the problem has a move limit of 4 workcentres per period.

For time period 1 the list of candidates and their priorities will be:

Time period 1

Workcentre	1	2	3	4	5	6	7	8	9	10	11	12
Priority	4	3	2	2	2	1	1	1	5	5	6	6

Following the relocation heuristic and using Table 8, the table of obstructing workcentres i.e. those workcentres occupying the final location of each workcentre, the result is:

Selection 1 = workcentre 6

Additional moves required = workcentre 7

Total = 2

CELL	INITIAL LAYOUT		FINAL LAYOUT		RELOCATION COST	POTENTIAL GAIN	PRIORITY	WORKCENTRES IN CELL
	INT MATL MVMT	EXT COST	INT MATL MVMT	EXT COST				
1	100.0	300.0	20.0	240.0	50.0	60.0	4	1
2	200.0	220.0	80.0	180.0	50.0	90.0	3	2
3	260.0	160.0	20.0	150.0	150.0	95.0	2	3 4 5
4	240.0	180.0	15.0	90.0	150.0	120.0	1	6 7 8
5	120.0	170.0	40.0	120.0	100.0	5.0	5	9 10
6	150.0	250.0	100.0	180.0	100.0	-15.0	6	11 12

TABLE 7. WORKCENTRE RELOCATION HEURISTIC TEST EXAMPLE

WORKCENTRE	WORKCENTRES OBSTRUCTING FINAL POSITION
1	11
2	4 5
3	
4	2 5
5	2 4
6	7
7	
8	4
9	
10	12
11	
12	

TABLE 8. INTER-WORKCENTRE OBSTRUCTIONS

Number of moves available = 4

Relocate workcentres 6 and 7

Selection 2 = workcentre 8

Additional moves required = workcentres 2,4 and 5

Total = 4

Number of moves available = 2

Proceed to next selection

Selection 3 = workcentre 3

Additional moves required = none

Total = 1

Number of moves available = 2

Relocate workcentre 3

Selection 4 = workcentre 4

Additional moves required = workcentres 2 and 5

Total = 3

Number of moves available = 1

Proceed to next selection

In a similar manner selection 5 (workcentre 5), selection 6 (workcentre 2) and selection 7 (workcentre 1) will fail, leaving:

Selection 8 = workcentre 9

Additional moves required = none

Total = 1

Number of moves available = 1

Relocate workcentre 9

The available relocations for time period 1 are now complete and the project proceeds to the next time period.

Time period 2

Workcentre	1	2	4	5	8	10	11	12
Priority	4	3	2	2	1	5	6	6

Selection 1 = workcentre 8

Additional moves required = 2,4 and 5

Total = 4

Number of moves available = 4

Relocate workcentres 2,4, 5 and 8

The available relocations for time period 2 are now complete and the project proceeds to the next time period.

Time period 3

Workcentre	1	10	11	12
Priority	4	5	6	6

Selection 1 = workcentre 1

Additional moves required = workcentre 11

Total = 2

Number of moves available = 4

Relocate workcentres 1 and 11

Selection 2 = workcentre 10

Additional moves required = workcentre 12

Total = 2

Number of moves available = 2

Relocate workcentres 10 and 12

This completes the relocation of all workcentres in the exercise. This illustrating example shows clearly the influence of obstructing workcentres on the sequencing of relocation moves, an influence which will change the most desirable order of moves, require a number of cells to undergo changes at the same time with a resultant increase in disruption time and may even stop a project before completion.

An example of the project being stopped before completion can be seen in relocating workcentres 2, 4 and 5 of the project. The three workcentres form a closed subset each of which must move at the same time, if the limiting number of moves is set at 2 then the relocation project could not be completed.

The extent of final position obstruction is related to the ratio -

$$\frac{\text{Total workcentre area}}{\text{Nett layout area}}$$

This ratio, discussed previously in connection with the static layout procedure, indicates the degree of crowding within the layout area where a high ratio indicates the possibility of a high number of obstructions and a low ratio will allow adjustment to reduce obstructions. Where no obstructions exist the sequencing of relocations is simplified and workcentres will be relocated in strict order of priority and in a minimum time interval.

Concluding the dynamic simulation chapter, the relationship between the evaluation model, relocation heuristic and the overall two stage philosophy can be restated.

The philosophy has been proposed that the layout of workcentres in a job shop situation goes through two stages, firstly an alternative static arrangement of workcentres is determined to suit the requirements of a new production program. Secondly a dynamic analysis of the changeover from the original to the new layout design will enable an assessment to be made of whether the benefits of the new static design can be obtained under varying conditions. The dynamic model presented formulates a more accurate evaluation of materials movement cost and combines this cost with workcentre relocation costs in a financial model used to examine project return and cash flows for a number of changeover alternatives, including a relocation heuristic for automatic changeover in the absence of a designer selected sequence.

6. A COMPUTERISED LAYOUT DESIGN SYSTEM

To examine job shop problems of a practical size using the progressive two stage approach presented in the static layout design and dynamic simulation models will require considerable amounts of calculation and data manipulation the level of which would be beyond hand calculation.

The use of a digital computer for this work has two particular advantages, speed and capacity. The ability to perform large numbers of calculations rapidly combined with the ability to store and manipulate quantitative data presents the computer as a useful aid to plant layout designers and has resulted in an increasing number of computerised techniques, discussed in the review of existing layout methods.

From the review it has been shown that the design and construction of each program influences the practical usefulness of the proposed algorithm or heuristic and amongst the possible limitations, particularly with regard to the layout of workcentres in a job shop situation, are firstly the representations used for facilities and layout area, secondly oversimplified materials movement evaluation which generally uses approximated distances and handling costs directly proportional to distance, and finally the operating nature of each program. Early computer programs used rigid operating procedures (CRAFT 1961) which severely restricts the influence of the designer during the program execution stage, a limitation partially relieved by later programs

(CORELAP8 1971) and (PREP 1973) by the use of interactive terminals.

With the increasing sophistication of computer equipment and software programming techniques the role of computers has progressed past that of simple calculators and there is now a need to examine how best computer systems can be arranged to aid the design procedure. Two aspects of the use of computers for workcentre layout are examined in this chapter:

1. The selection of computer equipment to enhance the interactive layout models.
2. The design and specification of a set of computer programs based upon the two part philosophy proposed within this research.

6.1. Computer Equipment for Facility Layout Programs

The approach adopted within the two problem stages is based upon the desire to achieve the best possible balance between the designer and the quantitative models. To achieve this balance a number of objectives can be set for the computer equipment:

1. To enable rapid quantitative evaluation.
2. To allow adequate consideration of subjective factors during the actual design exercises.

3. To enable a sufficient display of information for reasonable problem comprehension.
4. To limit the amount of information that has to be input by the designer.
5. To produce permanent copies of information on the results of each layout exercise for record and study purposes.

The main computer or central processor will perform the necessary rapid quantitative evaluations leaving the main area of examination as that of the selection of peripheral equipment for transmitting the various channels of information to and from the central processor in the most efficient manner. Consider the peripheral system shown in Figure 20. Within the system exists the designer, a visual display terminal, a normal on-line terminal and the central processor containing the computer programs. The system operates through two channels, one relaying quantitative decisions and the other displaying a visual image of the state of the project, enabling the designer to monitor decisions during the design exercise.

Within the computer system the visual display equipment clearly performs several important functions and although the initial set of programs developed at this stage does not include visual display images a number of observations regarding the usefulness of this equipment can be made:

1. Commercial software programs and equipment are now readily available and can

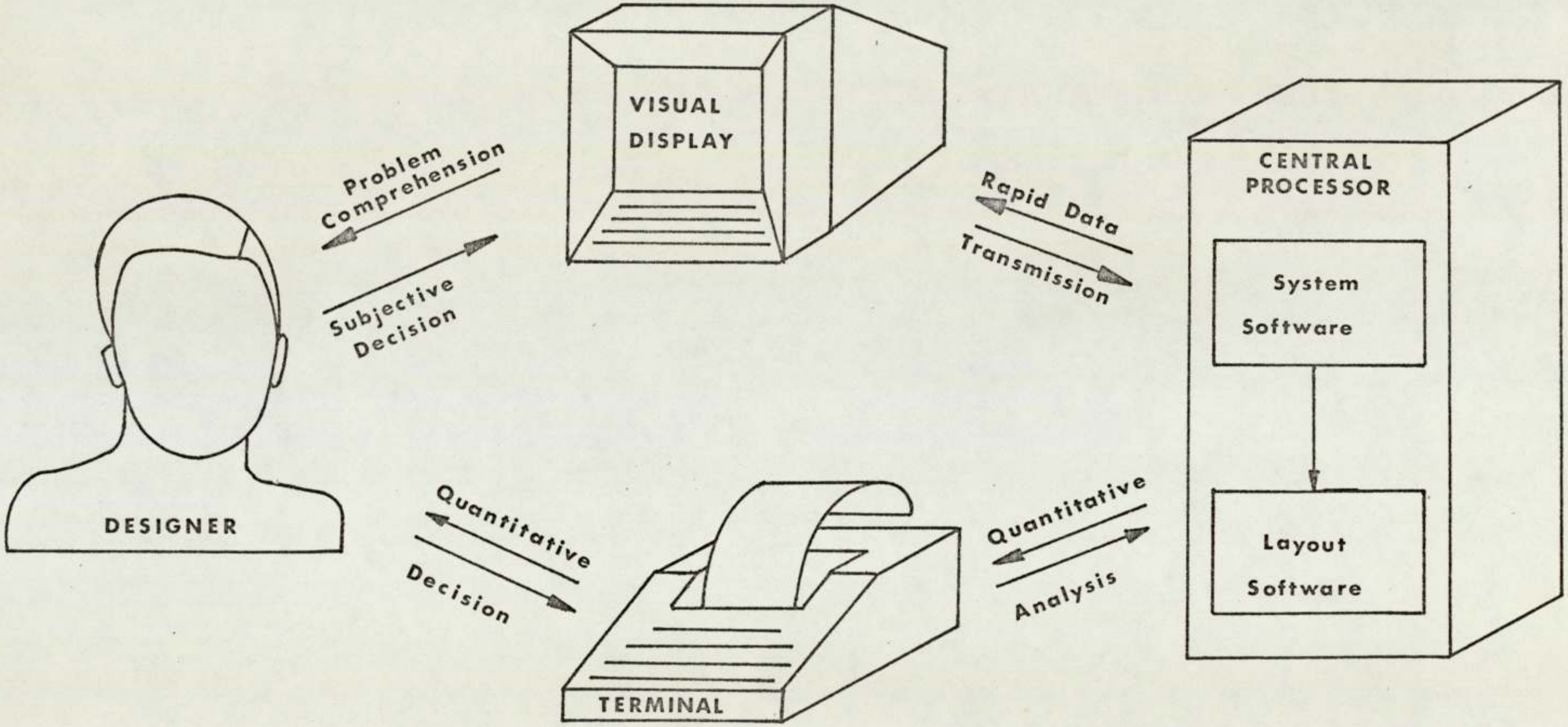


FIG 20 AN INTERACTIVE FACILITY LAYOUT SYSTEM

be linked into major computers with relative ease.

2. The equipment is increasingly used in architectural applications and has been shown to be capable of complex two and three-dimensional representations.
3. The use of a visual display terminal would in one direction greatly increase the designers ability to comprehend each problem and in the other direction would enable the rapid transmission of layout changes back to the central processor.

Of those quantitative programs designed for the layout of manufacturing areas none to date has explored the use of this equipment to the same extent as in the field of architectural design.

A complete range of equipment for an interactive facility layout system is illustrated in Figure 21. In addition to the terminal and visual display screen a conventional card reader is included for inputting the bulky quantitative data, a graph plotter for the direct production of layout drawings and a hard copier, linked to the visual display terminal, for the quick reproduction of displays. The standard cassette recorder, which can be linked to the visual display terminal by the use of an optional interface is capable of recording screen images throughout a layout exercise enabling the problem to be re-run off-line thus providing a use-

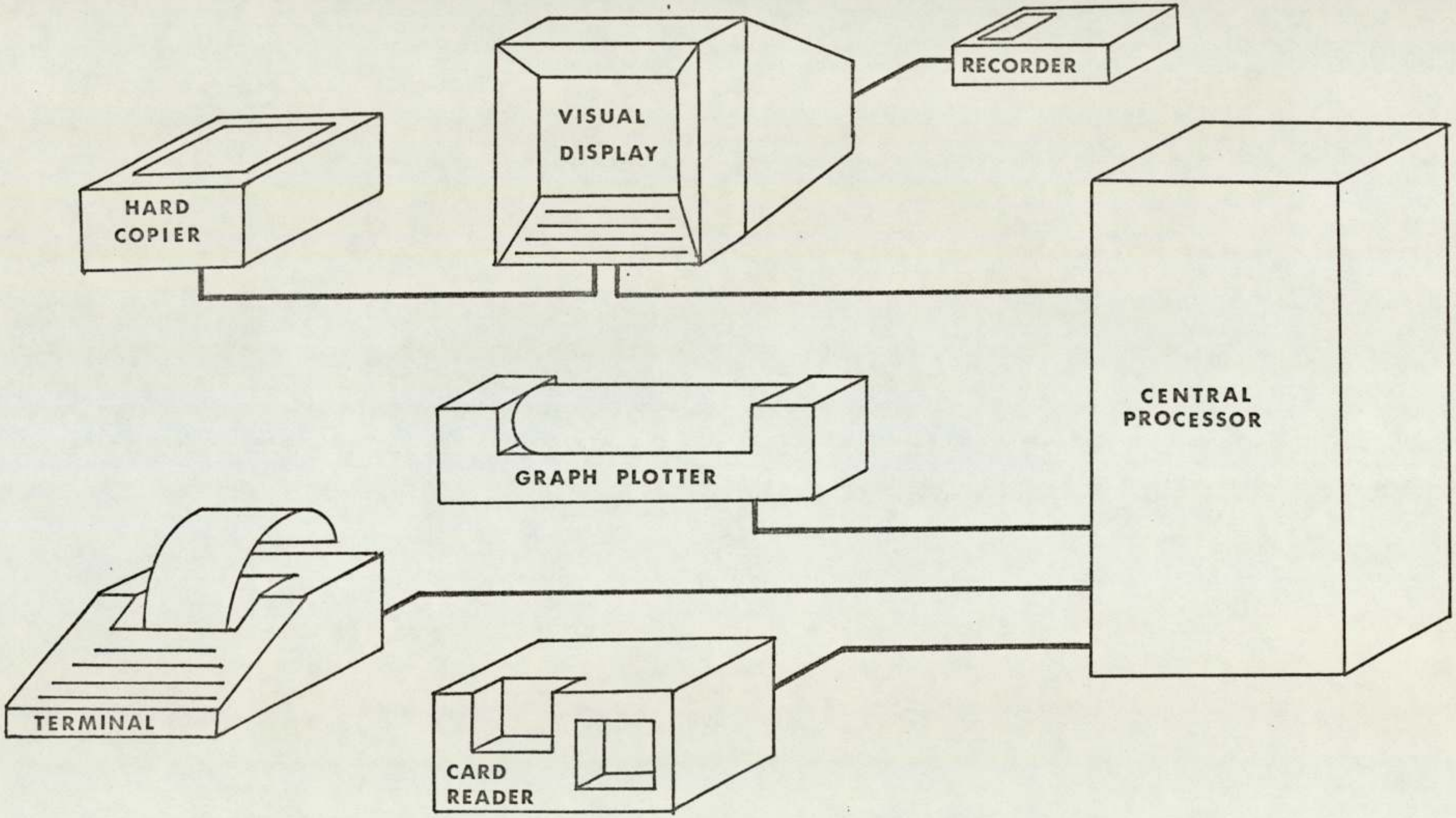


FIG 21 A COMPUTER HARDWARE SYSTEM FOR INTERACTIVE JOB SHOP LAYOUT

ful facility for revising decisions and training plant layout personnel.

Whilst this chapter is primarily concerned with the development of a set of computer programs for the two part layout philosophy the brief discussion on computer hardware equipment demonstrates that in addition to considering the importance of the design model the actual design process, which relates the functions of model, designer and equipment, can improve or decrease the possibility of obtaining a good design layout.

6.2. A Program Suite for Job Shop Layout

When examining computer programs for facility layout two separate areas present themselves for investigations:

1. The technical construction of programs.
2. The manner in which the programs satisfy the design system.

The major portion of the detailed technical construction of the program suite developed in this research for the examination of job shop rearrangement has been extracted from the main thesis and included in two appendices, Appendix B containing the main program listings and general flow charts and Appendix C containing a comprehensive user's guide.

Written in the Fortran language for use on an ICL computer an initial set of three programs UA1, UA2 and UA3 have been developed on a modular basis to implement the progressive two stage heuristic philosophy presented as part of this work. In addition two further programs UA4 and UA5 have been added to the system by Choi (16) to enable the automatic preparation of layout diagrams at any stage in the simulation changeover. The overall arrangement of modular programs and intermediate files are shown in Figure 22, which also contains an indication of the points at which information is input and output form the program suite.

Whilst detailed discussion of programs is inappropriate at this stage two important observations can be made regarding the modular nature of the programs. The models presented for job shop layout and examination are necessarily detailed and involve certain assumptions and restrictions. With a view to developing the models into further problem formulations or alternative criteria the modular nature of the programs will allow easier changes in program construction.

The second observation concerns the important question of computing time. The development of any program for the general facility layout class of problem requires a constant balancing of accuracy and computation time, a point given consideration in the development of the two stage model. By arranging the programs on a modular basis further savings were possible without compromising the original models. The approach of developing separate programs and linking by mag-

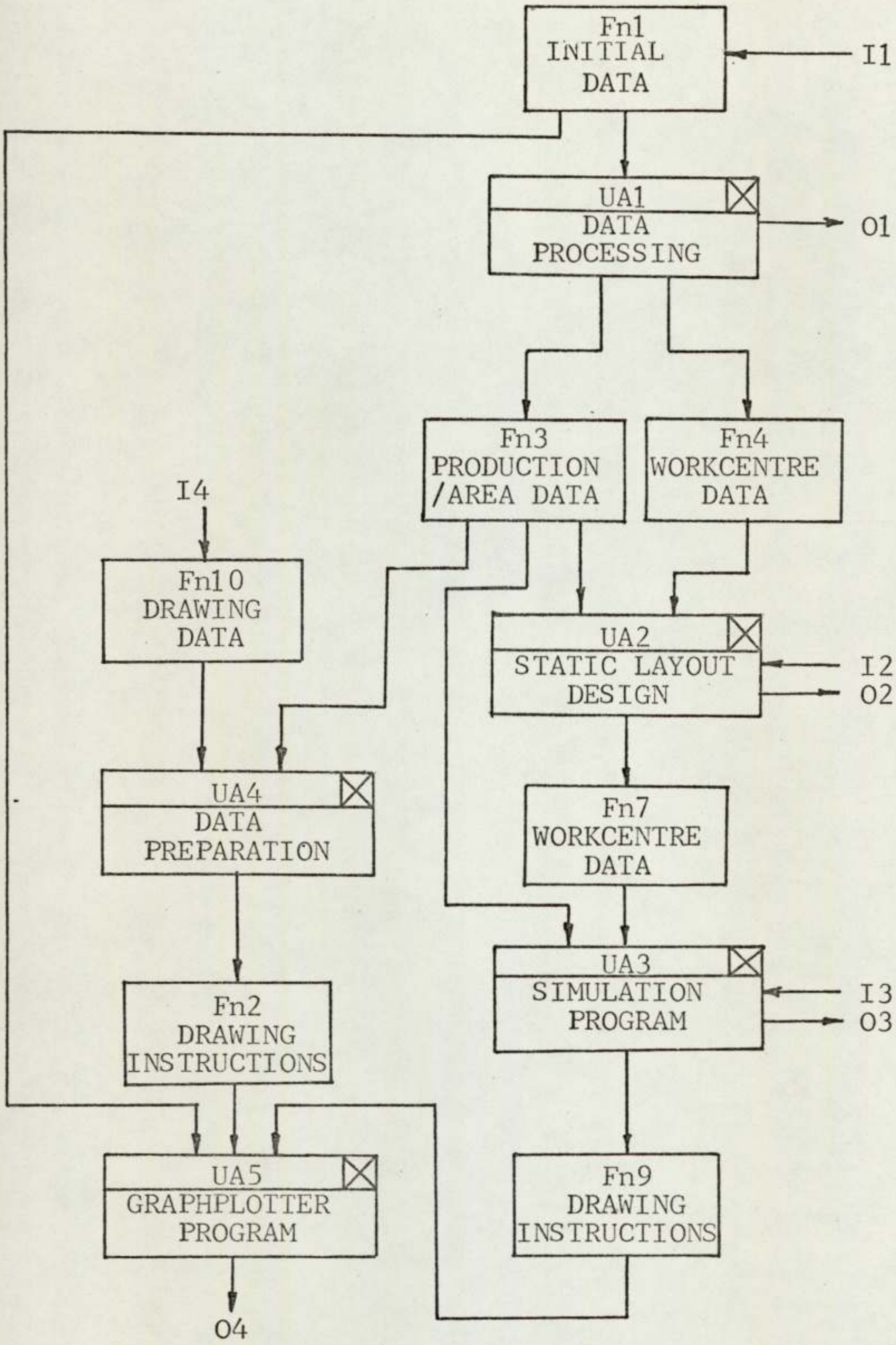


FIG 22 PROGRAM AND FILE ARRANGEMENT

netic file stores is both clear and efficient. The tasks of the three programs are:

UA1	Data checking
UA2	Static layout design
UA3	Dynamic changeover simulation.

In splitting up each section of the design process an additional cost in computation time is incurred writing to files and re-reading files into the next program. This however is more than compensated for by the savings made from unnecessary calculation repetitions. An average test case, discounting errors, will require program UA1 once, program UA2 two to four times whilst UA3 could be used to simulate more than a dozen varying changeover conditions of life span, boundary distance, rate of return or other parameters. By segregating on a modular basis the different levels of use substantial computation savings are possible.

Discussing computer programs in a more general sense an important part of their function is to satisfy and enhance the design process in a similar manner to that discussed earlier in the case of computer equipment. Apple and Deisenroth (4) and Muther and McPhereson (49), referring to a design seminar held on computer aided plant layout, put forward a list of desirable criteria for computer layout programs which is shown reproduced in Table 9. and which can be used to examine the usefulness of programs UA1 to UA3.

Five of the sixteen points (5,6,7,13 and 16) are con-

1	Reliability
2	Realistic - i.e. using real data
3	Ability to weight inputs
4	Elimination of human evaluation of solutions
5	Develop better configurations of activity centres
6	Allow for fixed activity centres
7	Honour building restrictions
8	Permit use on multi-story layouts
9	Consider cost incurred by alternative layouts generated
10	Provide more realistic cost evaluation
11	Contain a minimum of restrictions to retain flexibility
12	Ability to extract desirable features from a specific layout for insertion into another
13	Result in a more realistic graphical output
14	Eliminate manual adjustment of graphical output
15	Handle undesirable (negative) interrelationships
16	Applicability to detail layout - i.e. machine layouts, etc.

TABLE 9 CRITERIA FOR A COMPUTER LAYOUT PROGRAM
(After Apple and Deisenroth)

cerned with realistically representing facilities and layout area. In the initial program suite this representation of facilities and layout area has been developed using an outline co-ordinate system, capable of maintaining shape and area. The limited usefulness of popular block diagram representation has been discussed in the review of existing techniques and as a result has been discarded in favour of the co-ordinate system which at a future point will enable an easier modification to include visual display programs.

Using co-ordinate representation affects the computer program in two respects, core size requirements and computer run time. With the use of the co-ordinate representation of shapes the program core image requirement is not related to the unit size of each matrix segment and therefore can be standardised for a range of problems.

However with the use of co-ordinate representation there is also an increase in computer time requirements. The design of computer programs to embody a layout philosophy requires a constant balancing of accuracy against computation time. The more accurate the representation or the more accurate the determination of movement the greater the computational cost. In developing the techniques for determining movement distance used in the dynamic simulation model a relationship between the estimated number of required calculations and the number of possible obstruction lines was noted. Illustrated in Figure 23. for the three techniques that checked movement against obstructions the diagram shows that

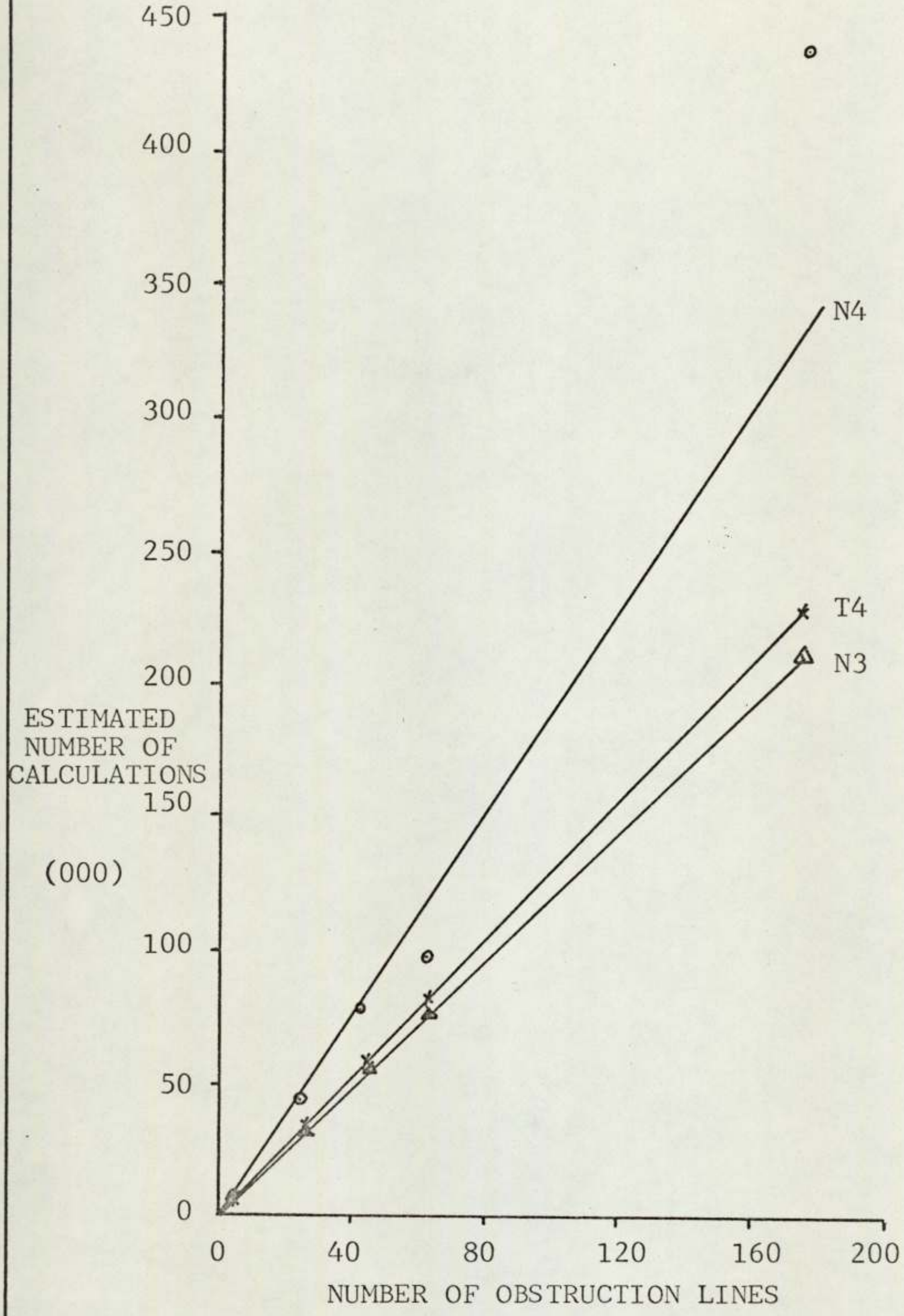


FIG 23 EFFECT OF LAYOUT COMPLEXITY ON THE NUMBER OF REQUIRED CALCULATIONS TO DETERMINE MOVEMENT DISTANCE.

there is a proportional increase in computation costs as the number of outlines increases. Clearly the more realistic and detailed a layout representation used the greater will be the computer time requirement.

One aspect of realistic representation is not covered in the present set of programs and that is the question of multi-storey layout (Point 8). With the current trend towards lower cost single-storey manufacturing buildings and the problem being one of arranging workcentres in a department rather than arranging departments within a building the number of occasions on which a department will extend over more than one floor level is relatively few in comparison.

The interactive approach developed as part of the programs satisfies three of the criteria (Points 3,12 and 15), allowing the designer to give account to subjective factors in what is essentially a quantitative model. However the interactive approach appears to be contrary to two further points, firstly the elimination of human evaluation of solutions and secondly the elimination of manual adjustment of graphical output. The need to use designer judgement has been discussed in the development of the static layout design model and is considered essential at the detailed job shop level. Whilst it is desirable to use the computer whenever possible the complex nature of realistic problems will almost certainly require the designer to examine layout arrangements at some stage in the design process.

Two further criteria in Table 8 stand out in importance, the need for realistic data and providing a more realistic cost evaluation. Within this work a number of major modifications to the quantitative materials movement criteria have been included in the changeover simulation model to provide a more practical evaluation of layout designs.

Obtaining realistic data is a problem encountered by all layout designers and is particularly applicable at the job shop level. Within any one job shop determining the product data is the most difficult task. Not only are product batch sizes subject to variation but in practice with the large number of products involved workcentre sequences may have to be partially estimated and representative product lines selected. Under these circumstances it is necessary to assume that the problem data represents how the job shop should operate and to view the results obtained in the light of the estimated data accuracy.

Before concluding the section on the computerised layout system one further aspect is worthy of mention. The approach adopted is an interactive one between designer and computer which leads to the question of assigning tasks in the design process between the two. In an interactive relationship it is not the most efficient way to assign all the tasks possible to the computer, an example of this is the question of interpreting visual images. A designer is capable of telling at a glance the overlapping of facilities when presented in visual form whereas a computer would need to undertake an extensive set of comparison calculations where a co-ordinate system is in use. The inability to comprehend pictures is one of the major limitations of present computers. Alternatively data checking and quantitative calculations are achieved more efficiently by computers. As a general guide within programs UA1 to UA3 subjective and visual decisions where assigned to the designer and quantitative calculations, data checking and data manipulation were assigned to the computer.

Within this chapter the selection of computer equipment and the design of computer programs for workcentre layout problems have been examined. The technical description of the programs written to embody the static layout design model and the dynamic changeover model have been introduced and reference made to detailed listings and instructions contained in Appendices B and C. At the same time a more general examination of the overall concepts of a computer system has been discussed with a view to defining those objectives that would enhance the possibility of obtaining improved layout arrangements.

7. EXAMINATION OF PARAMETERS

The extended layout approach adopted for examining the layout of workcentres in a job shop situation has brought forward a number of parameters that can affect the introduction of layout changeover and the financial return to be obtained from the project. These parameters can be identified as:

PF	The fixed cost values associated with moving each batch of products.
E	Boundary distance between local movement (excluded from cost model) and departmental movement (included in cost model).

Associated with the evaluation of materials movement.

WR	Relocation cost associated with moving workcentres.
R	Rate of return on cash flows throughout the project.
TP	The number of time periods in the project.

Associated with the financial evaluation model.

LN	Limiting number of workcentre relocations per time period.

Associated with the dynamic changeover simulation.

The highly individualistic nature of layout problems will prohibit the formulation of specific relationships between project return and each parameter, however an indication of their influence on layout projects can be obtained by the examination of an industrial test case.

7.1. Selection of Test Cases

The test case selected is based upon the manufacturing program of a company engaged in the production of high speed cylindrical knitting machines and involves the relocation of 34 main workcentres and 5 dummy workcentres in the area shown in Figure 24 to suit the introduction of group technology cells. In designing the tests five permutations of the basic problem are examined to allow for the possible influence of flow dominance in the production data. The supporting information for each problem and test result has been included in Appendix D.

The five problem variations, designated A1 to A5, have been derived in the following manner:

A1 Using the original problem data (A5) each workcentre relocation cost and fixed cost of moving product batches is reduced to zero. This leaves only the distance variable materials movement cost for inclusion in the financial model. The resultant problem therefore is in the most "sensitive" form where costs will be related in the most direct way to workcentre positions.

A2-A4 These three test cases contain the variation in batch quantities used to reduce the influence of dominance in materials movement.

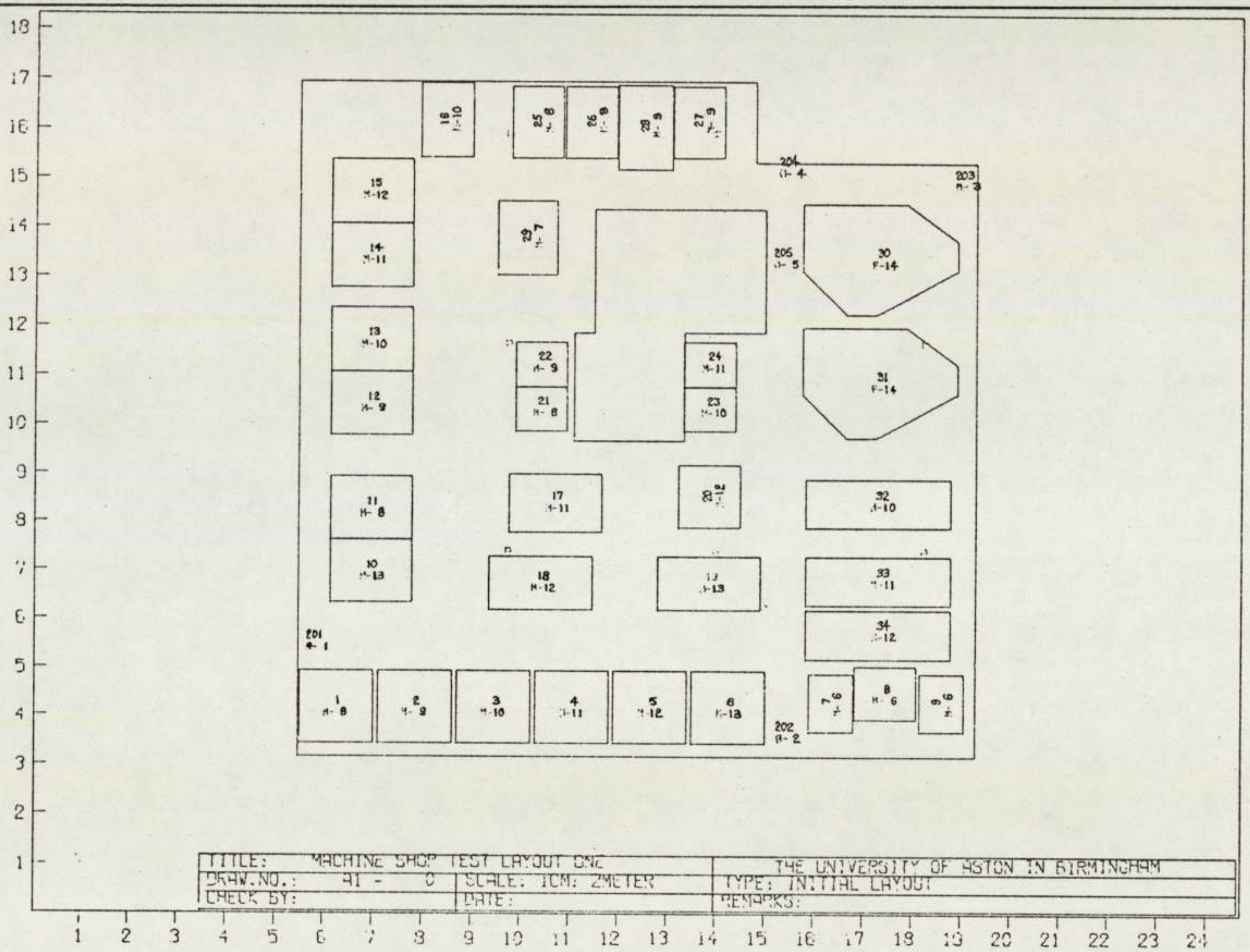


FIG 24 INITIAL LAYOUT FOR TEST CASES A1 TO A5

The coefficient of variation*, used originally by Vollman (61) as a means of indicating dominance independent of production quantities, has been adopted as a measure of variance. The variation in product batches ranged from 81% (case A1) to 397% (case A4). The variance of inter-workcentre movement cost, a better indicator of real variance, ranged from 80% (case A1) to 156% (case A4).

A5 This is the original problem with all cost values returned and is used to examine in detail the effect of the number of relocation moves per period (LN).

7.2. Static Layout Design using Test Cases

The first stage in the examination of parameters is to develop the final layout arrangement for each test case. Two of the five test cases, test case A1 and test case A5 contain the same product batch quantities and variable movement costs and therefore will produce the same cell diagrams, leaving four arrangements to develop.

The initial placement order for the fourteen cells in each of the five test cases is shown in Table 10. The first six cells, cells 1 to 5 and 14 all fall in the

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* The coefficient of variation equals the standard deviation divided by the mean and expressed as a percentage.

PLACEMENT ORDER	TEST CASE A1 AND A5	TEST CASE A2	TEST CASE A3	TEST CASE A4
1	1	1	1	1
2	2	2	2	2
3	3	3	3	3
4	4	4	4	4
5	5	5	5	5
6	14	14	14	14
7	7	12	12	12
8	13	7	7	9
9	11	11	11	7
10	12	13	9	11
11	9	9	13	13
12	10	10	10	10
13	8	8	8	8
14	6	6	6	6

TABLE 10 PLACEMENT ORDER FOR CELLS IN TEST CASES A1 TO A5

completely prefixed group and therefore were given priority location, as in practice each workcentre in these cells already occupies its final position. With the absence of partially fixed cells the remaining free cells were placed in order of their potential external movement. The resultant cell centres (Table D3) and cell diagrams (Figures D1 to D4) are included in Appendix D.

The shape of the layout area for the five test cases produced an illustration of both the problem of working at a more detailed level and the concept behind adopting an interactive designer-heuristic approach. With the fixed cells transferred there resulted a concentration of cells within the restricted north-eastern corner of the layout area. Cell 4 (workcentre 204), cell 5 (workcentre 205) the two starting and finishing cells for product sequences, along with cell 3 (workcentre 203) and cell 14 (workcentre 30 and 31) are all concentrated within the north-eastern corner. In consequence the minimum cost position for each of the free cells, next allocated for placement, will be in an unacceptable position within this area. Inspecting the diagram the designer can choose between searching for a possible location around the minimum point or to move using the guide. In each test case cells were relocated to the nearest available area using the movement guide, with the result that as more cells were located so the minimum cost positions varied.

In the review of present techniques a number of general schematic techniques were criticised for the large number of interpretations that can be given to schematic diagrams. At this point it is worth noting the distinction between the variability just described and the variability inherent in an interactive design process. Decisions made by the designer in the interactive process are firstly made during the exercise at the correct time and secondly specific quantitative information is provided on which to base decisions, whereas earlier schematic methods were a question of interpreting loosely constructed arrangement diagrams.

The next stage after designing the cell diagram is to position workcentres within cell areas, a function at present achieved manually by the designer. The workcentre arrangements for the test cases resulting from this stage (Figures D5 to D9) and the workcentre co-ordinates (Table D4) are included in Appendix D.

In defining the objectives of the static layout stage two points are of major importance:

1. To create a satisfactory arrangement of workcentres to suit the new production program using materials movement cost as the layout criteria.
2. To maintain within any new arrangement the close proximity of workcentres in the same cell as far as is possible.

In the static layout model workcentre cells are represented by proportional area circles which during the final transition from cell diagram to workcentre layout will in practice assume a variety of shapes not necessarily circular. An indication of the variation in final cell shape for the four test cases is given in Table 11.

Spread ratio expresses the mean displacement of workcentres from the cell centre as a function of cell size, for with large cells physical size will require workcentres to be spread out further. The maximum cell length, taken as the maximum possible straight line distance between the two extreme workcentres in each cell also indicates distortion and in the four test cases the maximum cell length was 13.0 metres in a cell circle of radius 6.7 metres. This cell will have assumed a distorted ellipse shape within the layout.

Two difficult types of layout situation exist with regard to the workcentre placing stage, firstly one cell may contain two fixed workcentres that have to be placed apart thus making a compact cell impossible, and secondly a number of cell centres may have been placed in close proximity, cramping the workcentres in one particular cell. As neither of these two cases were experienced in the static layout design stage the workcentre arrangements for test cases A1 to A5 were both continuous and compact.

From the static layout exercise the following general observation was formed:

> "The adoption of a two stage approach of
> firstly placing cells and then individual

CELL	CELL CIRCLE RADIUS	MEAN DISTANCE				SPREAD RATIO				MAXIMUM CELL LENGTH			
		A1	A2	A3	A4	A1	A2	A3	A4	A1	A2	A3	A4
6	2.7	2.3	2.9	1.9	1.9	0.85	1.07	0.70	0.70	3.2	2.7	2.8	2.8
7	1.9	1.9	2.4	2.2	1.7	1.00	1.26	1.16	0.89	0.0	0.0	0.0	0.0
8	5.8	3.9	5.1	6.6	6.6	0.67	0.88	1.14	1.14	6.3	3.0	7.3	7.3
9	5.9	3.7	3.9	4.0	2.7	0.63	0.66	0.68	0.46	11.0	11.0	7.5	5.9
10	6.3	7.2	3.8	4.4	4.5	1.14	0.60	0.70	0.70	8.2	7.2	11.1	11.3
11	6.5	3.4	3.3	3.1	3.7	0.52	0.51	0.48	0.57	6.8	6.8	6.8	7.4
12	6.7	5.1	6.0	6.0	6.0	0.76	0.90	0.90	0.90	13.0	13.0	13.0	13.0
13	5.2	3.4	3.2	3.3	3.1	0.65	0.62	0.63	0.60	8.1	7.6	8.1	8.1
AVERAGE VALUES		4.2	4.1	4.3	4.2	0.78	0.81	0.80	0.74	8.1	7.4	8.1	8.0

$$\text{SPREAD RATIO} = \frac{\text{MEAN DISTANCE}}{\text{CELL RADIUS}}$$

TABLE 11 INDICATION OF PROXIMITY OF WORKCENTRES TO CELL CENTRES

> workcentres has resulted in the formation of compact facility groups satisfying the major layout objective of close proximity of workcentres in each cell. In addition the use of a manual method for locating workcentres within cells saves considerable computational effort for what would be an exhausting and highly complex task, a task beyond present programs and one in which there is no guarantee at all that comparable results can be achieved by computer for practical numbers of facilities."

Having discussed the more physical aspects of static layout for the four test cases there remains the question of examining the effect of the initial list of parameters on the financial evaluation model and dynamic changeover.

7.3. PF - Fixed Cost per Batch

Within the dynamic changeover model a modified version of materials movement cost has been developed introducing two additional parameters, a fixed cost per batch and a boundary distance between local and departmental movement. An indication of the potential influence of increasing fixed costs is shown in Figure 25. Fixed movement cost per batch, in common with a number of other parameters examined, introduces a cost influence not dependent on the position of workcentres and which consequently increases the general level

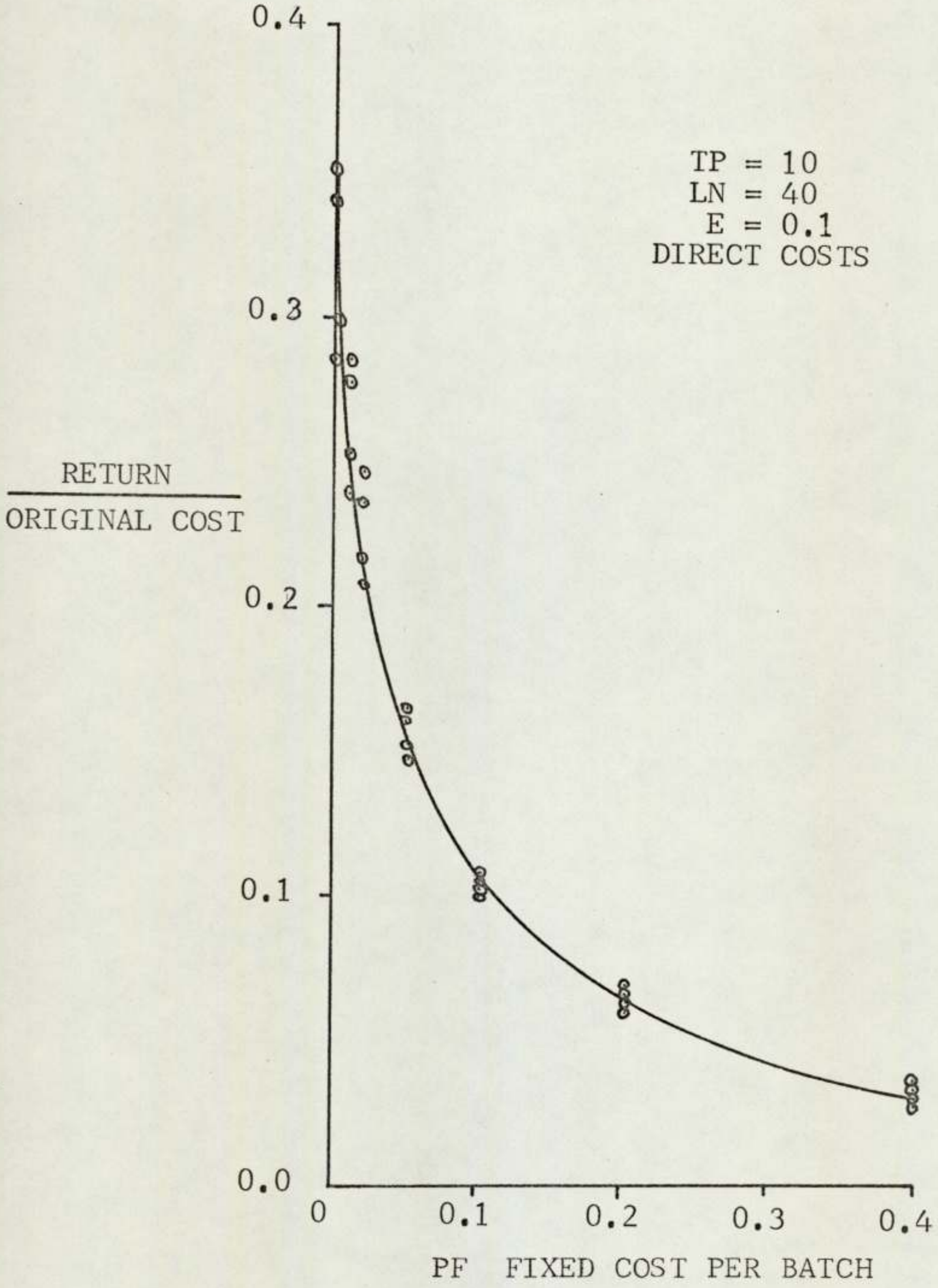


FIG 25 PROJECT RETURN RATIO AGAINST FIXED COST PER BATCH

of costs and reduces the ratio between project return and layout cost as illustrated in Figure 25.

In the test cases the fixed cost of moving each batch was increased from 0.0 to 0.4 units per batch with the result that the ratio of return over original cost declined from 0.35 to 0.035. The viability of an actual industrial project might be affected if a changeover only produces a 3.5% change in materials movement cost to offset capital outlay. Whilst in practice fixed movement cost varies for each product according to the handling equipment used, the test further indicates the influence of fixed cost in a job shop situation where movement distances are comparatively shorter than in inter-departmental movement. Using metric distances the ratio between fixed and variable cost was in the range 1/40 to 1/80 for the full test case (A5). Applying this ratio to the test layout area 27 metres long by 27 metres wide, and assuming an average movement distance of 20 metres the fixed cost parameter could contribute between 25% to 50% of total materials movement cost.

7.4. E - Boundary Distance

The second modification to the materials movement cost criterion is the use of a boundary distance to differentiate between local and departmental movement. In a job shop environment where the product range is physically small enough to enable movement by hand machine operators will generally undertake movement between neighbouring workcentres without requiring the use of handling equipment. Whilst this local movement is achieved by an unofficial arrangement within the job shop movement of this type does in practice occur, movement within group technology cells will be largely local in nature.

To examine the effect of introducing a local movement factor the value of E, measured as the straight line distance between workcentres, was varied from 0.0 metres to 20.0 metres, with regard to final layout cost and project return.

The result of increasing boundary distance on the materials movement cost of a layout is shown in Figure 26. for the four final layouts of test cases A1 to A4. Initially no change occurs until E reaches the minimum movement distance of approximately 2.0 metres, after which layout costs decline steadily as would be expected with increasing E values.

The effect of this increasing E value on project return is shown in Figure 27. Assuming that each of the four final layouts are less expensive in materials movement cost than the initial layout then this would be the result of a lower distribution of movement distances, as illustrated in Figure 28. Examining this distribution, as E increases initially more final layout distances will drop out of the cost calculation resulting in an increase in project return. Eventually a greater number of initial layout distances will drop out than final distances and combined with the overall

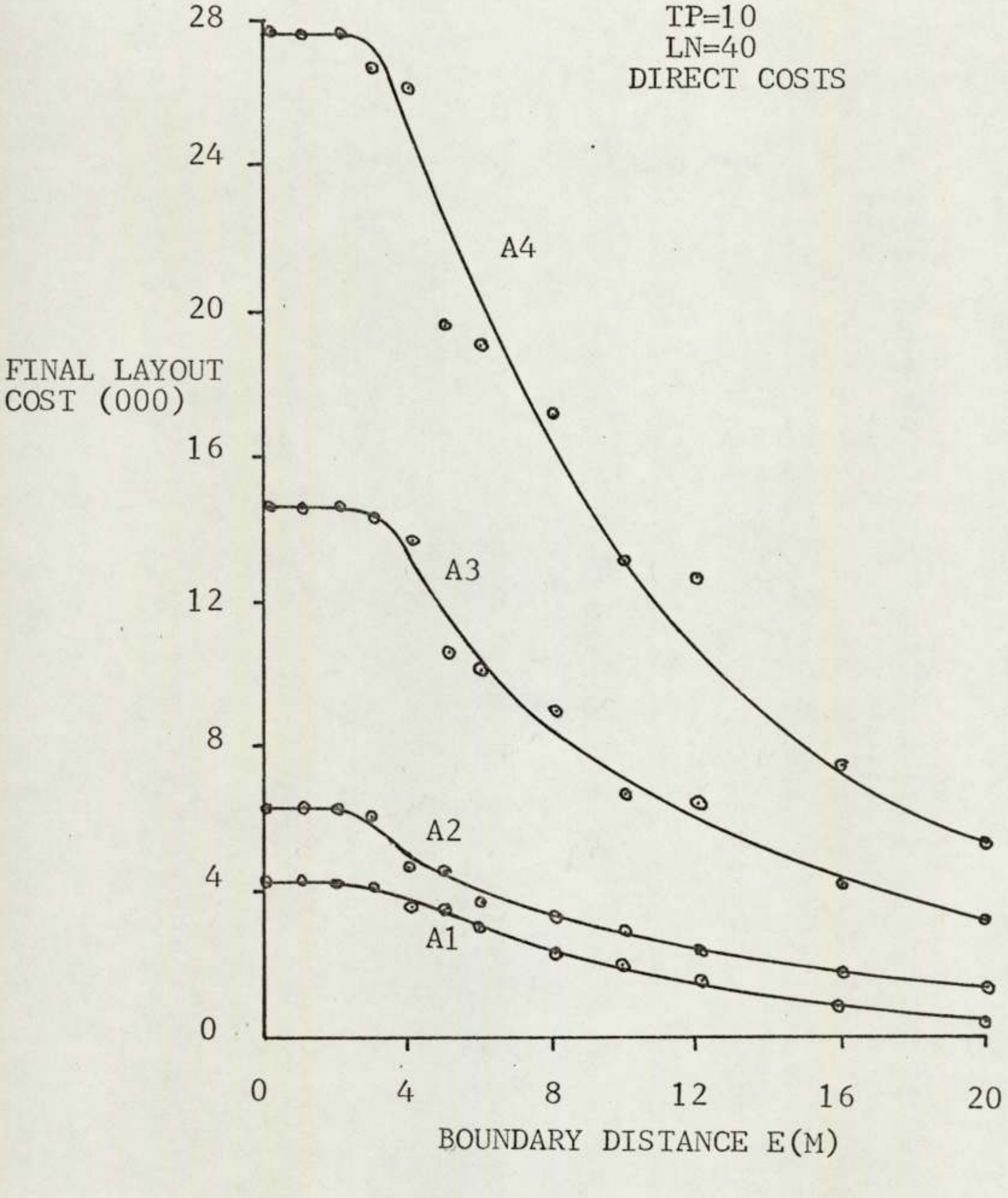


FIG 26 EFFECT ON FINAL LAYOUT COST OF BOUNDARY DISTANCE

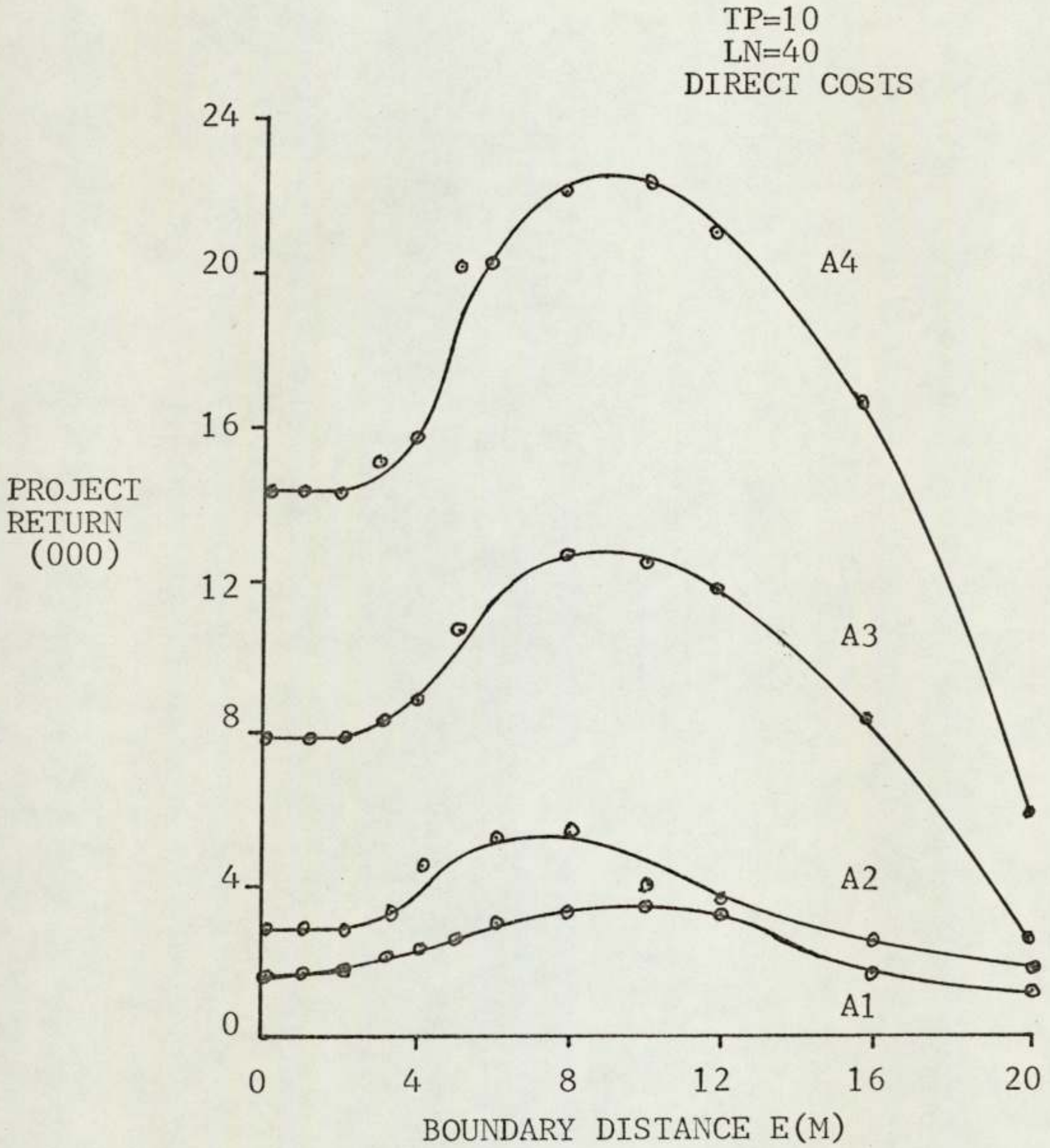


FIG 27 EFFECT ON PROJECT RETURN OF BOUNDARY DISTANCE

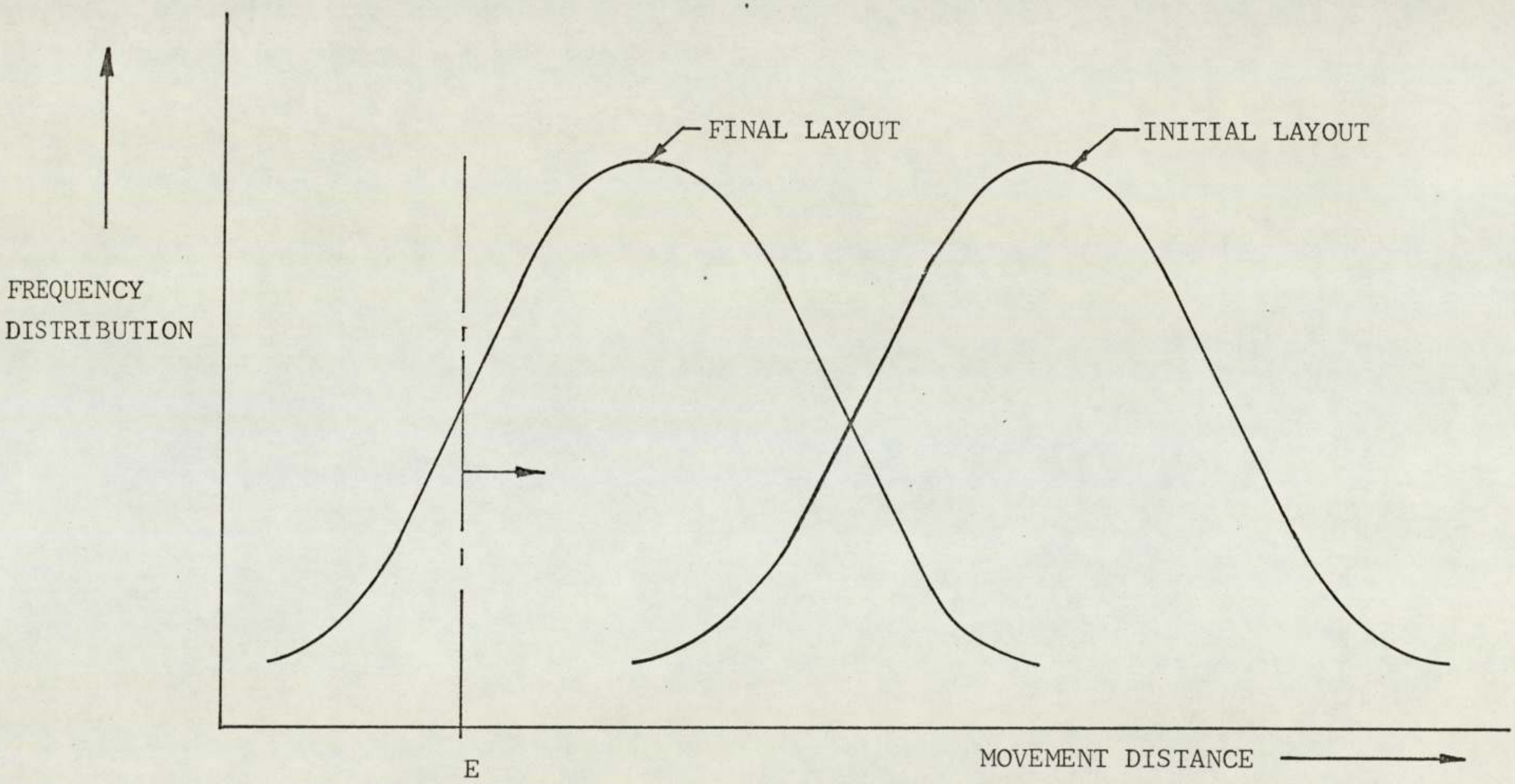


FIG 28 EFFECT OF BOUNDARY DISTANCE ON THEORETICAL DISTRIBUTION OF MOVEMENT

decrease in layout movement costs there will be a resultant decline in project return.

Considering the influence of local movement in a similar manner to fixed movement cost on materials movement as a criterion the effect of using an average 5.0 metre boundary distance would be to decrease the cost of final layout by 14% to 30% in total. The average length of workcentre cells within these examples was 7.9 metres showing that if products were suitable for local movement a boundary distance of 5.0 metres would not be unreasonable, giving a resulting increase in project return as indicated.

The fixed movement cost per product batch and boundary distance for differentiating between local and departmental movement, along with a more accurate distance measuring heuristic, have been introduced to model more realistically the behaviour of materials movement in a practical job shop situation. On investigating the two parameters fixed movement costs have been found to influence overall materials movement costs as a result of the relatively short distances moved within a job shop and for the same reason boundary distances in the range 4.0 to 8.0 metres have also affected results.

7.5 R - Expected Rate of Return

TP - Number of Time Periods

Taking an overall view of relocation projects three parameters i.e. rate of return, project life span and relocation costs can affect the viability of a project.

These three parameters are important factors related to discounted cash flow theory, a widely accepted technique for capital investment appraisal and whilst essentially an industrial engineering problem, a financial model has been chosen to assess the contribution of layout decisions to the overall manufacturing system.

Within the dynamic simulation of layout changeovers there exists all the important factors of capital evaluation theory, with cash flows in the form of changing materials movement costs, capital outlay in the form of workcentre relocation costs and pay back period in the form of projected life span. Under these conditions it is important to consider both the direct costs involved in layout decisions and the parallel effect of declining or appreciating value placed on money. For this reason the evaluation model, as part of the dynamic simulation stage included in program UA3, outputs both sets of costs for consideration by the designer.

Before proceeding to examine the full range of dynamic changeover situations an indication of the effect of these parameters can be obtained by discussing the case of the immediate changeover of layout arrangements at the beginning of the project i.e. all workcentres relocated in one attempt.

Using test case A1 the influence on project return of time periods and rate of return is shown in Figures 29 and 30 respectively. The effect of rate of return is to reduce the relative importance of cash flows in the later stages of a project and therefore where a rate of return is expected changeover decisions are affected in two ways:

1. The eventual real contribution to the overall project may not be sufficient to justify proceeding with a particular changeover sequence.
2. The declining value of cash flows could be used to reduce the maximum capital outlay required throughout a project.

7.6. WR - Workcentre Relocation Costs

In the two part philosophy materials movement is used in the static layout stage as a basis for layout of cells and in the dynamic simulation stage materials movement is used in the evaluation model. To a certain extent this has prejudged the relative importance of materials movement as a layout criterion, selected because of the relationship to actual workcentre positions.

Consider the relative scales of materials movement and relocation costs as illustrated in Figure 31. Region A could be associated for example with short life span projects where relocation costs would be proportionately higher than the materials movement cost incurred throughout the

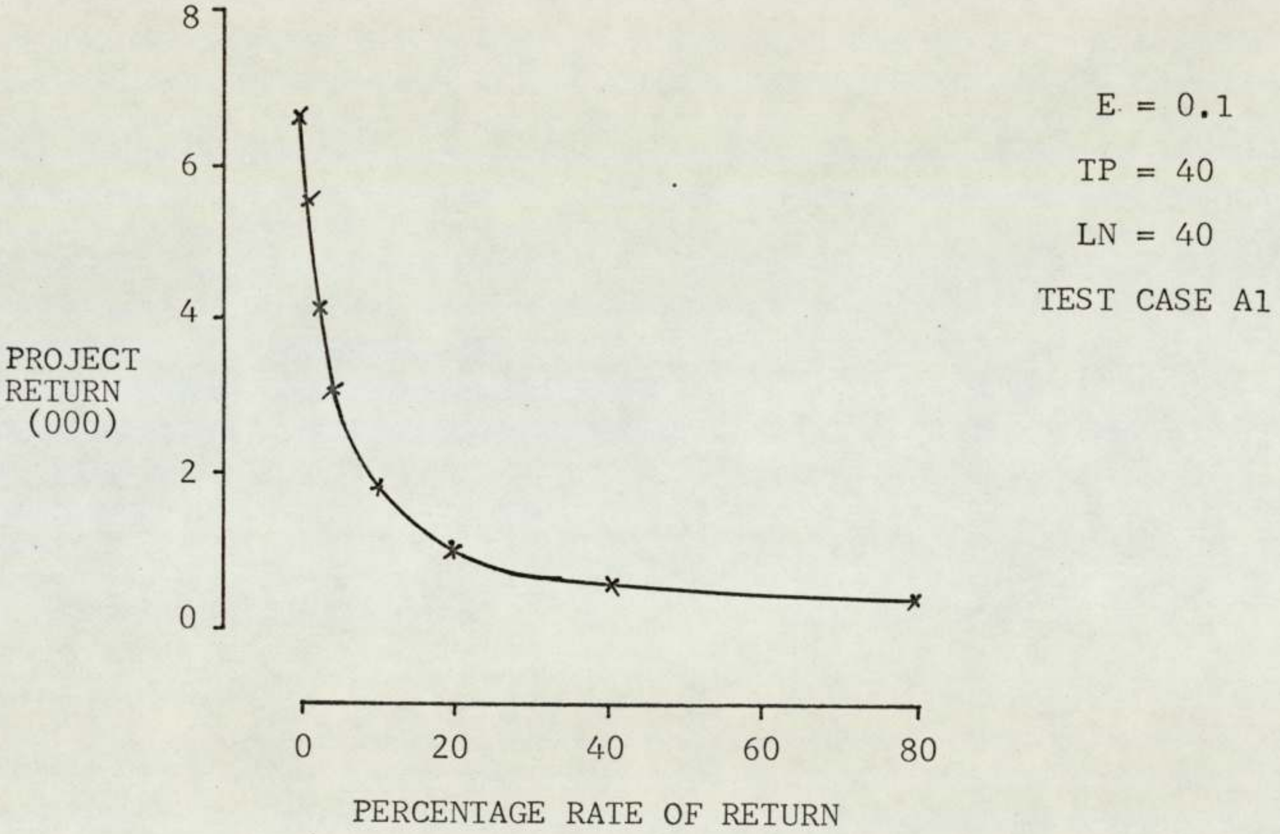
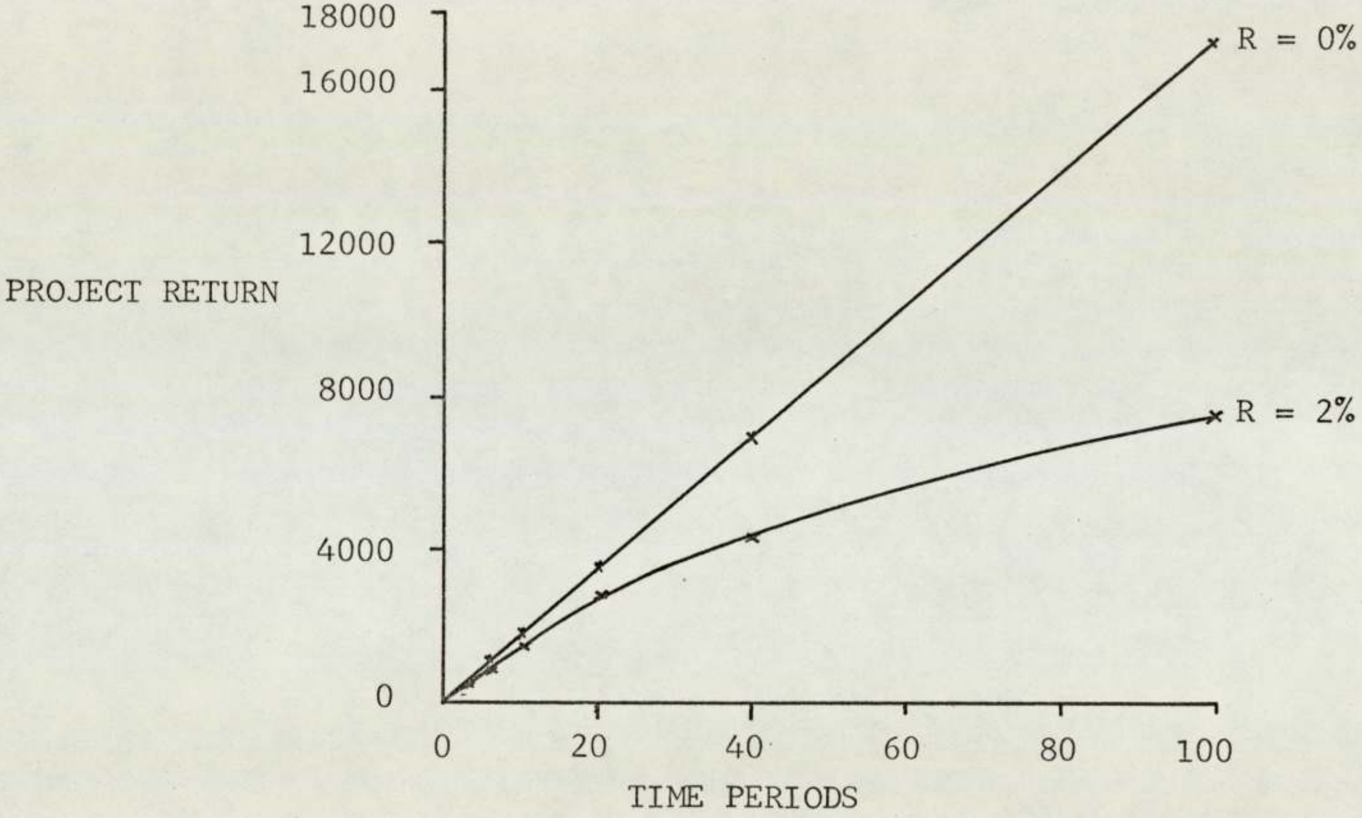


FIG 29 INFLUENCE OF PERCENTAGE RATE OF RETURN ON PROJECT RETURN



E = 0.1

LN = 40

TEST CASE A1

FIG 30 INFLUENCE OF TIME PERIODS ON PROJECT RETURN

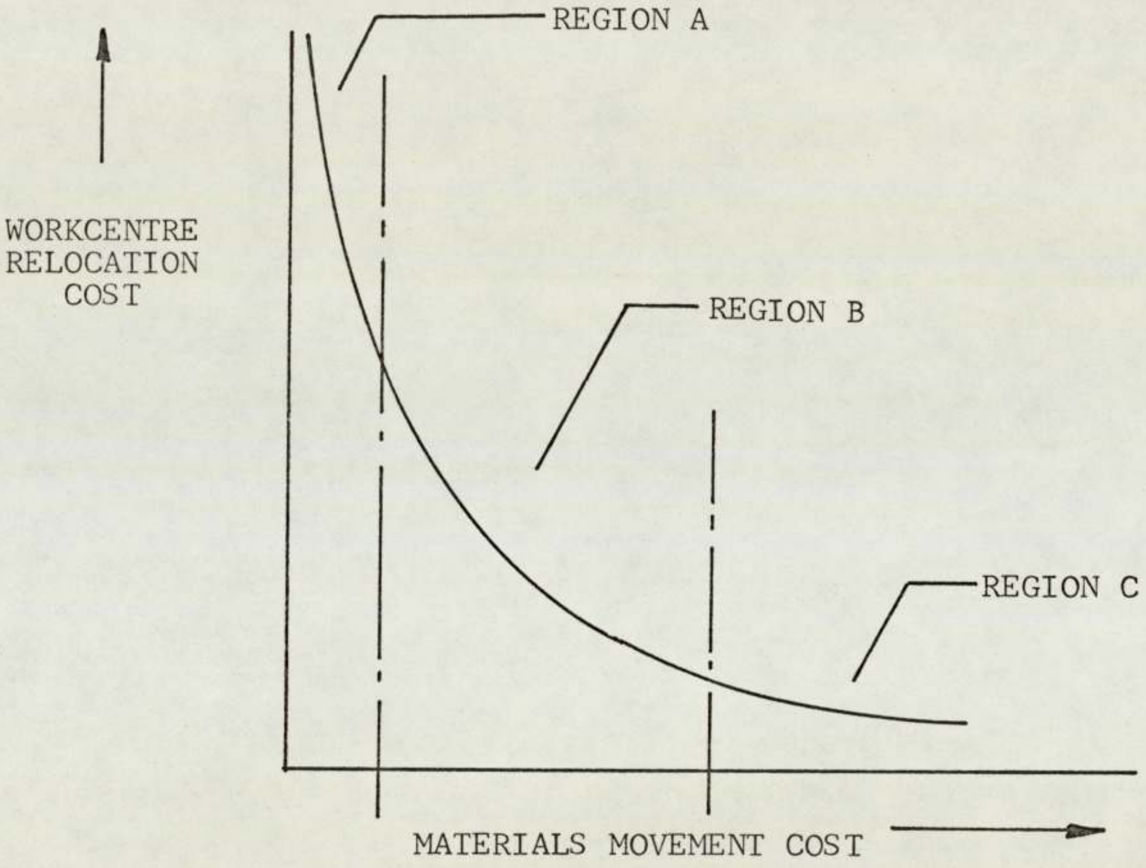


FIG 31 THEORETICAL RELATIONSHIP BETWEEN RELOCATION AND MATERIALS MOVEMENT COSTS

project life span. This presents the need to develop alternative layout models using a more appropriate evaluation criterion. Regions B and C contain a more proportionate relationship between the two costs in which the expected contribution to the overall project can be dependent upon any of the parameters discussed so far. Test case A5 for example contains total relocation costs of 2080 units, comparing this to a life span of 32 time periods the result of relocating on direct costs would produce a project return of 3450, reducing life span to 10 time periods would result however in a negative project return of -352 units.

Within individual layout projects therefore it is necessary to consider the relative influence of workcentre relocation costs with respect to the overall contribution to the manufacturing system.

7.7. LN - Limiting Number of Workcentre Relocations Per Period

The examination of parameters up to this point has indicated the possible influence on evaluation results of a number of parameters, namely fixed cost of moving product batches (PF) and boundary distance (E), associated with materials movement cost, and the rate of return (R), life span (TP) and workcentre relocation costs (WR), associated with the financial appraisal of the changeover contribution to the overall project.

With the examination of the final variable, the limiting number of moves per period, an indication of the dynamic interaction of parameters can be obtained using test case A5 which contains the full range of costs. One modification to the problem has been included to enable small values of LN to be examined. In the development of the dynamic simulation model the problem of a high workcentre area to layout area ratio was introduced with the possible effect of workcentre relocations forming interdependent chains. This occurs with problem A5 where a ratio of 0.54 resulted in a minimum number of moves set at 18. Being concerned more with illustration of the effect of parameters rather than detailed examination of problems, temporary adjustment of positions was allowed to enable the minimum number of moves to be reduced.

The resulting effect of the limiting number of moves on test case A5 for direct costs and a 10% rate of return per period are shown in Figures 32 and 33 respectively.

The resultant variation in project return demonstrates the reasoning behind adopting a modelling approach rather than an immediate attempt to find an optimisation solution. Each of the figures can be interpreted with at least three objectives in view. Firstly there is the examination of capital outlay in the project. In a particular test there may be a restriction of the amount of finance available at the beginning of a project. Considering direct costs this restriction may be overcome by the gradual relocation of

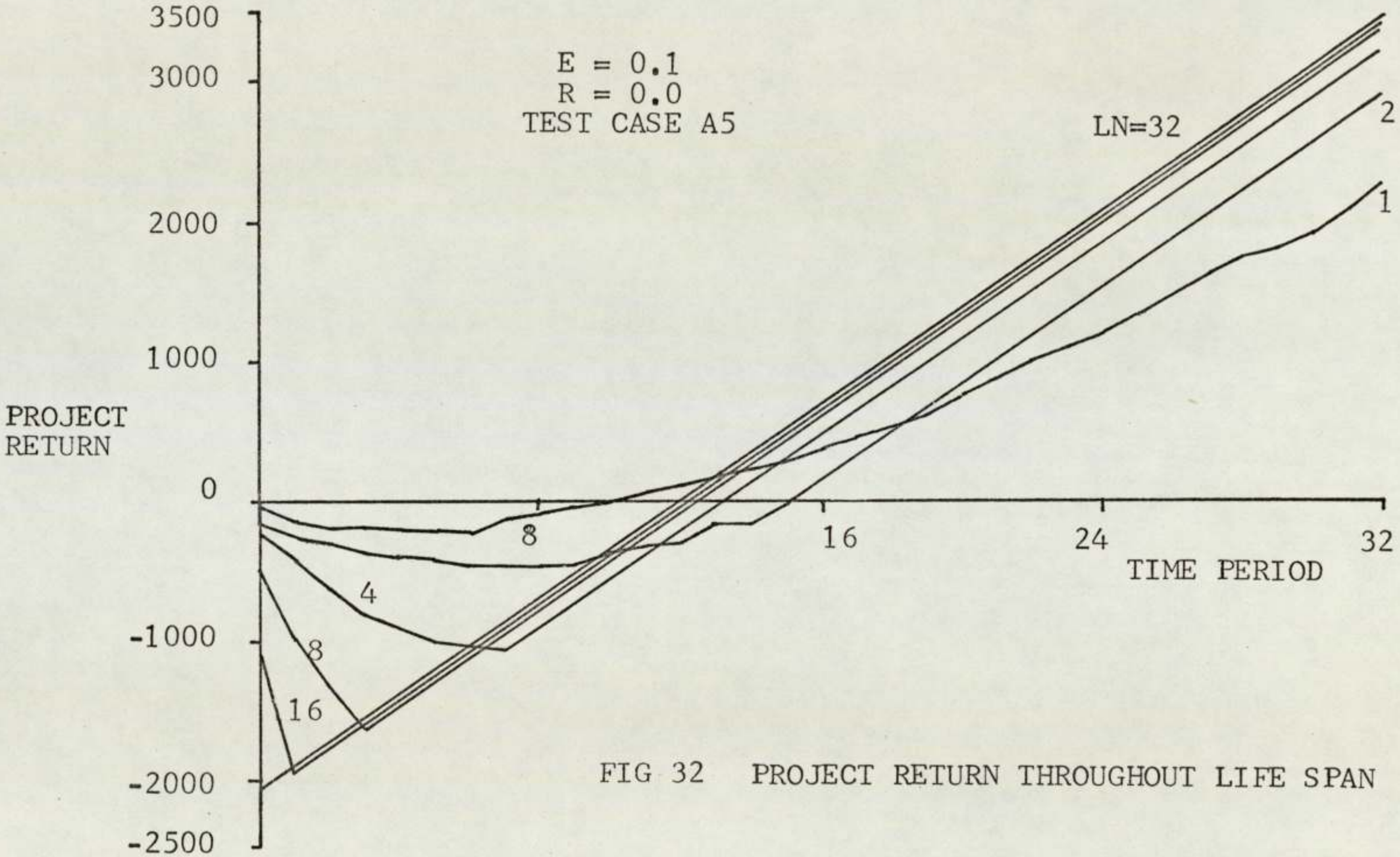


FIG 32 PROJECT RETURN THROUGHOUT LIFE SPAN

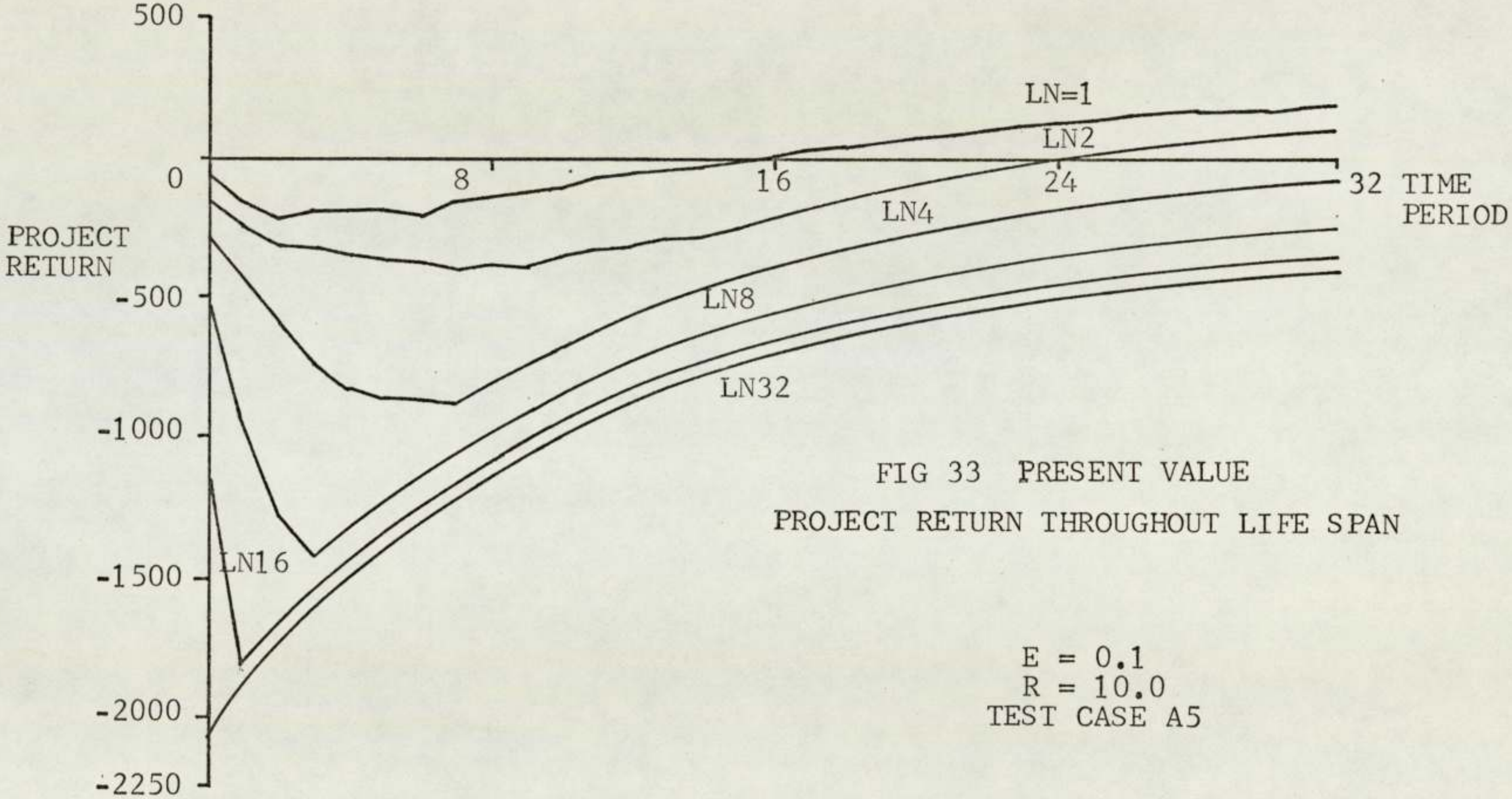


FIG 33 PRESENT VALUE
PROJECT RETURN THROUGHOUT LIFE SPAN

E = 0.1
R = 10.0
TEST CASE A5

facilities where the capital expenditure is reduced and where partial layout benefits can be recovered to assist financing. For test case A5 the maximum capital expenditure declined from 2080 units to 228 units and the changeover was phased out over a greater time span. In the present value case capital outlay can be further reduced by considering the use of the changing value of money. Although high in value the 10% rate of return per period further declined the maximum required capital outlay to 213.5 money units with LN=1.

The decreasing value of LN however has the opposite effect upon final project return. The direct cost case shows the gradual decline in project return from 3450 units to 2281.6 units as a result of the more gradual introduction of new cells and their benefits. The result of using present value factors is clearly illustrated in Figure 33 where the profitability of the number of relocation moves has reversed completely, with the slowest relocation showing the greatest profit. Examining this reversal further there exists the possibility that for any individual problem there is a rate of return for which variation in the number of relocations per time period will still yield approximately the same project return. For test case A5 this rate of return is around 4%, illustrated in Figure 34.

The third objective suggests a possible alternative to financially motivated evaluation of layouts. This is the desire to minimise production disruption to introduce cells within the minimum possible time. Although not examined in

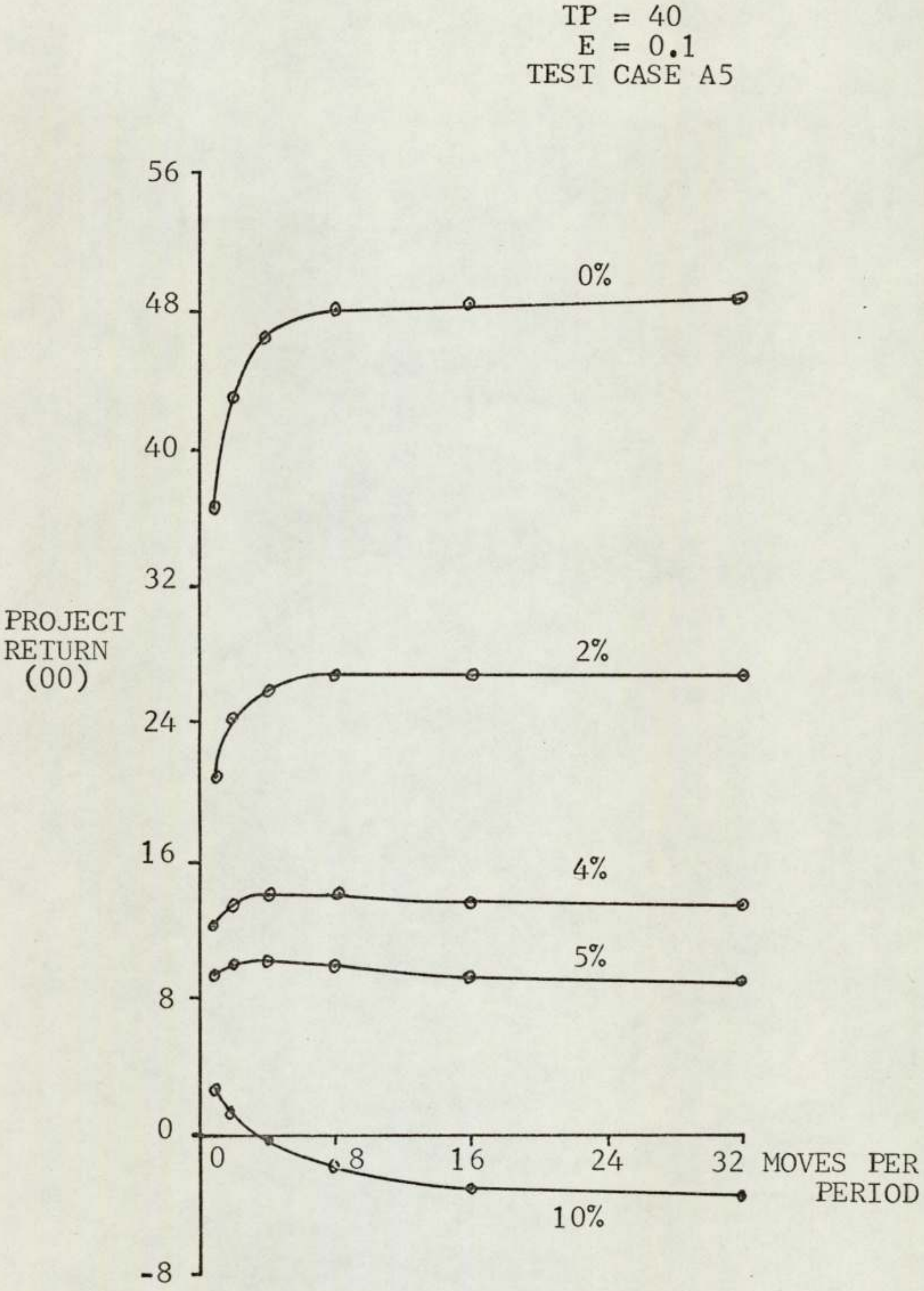


FIG 34
RELATIONSHIP BETWEEN PROJECT
RETURN AND MOVES PER PERIOD

detail the inclusion of inter-workcentre obstructions will disrupt the sequencing of the layout changeover and affect the benefits to be obtained from other manufacturing areas. Where these benefits are important the financial heuristic in the dynamic simulation could be replaced with a heuristic concerned with engineering objectives, for example the introduction of cells in the minimum time interval.

The examination of parameters in this chapter has indicated the influence of a number of variables associated with the two stage philosophy. What is intended in this chapter is to show that the layout of workcentres in a job shop situation brings into conflict four areas of interest, the requirements of the overall manufacturing system, the physical requirements of arranging shapes and areas, engineering objectives within the job shop and finally financial objectives.

Two final observations remain regarding the examination of the test results. Firstly there is the question of the influence of flow dominance in the movement of product batches. At no stage could a relationship be found between the level of project return and the level of dominance for the test cases, possibly resulting from the highly non-linear appearance of the evaluation model after the introduction of the new parameters. However Carter and Whitehead (15), on examining various flow dominances by the use of class intervals, also came to a similar conclusion:

"A decrease in the coefficient of

> variation of the data however, does not lead to a corresponding proportional increase in layout cost".

Secondly there is the question of the overall objective of layout changes. Within the philosophy the overall objective is to assess the contribution of the layout changeover to the manufacturing system. In order to obtain the best total contribution it may be necessary to introduce a layout design that will contribute a loss in terms of the evaluation model. In the event of a negative project return then the attendant reversal of parameter influences should not be neglected.

8. FUTURE WORK

In a project concerned with the relocation of workcentres in the complex job shop manufacturing situation, particularly with the introduction of a new line of investigation, there must exist a number of areas for future work. These extensions of the initial formulation can be grouped for discussion under two headings:

1. Modifications to the present approach.
2. Alternative problem formulations.

8.1. Modifications to the Present Approach.

Within the two stage approach two heuristic techniques were developed for the static layout design section and for the automatic scheduling of workcentre relocations from the initial to the final layout. The static layout design procedure is not exact in nature, working in an interactive mode and containing at present a manual section for the placing of workcentres within cell areas. This manual placing was considered to save extensive computational effort at this detailed level at the cost of only minor increases in materials movement cost although the actual procedure gives no indication of which workcentres within each cell are more important from either a production or layout point of view. A potential area for further investigation is the study of the nature of activity within cells, examining work sequencing patterns and work loading to determine priority ratings for facilities. Lopez (37), examining a matrix grid formulation of the layout problem, located workcentres within cells by the use of a pivot workcentre selected on a relocation cost basis. Questions worthy of investigation regarding the internal layout of cells therefore include:

1. Can a dominant materials movement pattern be detected for internal cell activities and thus be used for arranging workcentres.
2. Could the existence of key production machines be used as a layout basis.
3. Could the existing locations of these key workcentres suggest actual cell locations for the new production program thus reducing relocation costs.

The second heuristic, concerned with the changeover of locations, has been developed to utilise cell priorities as a relocation basis, a priority normally based on potential project return. This problem formulation resembles a sequencing problem and constitutes on its own a major area of future investigation including examination of the following points:

1. How will varying LN during the project lifespan affect results.
2. How can the problem of inter-workcentre location obstructions, which complicates the changeover process, be reduced.
3. Could intermediate layout stages produce inefficient transitional arrangements due to the spread out of part completed

workcentre cells.

Both of the heuristics performed efficiently on the test cases examined. However their use was with regard to examining the nature of a number of new parameters and there is therefore a need to test the models on further industrial examples with a view to their practical usefulness and to compare results against possible alternative solution procedures.

Finally there are a few suggested modifications to the present suite of programs resulting from experience of their use. Most notable is the introduction of visual display equipment as discussed in Chapter 6 with regard to the best possible combination of designer and computer tasks. With the high standard of commercial equipment and software programs available this introduction of on-line images would enhance the practical usefulness of programs UA1 to UA3. Secondly, with the basic programs now complete, it should now be possible to construct an overall control program macro to simplify the number of instructions required from the designer, the intention being not to simplify the models but to simplify their use.

8.2. Alternative Problem Formulations

Throughout the development of the layout techniques and the subsequent testing of parameters observations regarding alternative approaches were noted with respect to parts of the existing models. Although beyond the scope of the present work these alternative problem formulations may help to extend the practical usefulness of the current approach.

Temporary locations for workcentres

At present workcentres may only occupy their initial or final locations throughout the changeover, a restriction that in practice leads to problems of inter-workcentre obstructions. A useful modification to this limitation would be to introduce temporary locations for difficult workcentres either in a predetermined area on the layout or in a minimum cost position that is vacant. This may increase marginally the materials movement cost associated with the workcentres involved and in addition a double relocation cost will have to be paid but in return certain key cells may be completed at a more advanced stage of the project.

Addition or subtraction of workcentres

The present model also assumes that the same workcentres will be required for the new production program. In practice there may occur an increase in the number of workcentres to meet an increase in production, a decrease in the number of workcentres to suit a decrease in production or a change in workcentres to suit a change in production methods. Under these circumstances the existing model may be too limited to use for the project return is derived from comparing original and new layout costs for the same workcentres. The extension of the present model to cover workcentre variation therefore would present a positive improvement but will require a re-examination of the basic principle of the financial evaluation procedure.

Inclusion of lost production

One of the model conditions is the requirement that workcentre relocations take place between production periods, a requirement which affects the selection of the value of LN, the limiting number of moves per period. The resultant model, a straight comparison between materials movement cost and workcentre relocation cost, can be extended to include the ability to examine trading loss of production against early completion of the layout changeover. The increasing of LN achieved by stopping production would be balanced against the addition of a capital outlay to represent losses resulting from the reduced production time.

Alternative engineering criteria

In the simulation of layout changeover the heuristic for selecting workcentres and the evaluation model are both financially orientated. This may not in practice be the best criterion in terms of the overall manufacturing system where engineering considerations, expressed in the formation of workcentre cells, have already been shown to influence workcentre layout. Where the benefits to be obtained from the overall project are greater than materials movement gains then more important criteria might include:

1. Minimise changeover time.
2. Minimise number of relocation moves
   or cost.

3. Minimise changeover time for individual cells.

A comparative study of alternative layout criterion may produce an indication of the most beneficial model.

Modification to the present value analysis

The use of present value theory has been introduced to give a more realistic evaluation of cash flows. In the present environment of financial uncertainty two further modifications to R, the rate of return, are suggested. The first modification is the inclusion of taxation on cash flows, a fairly standard financial procedure, and secondly there is the possible consideration of inflation on the model.

Non-uniform layout area

The present definition of layout area assumes that the nett available area is the same throughout and that the relocation cost for each workcentre includes the cost of connecting up services to local mains. Within a modern manufacturing plant adequate service mains are provided but in older areas this may not be the case, requiring either additional relocation cost or a restriction on possible locations. At present special problems of this kind are accounted for by the interactive consideration of subjective factors, an approach which could be extended to include information on other layout area factors for example floor strengths, ceiling heights and services.

Summarising on the question of future work, the present research has been largely concerned with justifying the extended approach to job shop layout, formulating a representative set of models and examining the influence of certain new parameters with the aid of a suite of layout programs for the models. Extensions to this work will be concerned with either testing the present procedures on industrial test cases or with the development of alternative techniques to improve or replace present heuristic modules within the approach.

9. CONCLUSIONS

The general problem

1. Plant layout is part of a larger manufacturing design task where layout improvements should be considered as a contribution to the overall project.
2. At the job shop level the manufacturing system places a restriction on possible layout designs in the form of pregrouping of workcentres to enable efficient control of production.
3. Solution approaches to practical layout problems at the job shop level must consider quantitative and subjective factors during the design process, indicating the use of an interactive technique.
4. The need to consider restrictions, quantitative and subjective factors within one problem means that a single criterion used in isolation will not adequately reflect the problem requirements.

The solution approach

5. The rearrangement of an existing job shop to suit the requirements of a revised production program goes through two stages:
    - I The creation of a new "static" layout design.
    - II The dynamic introduction of the new layout.
6. An interactive-heuristic approach to solving the problems represented by the two layout stages is suggested.

7. The use of heuristics, as opposed to an optimisation approach, is supported by:

   a The size of practical problems

   b Complex objectives which are a combination of engineering and financial considerations

   c The inherent inaccuracy of industrial information.

8. The use of interactive working is supported by:

   a The need to consider subjective factors during the design process

   b The need for the designer to understand and verify quantitative decisions

   c The desire to use the designer for those tasks he is most capable of performing.

<u>The use of computers</u>

9. The volume of calculations and information necessary for industrial size problems requires the use of a computer.

10. Computer programs for the layout of workcentres must be sufficiently versatile to cover a wide variation in problems, particularly with regard to:

    I Representing facilities and layout areas accurately, including internal obstructions

II Accounting for subjective factors

III Making the best use of commercially available computer equipment and standard programs

IV Achieving the best balance between realism and computational cost

V Allowing evaluation of alternative solutions

VI Enabling the best assignment of tasks between computer and designer.

11. The use of a co-ordinate method for facilities and layout area will give a highly accurate and compact representation that can be used for the layout of workcentres. The use of a matrix based method by present computer layout programs restricts their use to the departmental layout level.
12. The programs developed for examining the two layout stages made efficient use of the same information files and will eventually be adaptable to providing visual display images to assist the designer.

Static layout design

13. A two stage approach of firstly placing cells and then individual workcentres has resulted in the formation of compact workcentre cell sets, satisfying manufacturing system requirements.
14. The design procedure was required to take into account the influence of fixed workcentres on both cell positions and cell placement sequence.

15. The use of a manual method for locating workcentres within cell areas saves considerable computational effort for what would be an exhausting and complex task. This task is beyond present programs and there is no guarantee that comparable results can be achieved at this detailed level by computer for practical numbers of facilities.

16. The ratio -

$$\frac{\text{Total workcentre area}}{\text{Nett available layout area}}$$

gives an indication of the degree of difficulty which will be encountered in placing individual workcentres. A high ratio indicates that considerable adjustment in final positioning will be required, a process achieved more efficiently by eye than by exhaustive computer use.

17. The inclusion of a traffic system within the layout area may be prejudging a design solution. Where there is a possibility of this occurring the traffic should initially be moved.

<u>Dynamic changeover simulation</u>

18. Examining the introduction of a new layout has received little investigation to date. The possible variation in the rate of changeover, including project suspension, and the possible variation in financial parameters indicate that an interactive simulation approach would be more useful initially than an attempt to formulate a restricted optimisation problem.

19. The benefits to be obtained from a new layout design are affected by the dynamic manner in which the layout is introduced and by the change in value of cash flows throughout the project life span.

20. In evaluating the financial benefit of any particular changeover, changes in running cost must be examined against the capital outlay required to achieve the changeover. In the dynamic model proposed running costs are represented by materials movement costs and capital outlay by workcentre relocation costs.

21. Determining materials movement cost within a job shop involves two factors:

    a The distance moved

    b The function converting distance to cost

    Where a traffic system is in existence commonly used approximations were found to be inaccurate. Balancing the calculations required against accuracy a method based on predetermining distances around the traffic system was found to be suitable for the traffic route case and straight line distance for the no traffic route case.

22. The function converting distance to cost consists of both a fixed cost and a variable cost proportional to distance. With the short distances involved in job shop movement the fixed cost must be considered, contributing up to 50% of total movement cost in the test cases.

23. The effect of introducing fixed costs is to increase the general level of costs and therefore reduce the

percentage savings.

24. In a job shop situation where products are physically suitable movement over short distances may be undertaken by machine operatives, reducing materials movement costs. In a project giving a positive materials movement contribution the result of introducing local movement over short distances would be to increase profit and reduce the overall cost.

25. The dynamic nature of the layout changeover, extending over a number of periods, requires consideration of changes in cash flow values. A parallel cost evaluation using present value theory was found to give an accurate indication of changes in relocation and materials movement costs for varying project life spans and rate of returns.

26. The effect of introducing an expected rate of return is to reduce the influence of later cash flows. This declining value may be of use where there is a limit on the available relocation capital.

27. The introduction of a limit on the number of relocation moves per period will extend the changeover period. In addition, because of the slower changeover, the level of maximum capital outlay will be reduced, with the partial changeover profits obtained further reducing subsequent capital requirements.

28. In the case of a positive project return decreasing the number of relocation moves reduced the project return.

29. For any one project there is a certain rate of return

for which any number of moves per period will yield approximately the same project return.

30. The ratio -

$$\frac{\text{Total workcentre area}}{\text{Nett available layout area}}$$

also affects the relocation of workcentres. With a high ratio a large number of final positions will be occupied by unmoved workcentres, creating obstructions. These obstructions between workcentres can form interdependent chains of moves capable of stopping a relocation project where the minimum chain size is greater than the number of moves per period.

31. The inclusion of positional obstructions considerably complicates the sequencing of relocations, disrupting the selected sequences and extending the time required to complete the reorganisation of individual cells.

An overview

32. Care must be taken in the case of a negative project return. In individual examples, in order to obtain other benefits from the manufacturing system, it may be necessary to accept a more expensive final layout design giving a negative project return. Under these circumstances the conclusions drawn regarding dynamic parameters might well be reversed.

33. Within the complex model developed there was no detectable relationship between flow dominance and project return.

34. The changeover heuristic developed as part of the sim-

ulation model is essentially a financial orientated procedure. Equally valid alternatives might include relocation costs only where they are proportionately higher, or engineering considerations for example minimisation of introduction time.

35. The extended philosophy proposed has introduced a more realistic appraisal of the requirements of the layout of workcentres in a job shop situation and has examined the changeover of an existing layout area by the use of a simulation model. This initial formulation of the approach has produced a basis on which further industrial cases may be tested and by which alternative heuristic procedures may be examined.

APPENDIX A

EXAMINATION OF MOVEMENT DISTANCE

RANDOM GENERATED WORKCENTRE LOCATIONS
TEST LAYOUTS A TO E
RESULTS FOR NO TRAFFIC ROUTE CASE
RESULTS FOR TRAFFIC SYSTEM CASE

LAYOUT	A		B		C		D		E	
WORKCENTRE	X	Y	X	Y	X	Y	X	Y	X	Y
1	26.7	23.2	45.9	11.9	32.5	15.0	30.0	16.6	11.1	0.5
2	29.3	16.7	29.6	13.9	33.3	32.4	2.3	13.6	14.1	12.5
3	19.8	14.5	5.2	2.7	28.7	30.5	22.0	4.7	43.0	17.0
4	71.9	2.3	45.4	7.3	11.3	15.0	30.8	6.0	29.7	15.7
5	51.4	19.2	12.8	12.0	33.1	27.0	10.4	4.0	24.9	9.6
6	17.5	25.9	36.5	1.1	43.8	30.0	32.6	13.1	60.3	11.4
7	71.4	37.5	31.9	4.2	23.6	20.0	41.6	17.0	36.2	13.6
8	66.8	17.1	32.3	8.6	16.6	31.5	21.0	11.7	27.8	21.1
9	71.1	32.5	39.2	11.2	43.2	15.8	7.6	5.6	55.7	8.7
10	31.7	6.6	11.7	1.1	29.0	4.4	3.3	7.0	1.3	20.2
11	48.4	21.5	22.7	11.8	12.6	9.9	19.8	15.6	16.9	22.5
12	69.5	6.1	12.4	7.4	23.5	16.5	23.0	21.9	37.0	25.7
13	16.2	8.4	21.2	13.3	17.4	16.5	17.8	7.5	34.4	20.7
14	65.4	40.1	9.4	10.7	4.5	20.1	2.7	20.1	5.3	2.9
15	57.8	22.3	6.8	1.9	31.6	2.6	9.5	13.5	44.9	3.8
16	3.7	7.9	18.5	3.1	19.2	23.1	17.6	3.8	45.6	22.6

METRES

TABLE A1 RANDOM GENERATED WORKCENTRE LOCATIONS

EXAMINATION OF MOVEMENT DISTANCE

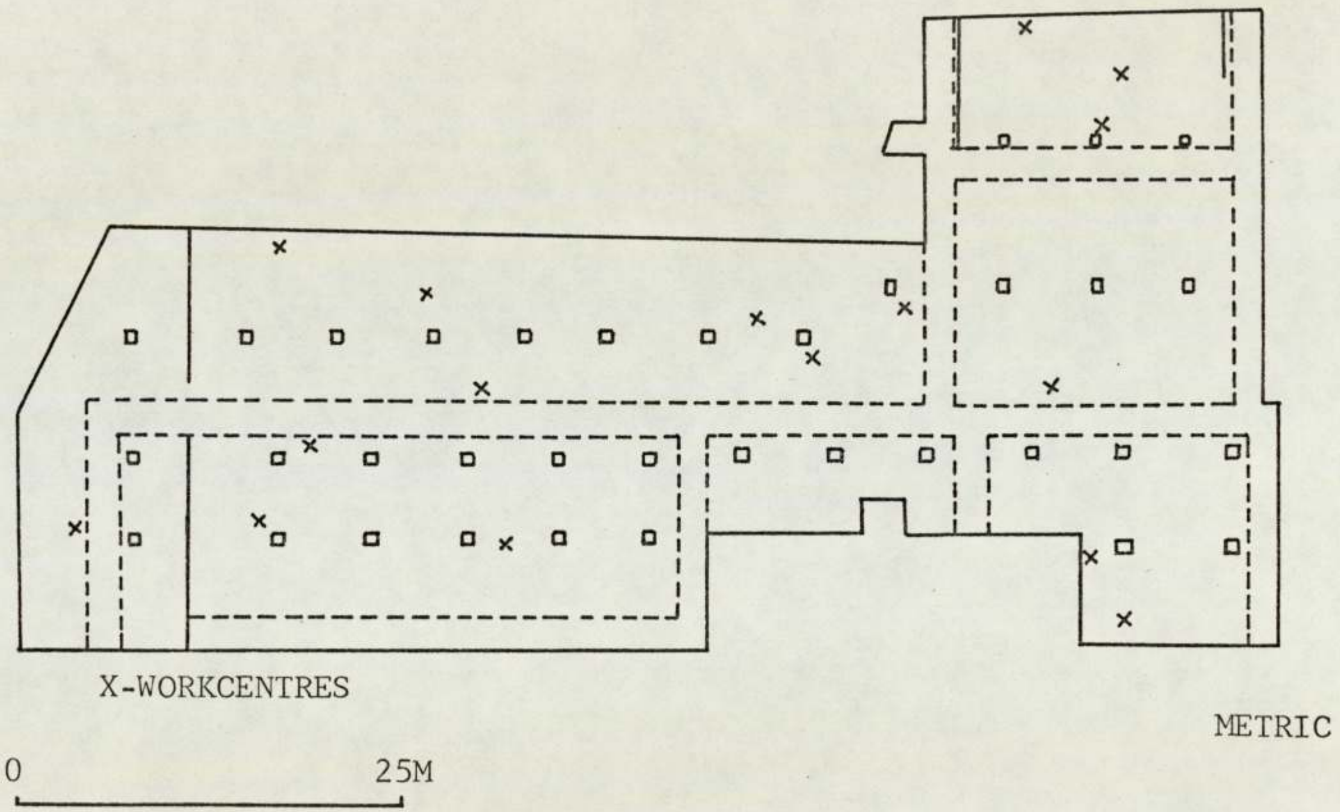


FIG A1 TEST LAYOUT A
EXAMINATION OF MOVEMENT DISTANCE

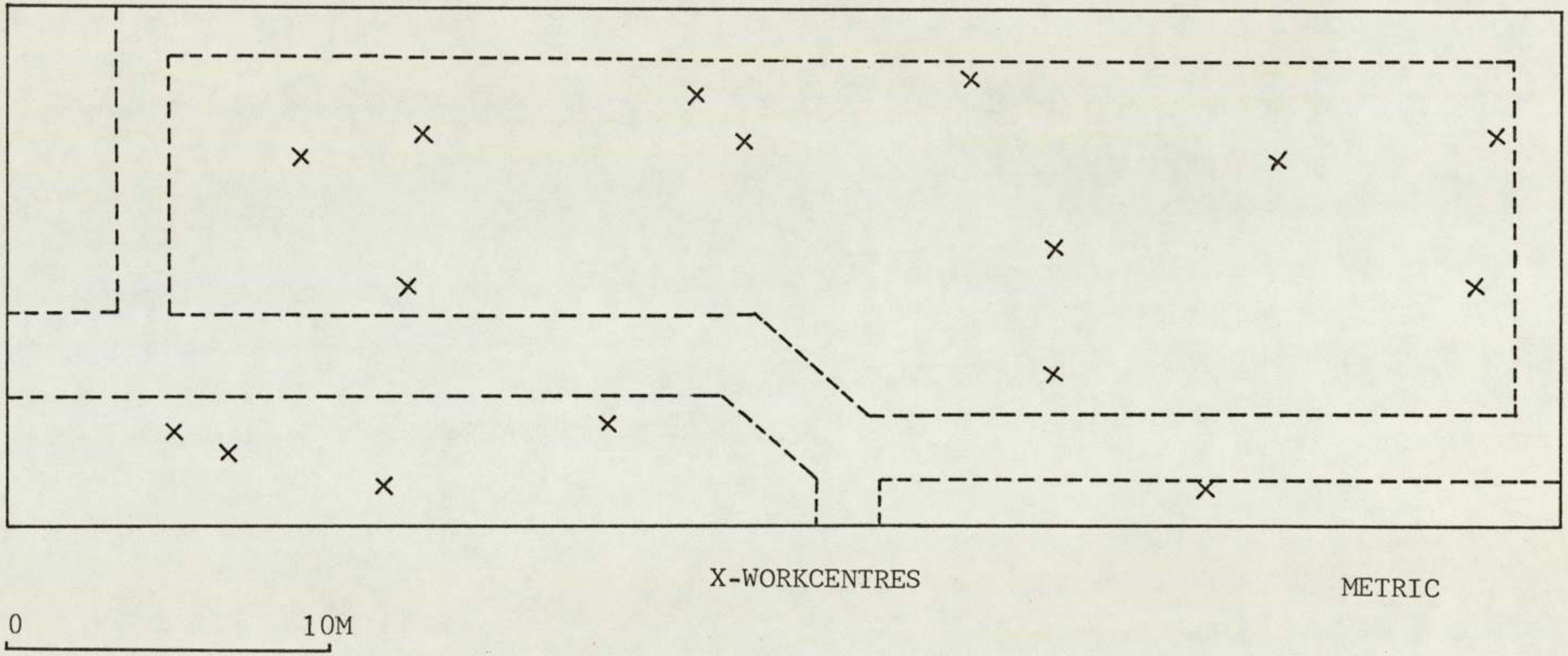


FIG A2 TEST LAYOUT B
EXAMINATION OF MOVEMENT DISTANCE

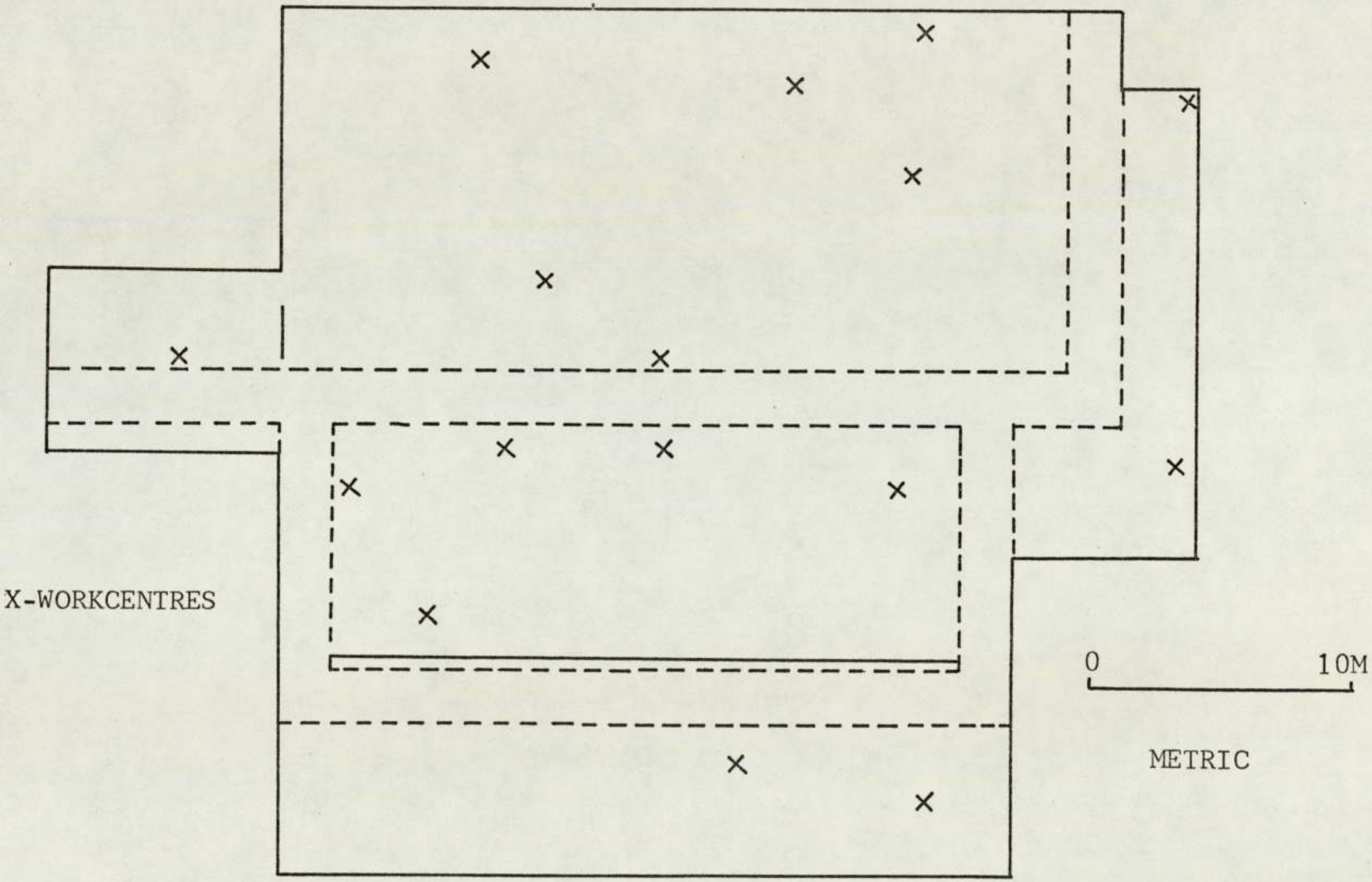


FIG A3 TEST LAYOUT C
EXAMINATION OF MOVEMENT DISTANCE

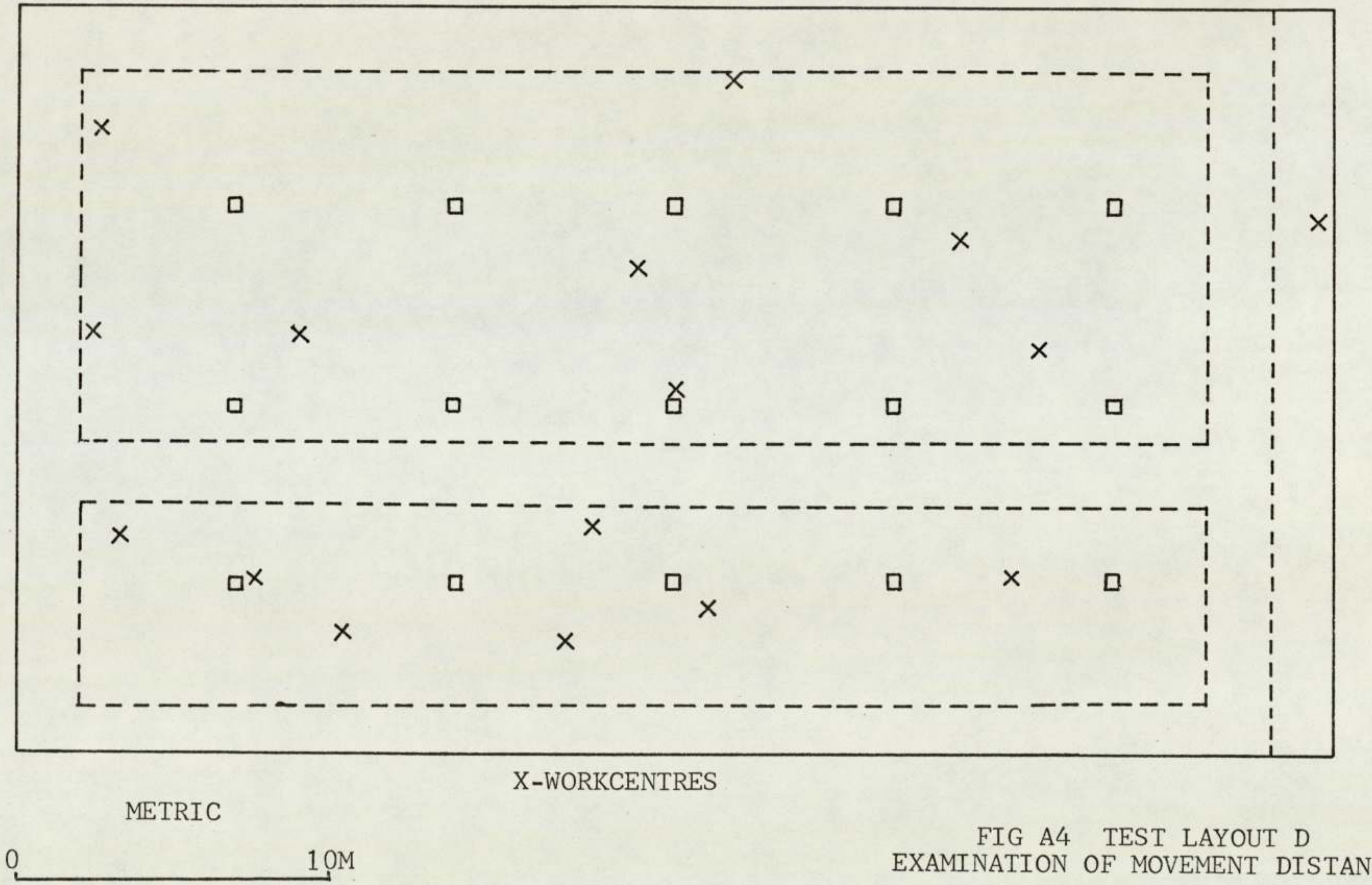


FIG A4 TEST LAYOUT D
EXAMINATION OF MOVEMENT DISTANCE

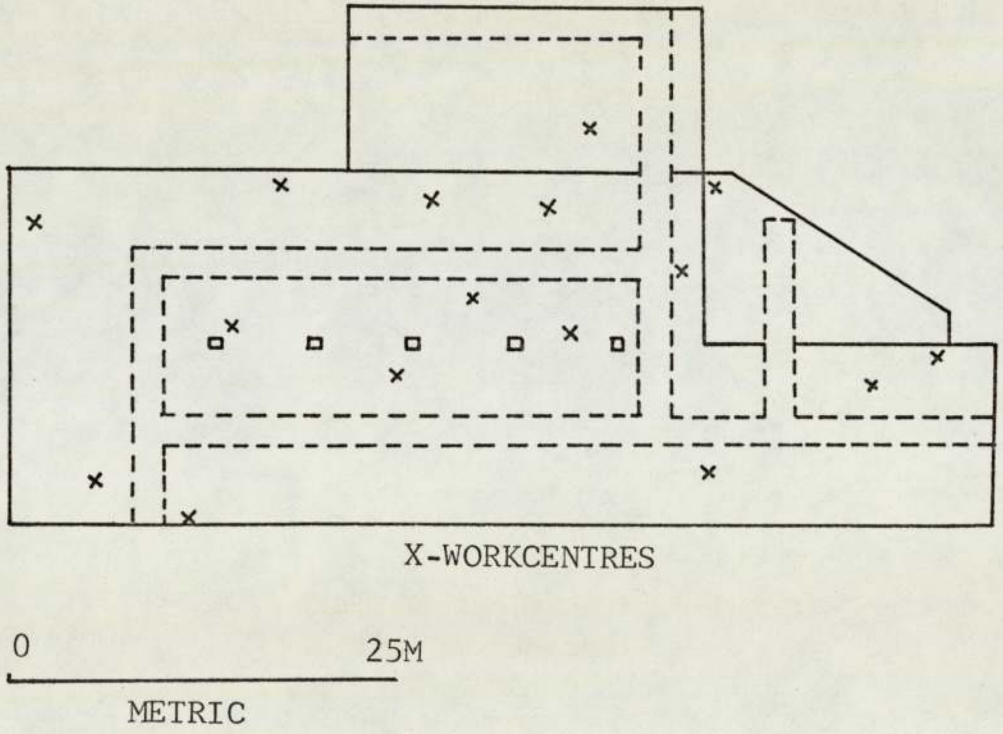


FIG A5 TEST LAYOUT E
EXAMINATION OF MOVEMENT DISTANCE

	METHOD	N1	N2	N3	N4
	LAYOUT				
CORRELATION	A	0.997	0.974	0.980	1.000
	B	1.000	0.979	1.000	1.000
	C	0.967	0.944	0.946	1.000
	D	1.000	0.974	1.000	1.000
	E	0.844	0.831	0.909	1.000
PERCENTAGE ERROR	A	-2.65	20.67	9.38	0.00
	B	0.00	20.18	0.00	0.00
	C	-5.22	20.33	9.53	0.00
	D	-0.25	23.82	0.53	0.00
	E	-14.67	5.95	19.53	0.00
NUMBER OF OBSTRUCTION LINES	A	176	176	176	176
	B	4	4	4	4
	C	20	20	20	20
	D	64	64	64	64
	E	43	43	43	43
ESTIMATED NUMBER OF REQUIRED CALCULATIONS	A	120	120	213800	440000
	B	120	120	4800	4800
	C	120	120	24820	32200
	D	120	120	77480	98560
	E	120	120	52760	76540

TABLE A2 . MOVEMENT DISTANCE TEST RESULTS
NO TRAFFIC ROUTE CASE

	METHOD	T1	T2	T3	T4
	LAYOUT				
CORRELATION	A	0.836	0.860	0.997	1.000
	B	0.546	0.600	1.000	1.000
	C	0.734	0.752	0.992	1.000
	D	0.451	0.472	1.000	1.000
	E	0.726	0.738	0.890	1.000
PERCENTAGE ERROR	A	-34.67	-18.70	0.58	0.0
	B	-47.76	-36.87	0.00	0.0
	C	-43.36	-28.11	1.28	0.0
	D	-53.05	-41.71	0.00	0.0
	E	-40.00	-25.47	-6.00	0.0
NUMBER OF OBSTRUCTION LINES	A	176	176	176	176
	B	4	4	4	4
	C	20	20	20	20
	D	64	64	64	64
	E	43	43	43	43
ESTIMATED NUMBER OF REQUIRED CALCULATIONS	A	120	120	1530	228500
	B	120	120	1016	5800
	C	120	120	923	26700
	D	120	120	967	83500
	E	120	120	1114	52700

TABLE A3 MOVEMENT DISTANCE TEST RESULTS

TRAFFIC ROUTE CASE

APPENDIX B

PROGRAMS UA1 UA2 AND UA3

GLOSSARY OF MAJOR PROGRAM TERMS
UA1 GENERAL FLOW CHART
GENERAL FLOW DIAGRAM FOR SUBROUTINE AREA1
GENERAL FLOW DIAGRAM FOR SUBROUTINE CMIN
GENERAL FLOW DIAGRAM FOR SUBROUTINE DAREA
GENERAL FLOW DIAGRAM FOR SUBROUTINE SQMIN
PROGRAM UA1
UA2 GENERAL FLOW CHART
GENERAL FLOW DIAGRAM FOR SUBROUTINE OVLP1
GENERAL FLOW DIAGRAM FOR SUBROUTINE OVLP2
GENERAL FLOW DIAGRAM FOR SUBROUTINE OVLP3
PROGRAM UA2
UA3 GENERAL FLOW CHART
GENERAL FLOW DIAGRAM FOR SUBROUTINE COST
GENERAL FLOW DIAGRAM FOR SUBROUTINE PLACE
GENERAL FLOW DIAGRAM FOR SUBROUTINE TDIST
PROGRAM UA3
GENERAL DESCRIPTION OF CONNECTING FILES

GLOSSARY OF MAJOR PROGRAM TERMS

GENERAL

D2/D22	The amount by which the outline is reduced and non-participation areas expanded to check for movement obstruction.
F	Matrix containing all locations and dimensions of workcentres.
FID	Matrix containing workcentre identification number.
IA	Matrix containing number of outline points in each non-participation area.
I3	Number of workcentres.
I4	Number of workcentre cells.
I5	Number of outline points.
I6	Number of non-participation areas.
I7	Number of traffic routes.
I8	Number of products.
PI	Matrix containing product identities.
PM	A three part matrix containing the number of batches per period, the fixed and variable cost per batch for each product.
PW	A matrix containing the sequence of workcentres for each product.
RLT	A matrix containing the list of workcentres obstructing the final location of each workcentre.

T	A matrix containing the shortest distances from each traffic junction point to the next.
TA	A matrix containing the distance from each workcentre to the nearest traffic aisle.
TB	The matrix location of the nearest traffic aisle for each workcentre.
TC	The distance from the nearest point of contact to each end of the closest traffic aisle for each workcentre.
TR	A matrix containing the end co-ordinates for each traffic aisle.
TT	A matrix containing the traffic junction numbers for each end of each aisle.
TITLE	Test case title.
WC	Cell identity of each workcentre.
WI	Workcentre identity numbers.
WR	Workcentre relocation costs.

<u>UA1</u>

AA1	Total layout area.
AA2	Total area of non-participation areas.
AA3	Total area of traffic routes.
AR1	Area of complex workcentres.
ARATIO	Ratio of total original workcentre area over nett available layout area.
BRATIO	Ratio of total modified workcentre area over nett available layout area.

CA	A two part matrix containing the total area and total relocation cost of workcentres in each cell.
CD	Two part matrix containing the total number of workcentres and the number of fixed workcentres in each cell.
F7	Width of traffic routes.
PB	Batch size of each product.
PF	Fixed cost of raising, lowering and locating each product load.
PQ	Total quantity of each product per time period.
PV	Variable cost of moving each product load per unit distance.
R	Ratio of original workcentre area over modified workcentre area.
RMIN	Radius of minimum enclosing circle.
TNAA	Total nett available layout area.
TNPA	Total non-participation and traffic route area.
WA	Radius of circular workcentre, base length of rectangular workcentre or co-ordinate of miscellaneous workcentre.
WB	Side lenth of rectangular workcentre or co-ordinate of miscellaneous workcentre.
W1-W4	Co-ordinates of miscellaneous workcentre.
WF	Fixed workcentre indicator.
WO	Workcentre orientation.

WT	Workcentre type.
WX	Workcentre X co-ordinate.
WY	Workcentre Y co-ordinate.
WAA	Total original workcentre area.
WAB	Total modified workcentre area.
WAC	Total relocation costs.

UA2

AIA	Matrix containing the co-ordinates of non-participation areas.
AOA	Matrix containing outline co-ordinates.
C	Total area and relocation cost of each cell.
CA	List of angles from 0° to 315° in 45° increments.
CC	Matrix of materials movement cost at various positions for a particular cell.
CI	Three part matrix containing cell identity number, total number of workcentres and the number of fixed workcentres in the cell.
CO,CO2	Matrix of cell priority order.
CR	Matrix of cell circle radii.
CX	Matrix of cell centre X co-ordinates.
CY	Matrix of cell centre Y co-ordinates.
DR	Direction of movement for repositioning cell centres.

FLW	Matrix of cell internal and external movement factors (sum of quantity x variable cost).
FLWE	Matrix of cell external movement factors.
ICNT	Number of final workcentres determined.
IL4	Matrix indicating final location of each workcentre determined.
MP	Number of locations tried by each cell.
MTP	Total number of locations tried.
MT	Number of cells located.
RR	Distance of movement for repositioning cell centres.
RAD	Distance from cell centre position of possible locations using automatic location routine.

UA3

A3	Matrix containing the internal and external local and departmental movement cost of the initial layout and the current layout for each cell.
CI	Three part cell matrix containing identity number, total number of fixed workcentres and total number of workcentres altogether in each cell.
CO	Matrix containing cell relocation order.

CR	Matrix containing sum of relocation costs of workcentres for each cell at varying time intervals.
CV,CLE	Matrix of estimated materials movement return for each cell.
CSTA	Workcentre relocation cost for each time interval.
CSTD	Departmental movement cost for each time interval.
CSTF	Departmental movement cost of initial layout.
CSTG	Local movement cost of initial layout.
CSTL	Local movement cost for each time interval.
E	Boundary distance between local and departmental movement cost.
I99	Layout drawing parameter.
LN	Limiting number of workcentre relocations per period.
NZ	Number of workcentres requiring a change in position from initial to final layout.
NCTR	Workcentre to be relocated by operator choice.
N98	Parameter controlling the printing of cell data.
PVTMC	Present value total departmental movement cost throughout layout changeover.
PVTML	Present value total local movement cost throughout layout changeover.

PVTRC	Present value total relocation cost throughout layout changeover.
PVRTN	Present value project return.
PVTC1	Present value total departmental movement cost of initial layout throughout life span.
PVTL1	Present value total local movement cost of initial layout throughout life span.
R	Expected rate of return.
TP	Life span of production program in time periods.
TMC	Total departmental movement cost.
TML	Total local movement cost.
TRC	Total workcentre relocation cost.
TC1	Departmental movement cost of initial layout throughout life span.
TL1	Local movement cost of initial layout throughout life span.
TPRTN	Total project return.

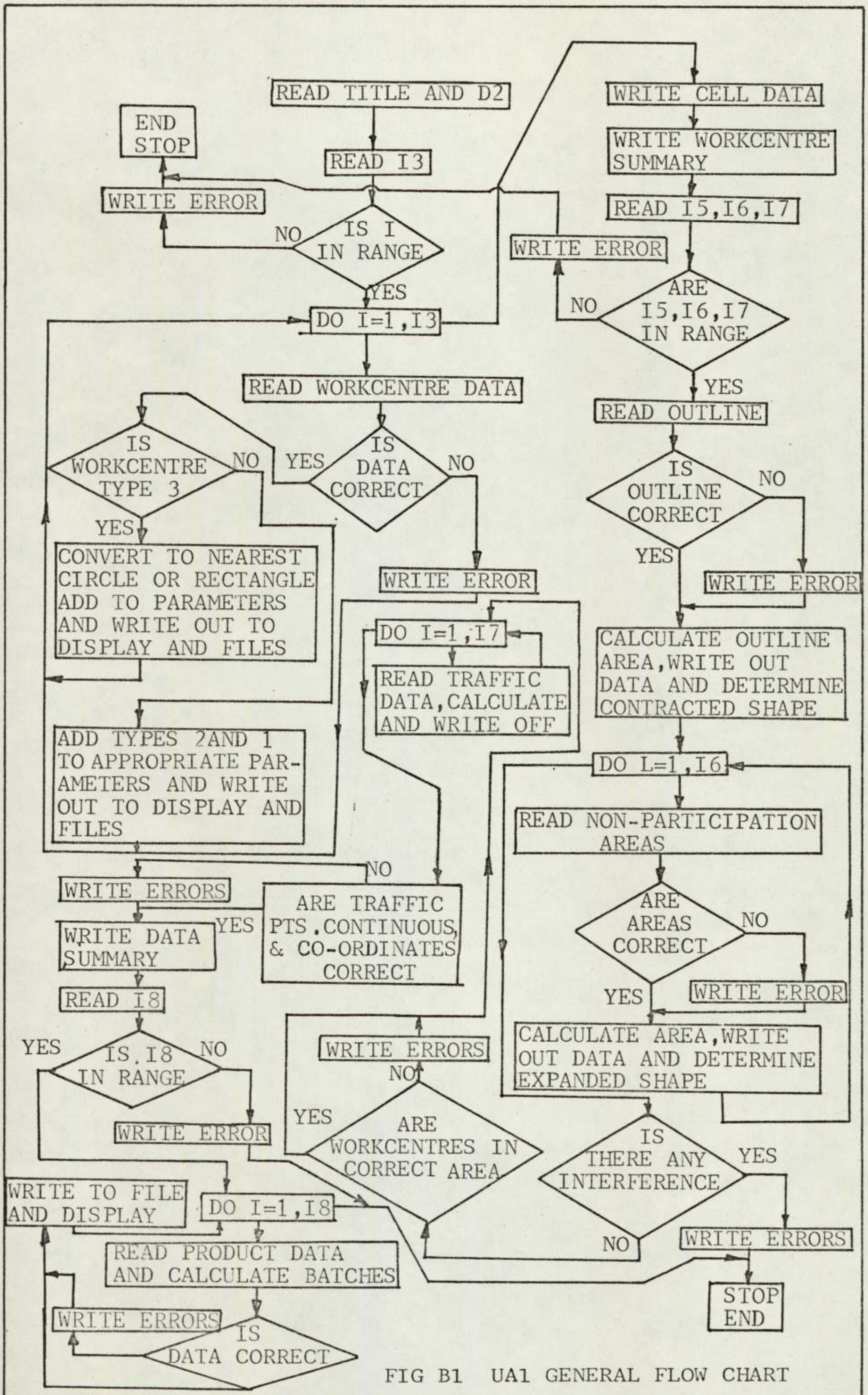


FIG B1 UA1 GENERAL FLOW CHART

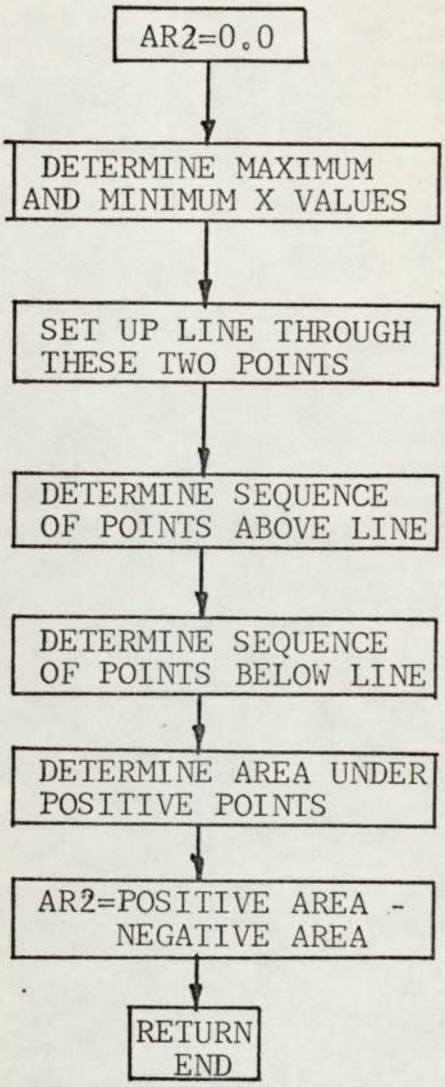


FIG B2 GENERAL FLOW DIAGRAM FOR SUBROUTINE AREA1

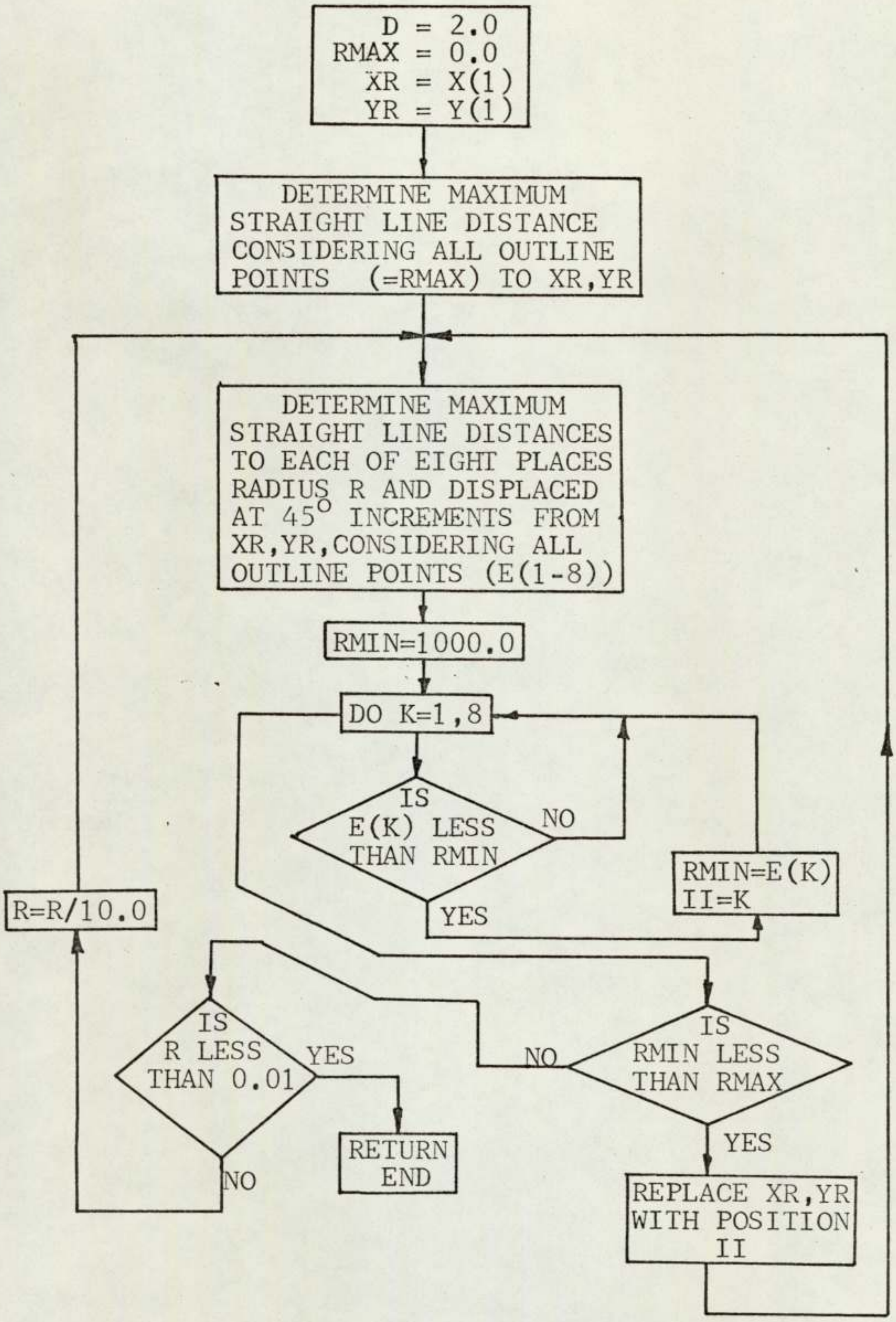


FIG B3 GENERAL FLOW DIAGRAM FOR SUBROUTINE CMIN

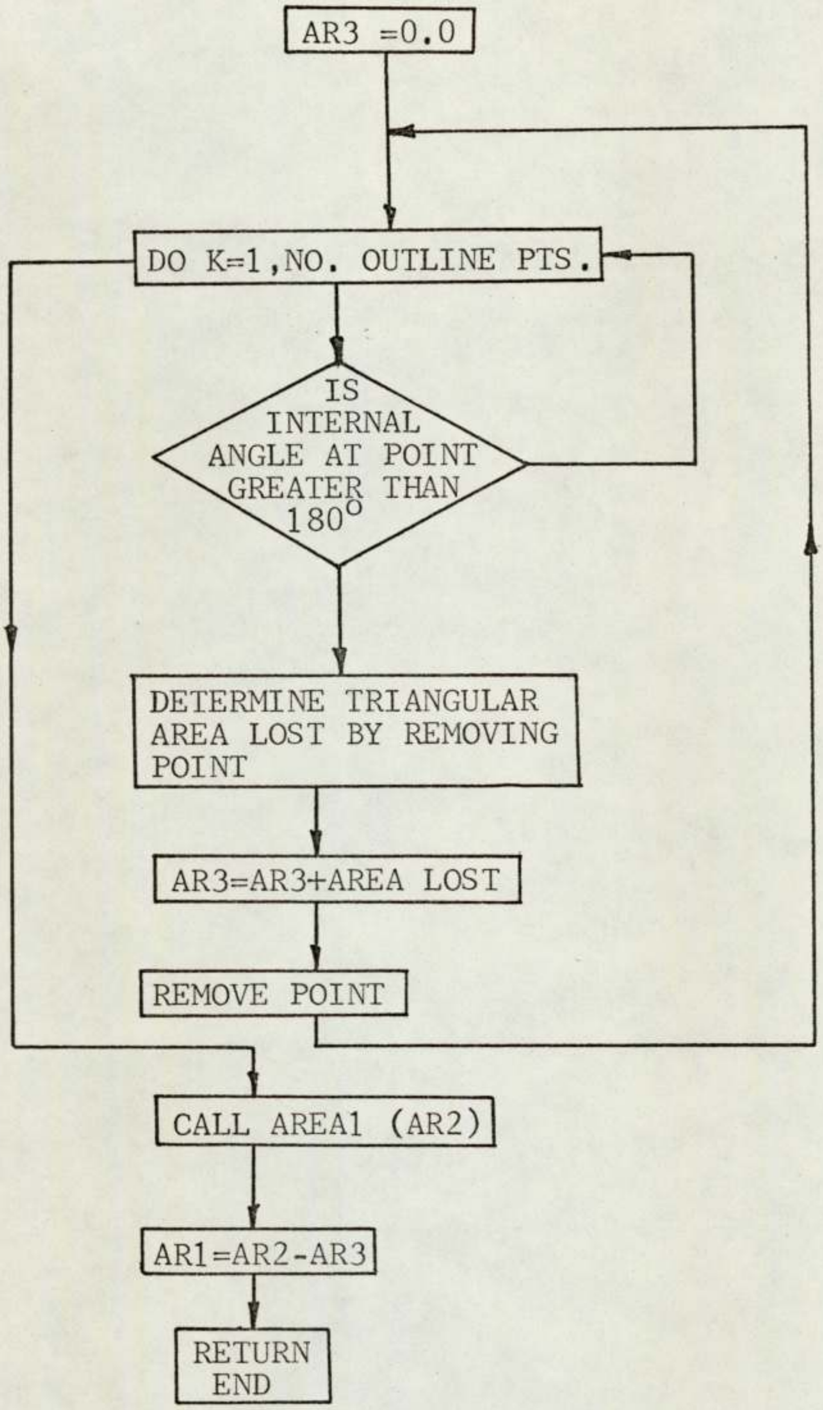


FIG B4 GENERAL FLOW DIAGRAM FOR SUBROUTINE DAREA

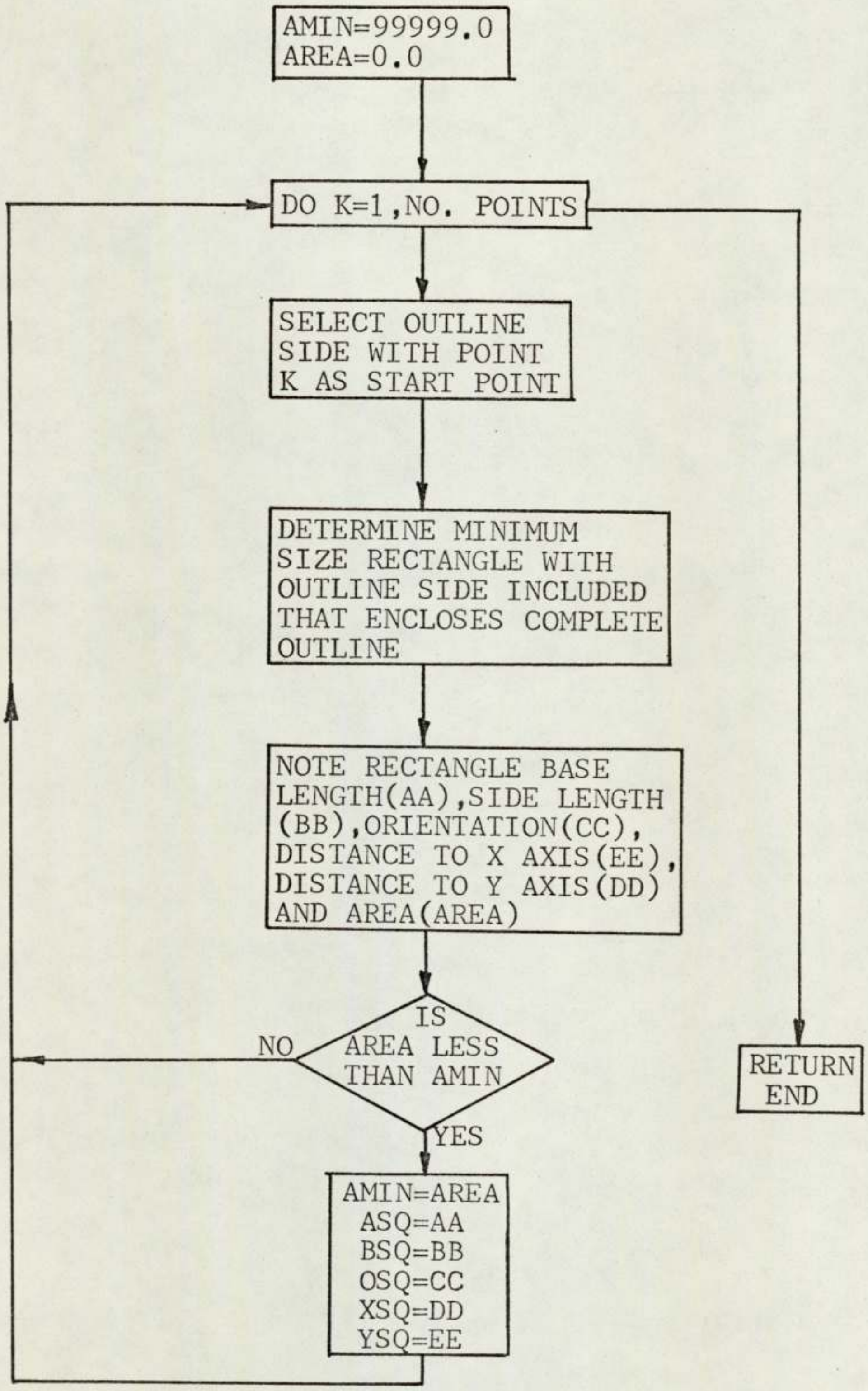


FIG B5 GENERAL FLOW DIAGRAM FOR SUBROUTINE SQMIN

PROGRAM UA1

```
      LIST(LP)
      PRØGRAM(FXXX)
      INPUT 1=CR1
      ØUTPUT 2=LP2
      ØUTPUT 3=CP3
      ØUTPUT 4=CP4
      CØMPRESS INTEGER AND LØGICAL
      CØMPACT
      END
      MASTER UA1
      INTEGER WI,WF,WC,WR,WT,F1,PI,PW,TT,TB,CD
      DIMENSIØN X(50),Y(50),TITLE(5),PW(30),CA(50,2),CD(50,2),TR(30,4),T
     1T(30,2),TA(30),TB(30),T(30,30),XE(50),YE(50),XA(100,15),YA(100,15)
     2,WX1(150),WY1(150),WI(150),IA(100)
      CØMMØN/SLAB1/X,Y
      PYE=3.1416
      WRITE(2,830)
      DØ 50 I=1,50
      DØ 50 J=1,2
      CA(I,J)=0.0
   50 CD(I,J)=0
      READ(1,800)(TITLE(I),I=1,5)
      WRITE(2,800)(TITLE(I),I=1,5)
      WRITE(3,800)(TITLE(I),I=1,5)
      READ(1,812)D2
      WRITE(3,812)D2
C
C     SECTIØN ØNE = INPUT ØF WØRKCENTRE DATA
C         TESTS : 1-NUMBER ØF WØRKCENTRES LESS THAN 150
C                 2-WØRKCENTRE TYPE IN RANGE 1 TØ 3 AND CØRRECT DATA
C                 3-WØRKCENTRE ØRIENTATION LESS THAN 90 DEGREES
C                 4-WØRKCENTRE CELL IN RANGE 1 TØ 50 AND MIN 1 FXD CELL
C                 5-WØRKCENTRE IN FIXED ØR UNFIXED PØSITIØN
C
      I=1
      READ(1,801)I3
      WRITE(4,801)I3,I
      IF(I3.GT.150.OR.I3.LT.1)GO TO 300
      WRITE(2,802)
      WAA,WAB,WAC=0.0
      DØ 58 I=1,I3
      WA,WB=0.0
      READ(1,803)WI(I),WC,WT,WA,WB,W1,W2,W3,W4,WF,WX,WY,WØ,WR
      IF(WT.GT.3.OR.WT.LT.1)GO TO 301
      IF(WF.GT.1)GO TO 302
      IF(WØ.GE.90)GO TO 303
      IF(WC.GT.50.OR.WC.LT.1)GO TO 308
      IF(WT.EQ.2.AND.WB.LE.0.0)WRITE(2,625)
      IF(WT.LT.3.AND.WA.LE.0.0)WRITE(2,625)
      IF(WF.EQ.1)WR=0.0
      NT=0
      IF(WT.NE.3)GO TO 55
      X(1)=WA
      X(2)=W1
      X(3)=W3
      Y(1)=WB
      Y(2)=W2
      Y(3)=W4
      I8=3
   51 IF(ABS(X(I8)+Y(I8)).LT.0.0001)GØ TØ 52
```

```
      READ(1,804)((X(I1),Y(I1)),I1=I8+1,I8+3)
      I8=I8+3
      IF(I8.NE.24)GØ TØ 51
   52 IF(ABS(X(I8)+Y(I8)).GT.0.0001)GØ TØ 53
      I8=I8-1
      GØ TØ 52
   53 CALL CMIN(XR,YR,RMIN,I8)
      CALL DAREA(I8,AR1,I9)
      CALL SQMIN(XSQ,YSQ,ASQ,BSQ,ØSQ,I9)
      NT=3
      WAA=WAA+AR1
      IF((PYE*RMIN*RMIN).GT.(ASQ*BSQ))GØ TØ 54
      R=AR1/(PYE*RMIN*RMIN)
      WX=WX+XR
      WY=WY+YR
      XSQ=XR
      YSQ=YR
      WA=RMIN
      GØ TØ 56
   54 R=AR1/(ASQ*BSQ)
      WX=WX+XSQ
      WY=WY+YSQ
      WØ=ØSQ
      WA=ASQ
      WB=BSQ
      WT=2
   55 IF(WT.NE.2)GØ TØ 56
      WAB=WAB+WA*WB
      I1=2
      IF(WF.EQ.1)I1=4
      CA(WC,1)=CA(WC,1)+WA*WB
      IF(NT.EQ.0)WAA=WAA+WA*WB
      GØ TØ 57
   56 I1=1
      IF(WF.EQ.1)I1=3
      CA(WC,1)=CA(WC,1)+WA*WA*PYE
      WAB=WAB+PYE*WA*WA
      WB,WØ=0.0
      IF(NT.EQ.0)WAA=WAA+PYE*WA*WA
   57 IF(WF.EQ.1)CD(WC,2)=CD(WC,2)+1
      CD(WC,1)=CD(WC,1)+1
      CA(WC,2)=CA(WC,2)+WR*1.0
      WRITE(2,805)I1,WI(I),WX,WY,WA,WB,WØ,WR,WC
      WRITE(4,806)I1,WI(I),WX,WY,WA,WB,WØ,WR,WC,XSQ,YSQ
      WX1(I)=WX
      WY1(I)=WY
      IF(NT.GT.0)WRITE(2,807)NT,R
   58 WAC=WAC+WR
      R=WAA/WAB
      D3=1.0
      WRITE(2,808)WAA,WAB,R,I3,WAC
      WRITE(2,809)
      I4,I33=0
      DØ 59 I=1,50
   59 IF(CD(I,1).GT.0)I4=I4+1
      WRITE(3,801)I4
      DØ 60 I=1,50
      IF(CD(I,1).EQ.0)GØ TØ 60
      WRITE(3,810)I,CD(I,1),CD(I,2),CA(I,1),CA(I,2)
      WRITE(2,810)I,CD(I,1),CD(I,2),CA(I,1),CA(I,2)
```

```
      IF(CD(I,1).GT.15)WRITE(2,822)
      IF(CD(I,2).GT.1)WRITE(2,823)
      IF(CD(I,2).GT.0)I33=1
 60   CØNTINUE
      IF(I33.EQ.0)WRITE(2,626)
C
C     SECTION TWØ = INPUT ØF LAYOUT AREA DATA
C         TESTS : 6- NUMBER ØF ØUTLINE PØINTS IN RANGE 3 TØ 50
C                 7- NUMBER ØF NØN PARTICIPATIØN AREAS LESS THAN 50
C                 8- NUMBER ØF TRAFFIC RØUTES LESS THAN 30
C                 9- NØ ØUTLINE - NØN PARTICIPATIØN AREA VIØLATIØN
C                10- NØ VIØLATIØN ØF NØN PARTICIPATIØN AREAS
C                11- WØRKCENTRES INSIDE MØDIFIED ØUTLINE
C                12- WØRKCENTRES ØUTSIDE MØDIFIED N.P. AREAS
C                13- INITIAL AREA PØINT ØN EXTREME LEFT
C                14- TRAFFIC SYSTEM CØNTINUØUS AND SEQUENTIALLY NUMBERED
C                15- EACH TRAFFIC PØINT HAS MINIMUM ØF TWØ RØUTES
C                16- CØØRDINATES ØF EACH TRAFFIC PØINT THE SAME
C
      READ(1,801)I5,I6,I7
      IF(I5.LT.3.ØR.GT.50)GØ TØ 304
      IF(I6.GT.50)GØ TØ 305
      IF(I7.GT.30)GØ TØ 306
      WRITE(3,801)I5,I6,I7
      WRITE(2,811)
C     READ IN,REDUCE AND CALCULATE AREA ØF ØUTLINE
      JCNT,J30=1
      READ(1,812)(X(I),I=1,I5)
      READ(1,812)(Y(I),I=1,I5)
      WRITE(3,812)(X(I),I=1,I5)
      WRITE(3,812)(Y(I),I=1,I5)
      WRITE(2,826)((X(K8),Y(K8)),K8=1,I5)
      DØ 100 I=2,I5
 100  IF(X(I).LT.X(1))WRITE(2,612)
      DØ 107 I=1,I5
      I1=I-1
      I2=I+1
      IF(I.EQ.1)I1=I5
      IF(I.EQ.I5)I2=1
 101  R1=X(I1)
      R2=X(I)
      R3=X(I2)
      R4=Y(I1)
      R5=Y(I)
      R6=Y(I2)
      J14=0
      IF(R1.EQ.R2.AND.R2.EQ.R3)GØ TØ 103
      IF(R1.EQ.R2)GØ TØ 104
      IF(R1.EQ.R2)GØ TØ 104
      IF(R2.EQ.R3)GØ TØ 105
      R7=(R4-R5)/(R1-R2)
      R8=(R6-R5)/R3-R2)
      IF(R7.EQ.R8)GØ TØ 103
      R9=(R4-R7*R1)-D2*D3/CØS(ATAN(R7))
      IF(R1.GT.R2)R9=R9+2.0*D2*D3/CØS(ATAN(R7))
      R10=(R6-R8*R3)-D2*D3/CØS(ATAN(R8))
      IF(R2.GT.R3)R10+2.0*D2*D3/CØS(ATAN(R8))
      R11=(R10-R9)/(R7-R8)
      R12=R9+R7*R11
 102  J14=1
```

```
 103  GØ TØ (106,109)J30
 104  R11=R1+D2*D3
      IF(R4.GT.R5)R11=R11-2.0*D2*D3
      R8=(R6-R5)/(R3-R2)
      R12=(R5+(R11-R2)*R8)+D2*D3/CØS(ATAN(R8))
      IF(R3.GT.R2)R12=R12-2.0*D2*D3/CØS(ATAN(R8))
      GØ TØ 102
 105  R11=R3+D2*D3
      IF(R5.GT.R6)R11=R11-2.0*D2*D3
      R7=(R5-R4)/(R2-R1)
      R12=(R4+(R11-R1)*R7)+D2*D3/CØS(ATAN(R7))
      IF(R2.GT.R1)R12=R12-2.0*D2*D3/CØS(ATAN(R7))
      GØ TØ 102
 106  IF(J14.EQ.0)GØ TØ 107
      XE(JCNT)=R11
      YE(JCNT)=R12
      JCNT=JCNT+1
 107  CØNTINUE
      CALL DAREA(I5,AA1,I9)
      I5=JCNT-1
C     READ IN,EXPAND AND CALCULATE NON PARTICIPATION AREAS
      IF(I6.EQ.0)GØ TØ 126
      WRITE(2,827)
      D3=-1.0
      AA2=0.0
      J30=2
      DØ 111 L=1,I6
      READ(1,813)IA(L),(X(J),J=1,10)
      READ(1,813)K8,(Y(J),J=1,IA(L))
      WRITE(3,813)IA(L),(X(J),J=1,IA(L))
      WRITE(3,812)(Y(J),J=1,IA(L))
      DØ 108 J=1,IA(L)
      IF(X(J).LT.X(1))WRITE(2,613)
 108  CØNTINUE
      JCNT=1
      DØ 110 I=1,IA(L)
      I1=I-1
      I2=I+1
      IF(I.EQ.1)I1=IA(L)
      IF(I.EQ.IA(L))I2=1
      GØ TØ 101
 109  IF(J14.EQ.0)GØ TØ 110
      XA(L,JCNT)=R11
      YA(L,JCNT)=R12
      JCNT=JCNT+1
 110  CØNTINUE
      CALL DAREA(IA(L),AB1,I9)
      AA2=AA2+AB1
      IA(L)=JCNT-1
 111  CØNTINUE
      DØ 112 K8=1,I6
      WRITE(2,828)IA(K8),((X(K8,K9),Y(K8,K9)),K9=1,IA(K8))
 112  CØNTINUE
C     CHECK ØN LØSS ØF AREA AND ØUTLINE VIØLATIØN
      J30,J16=1
      DØ 122 I=1,I6
      J15=0
      DØ 121 J=1,I5
      JJ=J+1
      IF(J.EQ.I5)JJ=1
```

```
    S1=XE(J)
    S2=XE(JJ)
    S5=YE(J)
    S6=YE(JJ)
    S15=SQRT((S6-S5)**2+(S2-S1)**2)
    DØ 121 K=1,IA(I)
113 KK=K+1
    IF(K.EQ.IA(I))KK=1
114 J14=0
    S3=XA(I,K)
    S4=XA(I,KK)
    S7=YA(I,K)
    S8=YA(I,KK)
    S18=SQRT((S4-S3)**2+(S8-S7)**2)
115 IF(ABS(S1-S2).LT.0.0001.AND.ABS(S3-S4).LT.0.0001)GØ TØ 117
    IF(ABS(S1-S2).LT.0.0001)GØ TØ 119
    IF(ABS(S1-S2).LT.0.0001)GØ TØ 118
    S9=(S6-S5)/(S2-S1)
    S10=(S8-S7)/(S4-S3)
    IF(ABS(S9-S10).LT.0.0001)GØ TØ 117
    S11=((S7-S5)+(S1*S9-S3*S10))/(S9-S10)
    S12=S5+(S11-S1)*S9
116 S13=SQRT((S11-S1)**2+(S12-S5)**2)
    S14=SQRT((S11-S2)**2+(S12-S6)**2)
    S16=SQRT((S11-S3)**2+(S12-S7)**2)
    S17=SQRT((S11-S4)**2+(S12-S8)**2)
    J77=0
    IF(S16.LT.S18.AND.S17.LT.S18)J77=1
    IF(S16.LT.S18.AND.S17.LT.S18)J14=J14+1
    IF(S13.LT.S15.AND.S14.LT.S15)J14=J14+1
    IF(J77.EQ.0.AND.S16.LT.0.000001)J32=J32+1
    IF(J77.EQ.0.AND.S17.LT.0.000001)J32=J32+1
117 GØ TØ (120,123,127,130)J30
118 S11=S1
    S12=S7+((S7-S8)/(S3-S4))*(S1-S3)
    GØ TØ 116
119 S11=S3
    S12=S5+((S5-S6)/(S1-S2))*(S3-S1)
    GØ TØ 116
120 IF(J14.LT.2)GØ TØ 121
    J16=2
    J15=J15+1
    IF(J15.GT.1)GØ TØ 121
    WRITE(2,614)I
121 CØNTINUE
    IF(J15.LE.2)GØ TØ 122
    J16=2
    WRITE(2,615)I
122 CØNTINUE
    J30=2
    IF(I6.EQ.1)GØ TØ 126
    DØ 125 L=1,I6-1
    DØ 125 I=L+1,I6
    J17=1
    DØ 124 J=1,IA(L)
    JJ=J+1
    IF(J.EQ.IA(L))JJ=1
    S1=XA(L,J)
    S2=XA(L,JJ)
    S5=YA(L,J)
```

```
      S6=YA(L,JJ)
      S15=SQRT((S1-S2)**2+(S5-S6)**2)
      J15=0
      DØ 124 K=1,IA(I)
      GØ TØ 113
123   IF(J14.LT.2)GØ TØ 124
      J16=2
      J15=J15+1
      IF(J17.GT.1)GØ TØ 124
      WRITE(2,616)L,I
      J17=J17+1
124   CØNTINUE
      IF(J15.LE.2)GØ TØ 125
      WRITE(2,617)L,I
125   CØNTINUE
      IF(J16.EQ.2)GØ TØ 500
C     CHECK ØN WØRKCENTRE PØSITIØN
126   S1,S5=-10.0
      WRITE(3,812)((XE(I),YE(I)),I=1,I5)
      J30=3
      DØ 129 J=1,I3
      S2=WX1(J)
      S6=WY1(J)
      S15=SQRT((S1-S2)**2+(S5-S6)**2)
      J15,J32=0
      DØ 128 K=1,I5
      J14=0
      KK=K+1
      IF(K.EQ.I5)KK=1
      S3=XE(K)
      S4=XE(KK)
      S7=YE(K)
      S8=YE(KK)
      S18=SQRT((S3-S4)**2+(S7-S8)**2)
      GØ TØ 115
127   IF(J14.EQ.2)J15=J15+1
128   CØNTINUE
      Z32=J32/2
      J15=J15+INT(Z32)
      Z32=J15/2
      J17=INT(Z32)
      IF(J15.NE.(J17*2))GØ TØ 129
      WRITE(2,618)WI(J)
      J16=2
129   CØNTINUE
      IF(I6.EQ.0)GØ TØ 135
      J30=4
      DØ 133 J=1,I3
      S2=WX1(J)
      S6=WY1(J)
      S15=SQRT((S1-S2)**2+(S5-S6)**2)
      DØ 132 L=1,I6
      J15,J32=0
      DØ 131 K=1,IA(L)
      GØ TØ 113
130   IF(J14.EQ.2)J15=J15+1
131   CØNTINUE
      Z32=J32/2
      J15=J15+INT(Z32)
      Z32=J15/2
```

```
      J17=INT(Z32)
      IF(J15.EQ.(J17*2))GØ TØ 132
      WRITE(2,619)J,WI(L)
      J16=2
  132 CØNTINUE
  133 CØNTINUE
      DØ 134 I=1,I6
      WRITE(3,801)IA(I)
      WRITE(3,812)((XA(I,J)),J=1,10)
  134 WRITE(3,812)((YA(I,J)),J=1,10)
  135 IF(I7.EQ.0)GØ TØ 154
C     TRAFFIC RØUTES
      WRITE(2,814)
      DØ 138 I=1,I7
      READ(1,815)(TR(I,J),J=1,4),F7,(TT(I,JA),JA=1,2)
      AA3=AA3+F7*(SQRT((TR(I,1)-TR(I,3))**2+(TR(I,2)-TR(I,4))**2))
      IF(TT(I,1).GT.0.ØR.TT(I,2).GT.0)AA3=AA3-0.5*F7*F7
      IF(ABS(TR(I,1)-TR(I,3)).LT.0.0001)GØ TØ 136
      F2=(TR(I,4)-TR(I,2))/(TR(I,3)-TR(I,1))
      X(1)=TR(I,1)+(F7/2.0)*(SIN(ATAN(F2)))
      X(2)=TR(I,1)-(F7/2.0)*(SIN(ATAN(F2)))
      X(3)=TR(I,3)-(F7/2.0)*(SIN(ATAN(F2)))
      X(4)=TR(I,3)+(F7/2.0)*(SIN(ATAN(F2)))
      Y(1)=TR(I,2)-(F7/2.0)*(CØS(ATAN(F2)))
      Y(2)=TR(I,2)+(F7/2.0)*(CØS(ATAN(F2)))
      Y(3)=TR(I,4)+(F7/2.0)*(CØS(ATAN(F2)))
      Y(4)=TR(I,4)-(F7/2.0)*(CØS(ATAN(F2)))
      GØ TØ 137
  136 X(1),X(3)=TR(I,1)-F7/2.0
      X(2),X(4)=TR(I,1)+F7/2.0
      Y(1),Y(4)=TR(I,2)
      Y(2),Y(3)=TR(I,4)
  137 WRITE(3,812)(X(J),J=1,4)
      WRITE(3,812)(Y(J),J=1,4)
  138 WRITE(2,825)(TR(I,J),J=1,4),F7,TT(I,1),TT(I,2)
      DØ 139 I=1,I7
  139 WRITE(3,815)(TR(I,J),J=1,4),F7,TT(I,1),TT(I,2)
      DØ 145 LB=1,I7-1
      L1=1
      DØ 140 LA=1,I7
      TA(LA)=9001.
  140 TB(LA)=0
      TA(LB)=0.0
      TB(LB)=1
  141 L2=0
      DØ 143 L=1,I7
      IF(TB(L).NE.L1)GØ TØ 143
      DØ 142 LA=1,I7
      IF(TT(LA,1).NE.L.AND.TT(LA,2).NE.L)GØ TØ 142
      IF(TT(LA,1).EQ.0.ØR.TT(LA,2).EQ.0)GØ TØ 142
      L3=1
      IF(TT(LA,1).EQ.L)L3=2
      TE=SQRT((TR(LA,3)-TR(LA,1))**2+(TR(LA,4)-TR(LA,2))**2)+TA(L)
      IF(TA(TT(LA,L3)).LE.TE)GØ TØ 142
      L2=1
      TA(TT(LA,L3))=TE
      TB(TT(LA,L3))=L1+1
  142 CØNTINUE
  143 CØNTINUE
      L1=L1+1
```

```
      IF(L2.EQ.1)GØ TØ 141
      DØ 144 LA=LB+1,I7
      IF(ABS(TA(LA)-9001.0).LT.0.0001)TA(LA)=0
  144 T(LB,LA),T(LA,LB)=TA(LA)
  145 CØNTINUE
C     CØNTINUITY CHECK
      DØ 147 L=1,I3-1
      LB=1
      DØ 146 LA=L+1,I7
      IF(LB.EQ.1.AND.T(L,LA).GT.0.0)LB=2
      IF(LB.EQ.2.AND.T(L,LA).LT.0.0001)LB=3
      IF(LB.EQ.3.AND.T(L,LA).GT.0.0)LB=4
  146 CØNTINUE
  147 IF(LB.EQ.4)WRITE(2,620)L
C     TRAFFIC PØINT CHECK
      DØ 148 L=1,I7
  148 IF(TT(L,1).EQ.TT(L,2))WRITE(2,621)TT(L,1)
      DØ 153 LA=1,I7
      JCNT=0
      DØ 151 L=1.I7
      IF(TT(L,1).NE.LA.AND.TT(L,2).NE.LA)GØ TØ 151
      X1=TR(L,1)
      Y1=TR(L,2)
      IF(TT(L,2).EQ.LA)X1=TR(L,3)
      IF(TT(L,2).EQ.LA)Y1=TR(L,4)
      JCNT=1
      DØ 150 LB=L+1,I7
      IF(TT(LB,1).NE.LA)GØ TØ 149
      IF((ABS(TR(LB,1)-X1)+ABS(TR(LB,2)-Y1)).GT.0.0001)WRITE(2,622)LA
      JCNT=JCNT+1
      GØ TØ 150
  149 IF(TT(LB,2).NE.LA)GØ TØ 150
      IF((ABS(TR(LB,3)-X1)+ABS(TR(LB,4)-Y1)).GT.0.0001)WRITE(2,622)LA
      JCNT=JCNT+1
  150 CØNTINUE
      GØ TØ 152
  151 CØNTINUE
  152 IF(JCNT.EQ.1)WRITE(2,623)LA
  153 CØNTINUE
      WRITE(3,812)((T(I,J),J=1,I7),I=1,I7)
  154 TNPA=AA2+AA3
      TNAA=AA1-TNPA
      ARATIØ=WAA/TNAA
      BRATIØ=WAB/TNAA
      IA1=I6+I7
      WRITE(2,817)I6,AA2,I7,AA3,IA1,TNPA,AA1,TNAA,BRATIØ,ARATIØ
      IF(J16.EQ.2)GØ TØ 500
C
C     SECTIØN THREE = INPUT ØF PRØDUCT DATA
C          TESTS  17-NUMBER ØF PRØDUCTS IN RANGE 1 TØ 100
C                 18-PRØDUCT QTY AND BATCH SIZE GREATER THAN ZERØ
C                 19-AT LEAST TWØ WØRKCENTRES IN WØRKCENTRE SEQUENCE
C                 20-NØ ZERØ WØRKCENTRE ENTRY
C
      READ(1,801)I8
      IF(I8.GT.100)GØ TØ 309
      IF(I8.EQ.0)GØ TØ 307
      WRITE(3,801)I8
      WRITE(2,818)
      DØ 204 I=1,I8
```

```
      READ(1,829)PI,PQ,PB,PF,PV,(PW(J),J=1,10)
      IF(PQ.LE.0.0.ØR.PB.LE.0.0)GØ TØ 310
      QTY1=PQ/PB
      QTY2=(INT(QTY1))*1.0
      IF(QTY1.NE.QTY2)QTY2=QTY2+1.0
      WRITE(3,820)PI,QTY2,PF,PV,(PW(J),J=1,10)
      K1=10
      DØ 200 K=1,10
  200 IF(PW(K).GT.0)K1=K
      IF(K1.NE.10)GØ TØ 202
      READ(1,801)(PW(J),J=11,30)
      WRITE(3,801)(PW(J),J=11,30)
      K1=30
      DØ 201 K=1,20
  201 IF(PW(10+K).GT.0)K1=10+K
  202 DØ 203 J=1,K1
      IF(PW(J).LE.0)GØ TØ 311
  203 CØNTINUE
      IF(K1.LT.2)WRITE(2,624)
      WRITE(2,819)PI,PQ,PB,PF,PV
      WRITE(2,821)(PW(J),J=1,K1)
  204 CØNTINUE
      GØ TØ 500
  300 WRITE(2,600)
      GØ TØ 500
  301 WRITE(2,601)
      GØ TØ 58
  302 WRITE(2,602)
      GØ TØ 58
  303 WRITE(2,603)
      GØ TØ 58
  304 WRITE(2,604)
      GØ TØ 500
  305 WRITE(2,605)
      GØ TØ 500
  306 WRITE(2,606)
      GØ TØ 500
  307 WRITE(2,607)
      GØ TØ 500
  308 WRITE(2,608)
      GØ TØ 58
  309 WRITE(2,609)
      GØ TØ 500
  310 WRITE(2,610)
      GØ TØ 204
  311 WRITE(2,611)
  600 FØRMAT(5X,37H NUMBER ØF WØRKCENTRES GT 150 ØR LT 1)
  601 FØRMAT(5X,26H INCØRRECT WØRKCENTRE TYPE)
  602 FØRMAT(5X,43H INCØRRECT WØRKCENTRE FIXED FACILITY NUMBER)
  603 FØRMAT(5X,27H INCØRRECT WØRKCENTRE ANGLE)
  604 FØRMAT(5X,22H ERRØR IN AREA ØUTLINE)
  605 FØRMAT(5X,33H ERRØR IN NØN PARTICIPATIØN AREAS)
  606 FØRMAT(5X,24H ERRØR IN TRAFFIC RØUTES)
  607 FØRMAT(5X,14H ZERØ PRØDUCTS)
  608 FØRMAT(5X,21H ERRØR IN CELL NUMBER)
  609 FØRMAT(5X,31H NUMBER ØF PRØDUCTS EXCEEDS 100)
  610 FØRMAT(5X,28H QUANTITY ØR BATCH SIZE ZERØ)
  611 FORMAT(5X,22H ZERØ WØRKCENTRE ENTRY)
  612 FØRMAT(5X,39H FIRST ØUTLINE PØINT EXCEEDED BY PØINT ,I4)
  613 FØRMAT(5X,5H NPA ,I4,26H FIRST PT GREATER THAN PT ,I4)
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614   FØRMAT(5X,26H ØUTLINE VIØLATIØN BY AREA,I4)
615   FØRMAT(5X,22H PØSSIBLE AREA LØSS BY,I4)
616   FØRMAT(5X,32H ØUTLINE VIØLATIØN BETWEEN AREAS,I4,4H AND,I4)
617   FØRMAT(5X,33H PØSSIBLE AREA LØSS BETWEEN AREAS,I4,4H AND,I4)
618   FØRMAT(5X,11H WØRKCENTRE,I4,16H ØUTSIDE ØUTLINE)
619   FØRMAT(5X,11H WØRKCENTRE,I4,13H INSIDE AREA ,I4)
620   FØRMAT(5X,19H LINK MISSING LINE I4)
621   FØRMAT(5X,15H TRAFFIC PØINT ,I4,19H TWICE ØN SAME LINE)
622   FØRMAT(5X,42H MISMATCHED CØØRDINATES FØR TRAFFIC PØINT ,I4)
623   FØRMAT(5X,41H ØNLY ØNE TRAFFIC RØUTE AT TRAFFIC PØINT ,I4)
624   FØRMAT(5X,38H LESS THAN TWØ WØRKCENTRES IN SEQUENCE)
625   FØRMAT(5X,36H RADIUS ØR LØWER SIDE ZERØ DIMENSIØN)
626   FØRMAT(5X,33H AT LEAST ØNE FIXED CELL REQUIRED)
800   FØRMAT(5A8)
801   FØRMAT(20I4)
802   FØRMAT(////,29X,16H WØRKCENTRE DATA,/,29X,16H ****************,////
     1,56H PFX  W/C    X      Y     A/R     B   ANGLE  CØST CELL,/)
803   FØRMAT(3X,I3,2(2X,I2),6(2X,F4.1),2X,I1,2X,2(F5.1,2X),F4.1,2X,I4)
804   FØRMAT(14X,6(2X,F4.1))
805   FØRMAT(/,1X,I1,3X,I4,5(2X,F5.1),2X,I4,2X,I2)
806   FØRMAT(2X,I2,I4,5F6.1,I4,I2,2F5.1)
807   FØRMAT(17H ØRIGINAL TYPE = ,I2,3X,14H AREA RATIØ = ,F5.3)
808   FØRMAT(///,20X,23H TØTAL ØRIGINAL AREA = ,F8.1,/,25X,18H TØTAL NEW
     1 AREA = ,F8.1,/,34X,9H RATIØ = ,F8.4,/,18X,25H NUMBER ØF WØRKCENTR
     2ES = ,I4,/,18X,25H TØTAL RELØCATIØN CØST = ,F8.1)
809   FØRMAT(//,15X,10H CELL DATA,//,2X,52H CELL     NØ.W/CS     NØ.FIXE
     1D     AREA     REL.CØST,/)
810   FØRMAT(5X,I2,8X,I3,10X,I3,6X,F6.1,4X,F7.1)
811   FØRMAT(////,28X,17H LAYØUT AREA DATA,/,28X,17H *****************,//
     1,5X,24H AREA ØUTLINE X/Y VALUES)
812   FØRMAT(15F5.1)
813   FØRMAT(1X,I4,15F5.1)
814   FØRMAT(//,5X,15H TRAFFIC RØUTES,//,47H    X1      Y1      X2      Y2
     1  WIDTH  TERMINATØR,/)
815   FØRMAT(5F5.1,2I4)
816   FØRMAT(//,20X,22H *** END ØF ØUTPUT ***)
817   FØRMAT(////,1X;31H NØN PARTICIPATIØN AREAS  QTY= ,I2,15H  TØTAL AR
     1EA = ,F7.1,//,1X,31H INTERNAL TRAFFIC RØUTES  QTY= ,I2,15H  TØTAL
     2AREA = ,F7.1,//,30X,5H ****,12X,10H *********,/,18X,9H SUBTØTAL,4X
     3,I3,15X,F8.1,//,10X,25H TØTAL DEPARTMENT AREA = ,F8.1,//,12X,23H N
     4ETT DEPARTMENT AREA = ,F8.1,//,5X,30H WØRKCENTRE/DEPT AREA RATIØ =
     5 ,F6.4,4H   (,F6.4,2H ))
818   FØRMAT(////,28X,20H PRØDUCT INFØRMATIØN,/,28X,20H ****************
     1***,//,54H    CØDE   QUANTITY     B/SZ      FXD.CST       VAR.CST)
819   FØRMAT(/,4X,I3,4X,F8.0,4X,F5.0,4X,F9.6,4X,F9.7)
820   FØRMAT(I4,F8.0,F9.6,F9.7,10I4)
821   FØRMAT(3(8X,12I4,/))
822   FØRMAT(10X,25H NØ. W/CS EXCEEDS FIFTEEN)
823   FØRMAT(10X,24H MØRE THAN ØNE FIXED W/C)
824   FØRMAT(10H SEQUENCE ,10I4,/,10X,10I4,/,10X,10(1X,I3))
825   FØRMAT(5(2X,F5.1),4X,I2,2X,I2)
826   FØRMAT(4(4X,2F5.1))
827   FØRMAT(///,41H NØN PARTICIPATIØN AREAS - X AND Y VALUES,//)
828   FØRMAT(I3,4(4X,2F5.1),/,3(3X,4(4X,2F5.1),/))
829   FØRMAT(I3,1X,F8.0,1X,F5.0,1X,F9.6,1X,F9.7,2X,10I4)
830   FØRMAT(//,28H UA1-DATA PRØCESSING PRØGRAM,/)
500   WRITE(2,816)
      STØP
      END
      SUBRØUTINE DAREA(I8,AR1,I9)
```

```
      DIMENSIØN X(50),Y(50),XØ(50),XD(50)
      CØMMØN/SLAB1/X,Y
      PYE=3.1416
C     SUBRØUTINE FØR DEPARTMENTAL AREAS
      I9=I8
      AR3=0.0
40    DØ 43 K=1,I9
      KK=K-1
      IF(K.EQ.1)KK=I9
      IF(ABS(X(K)-X(KK)).LT.0.0001)GØ TØ 41
      IF(ABS(Y(K)-Y(KK)).LT.0.0001)GØ TØ 42
      S1=(ATAN((Y(K)-Y(KK))/(X(K)-X(KK))))*360.0/(2.0*PYE)
      IF(X(K).LT.X(KK))S1=S1-180.0
      IF(S1.LT.0)S1=S1+360.0
      GØ TØ 43
41    S1=90.0
      IF(Y(K).LT.Y(KK))S1=270.0
      GØ TØ 43
42    S1=0.0
      IF(X(KK).GT.X(K))S1=180.0
43    XØ(K)=S1
      DØ 44 K=1,(I9-1)
44    XD(K)=XØ(K)-XØ(KK)
      XD(I9)=XØ(I9)-XØ(1)
      DØ 45 K=1,I9
45    IF(XD(K).LT.0)XD(K)=XD(K)+360.0
      DØ 46 K=1,I9
      IF(XD(K).GT.180.0)GØ TØ 47
46    CØNTINUE
      GØ TØ 52
47    J=K-1
      IF(K.EQ.1)J=I9
      JJ=K+1
      IF(K.EQ.I9)JJ=1
      IF(ABS(X(J)-X(JJ)).LT.0.0001)GØ TØ 48
      S1=ATAN(ABS((Y(J)-Y(JJ))/(X(J)-X(JJ))))
      S1=CØS(S1)*((Y(J)-Y(K))+(TAN(S1)*(X(J)-X(K))))
      AR3=AR3+0.5*(SQRT((Y(J)-Y(JJ))**2+(X(J)-X(JJ))**2))*(ABS(S1))
      GØ TØ 49
48    AR3=AR3+0.5*(SQRT((Y(J)-Y(JJ))**2+(X(J)-X(JJ))**2))*ABS(X(K)-X(J))
49    IF(K.NE.I9)GØ TØ 50
      I9=I9-1
      GØ TØ 40
50    DØ 51 I22=K,I9-1
      X(I22)=X(I22+1)
51    Y(I22)=Y(I22+1)
      I9=I9-1
      GØ TØ 40
52    CALL AREA1(AR2,I9)
      AR1=AR2-AR3
      RETURN
      END
      SUBRØUTINE CMIN(XR,YR.RMIN,I1)
C     SUBRØUTINE FØR MINIMUM AREA CIRCLE
      DIMENSIØN X(50),Y(50),E(8)
      CØMMØN/SLAB1/X,Y
      D=2.0
      XR=X(1)
      YR=Y(1)
      RMAX=0.0
```

```
      DØ 50 K=1,I1
      R=SQRT((X(K)-XR)**2+(Y(K)-YR)**2))
      IF(R.GT.RMAX)RMAX=R
   50 CØNTINUE
   51 DØ 52 K=1,8
      XS=XR+R*CØS(3.1416*(I-1)/4)
      YS=YR+R*SIN(3.1416*(I-1)/4)
      RTMAX=0.0
      DØ 52 J=1,I1
      R=SQRT((X(J)-XS)**2+(Y(J)-YS)**2))
      IF(R.GT.RTMAX)RTMAX=R
   52 E(K)=RTMAX
      RMIN=1000.0
      DØ 53 K=1,8
      IF(E(K).GE.RMIN)GØ TØ 53
      RMIN=E(K)
      II=K
   53 CØNTINUE
      IF(RMIN.LE.RMAX)GØ TØ 54
      IF(D.LE.0.01)GØ TØ 55
      D=D/10.0
      GØ TØ 51
   54 XR=XR+CØS(3.1416*(I-1)/4)*R
      YR=YR+SIN(3.1416*(I-1)/4)*R
      GØ TO 51
   55 RMIN=RMAX
      RETURN
      END
      SUBRØUTINE AREA1(AR2,I9)
      DIMENSIØN X(50),Y(50),XP(50,2),XN(50,2)
      CØMMØN/SLAB1/X,Y
      XMIN=9000.0
      DØ 41 M=1,I9
      IF(X(M).GT.XMIN)GØ TØ 41
      IF(ABS(X(M)-XMIN).LT.0.0001)GØ TØ 40
      XMIN=X(M)
      MM=M
      GØ TØ 41
   40 IF(Y(M).GT.Y(MM))GØ TØ 41
      MM=M
   41 CØNTINUE
      XMAX=-5.0
      DØ 43 M=1,I9
      IF(X(M).LT.XMAX)GØ TØ 43
      IF(ABS(X(M)-XMAX).LT.0.0001)GØ TØ 42
      XMAX=X(M)
      MY=M
      GØ TØ 43
   42 IF(Y(M).GT.Y(MY))GØ TØ 43
      MY=M
   43 CØNTINUE
      KA=1
      DØ 44 K=MM,MY
      XP(KA,1)=X(K)
      XP(KA,2)=X(K)
   44 KA=KA+1
      NA=KA-1
      KA=1
      DØ 45 K=MY,I9
      XN(KA,1)=X(K)
```

```
      XN(KA,2)=Y(K)
 45   KA=KA+1
      IF(MM.NE.1)GØ TØ 46
      XN(KA,1)=X(1)
      XN(KA,2)=Y(1)
      KA=KA+1
      GØ TØ 48
 46   DØ 47 K=1,MM
      XN(KA,1)=X(1)
      XN(KA,2)=Y(1)
 47   KA=KA+1
 48   CØNTINUE
      NB=KA-1
      AR2=0.0
      DØ 49 M=1,(NA-1)
 49   AR2=AR2+((XP(M,2)+XP(M+1,2))/2.0)*(ABS(XP(M,1)-XP(M+1,1)))
      DØ 50 M=1,(NB-1)
 50   AR2=AR2-((XN(M,2)+XN(M+1,2))/2.0)*(ABS(XN(M,1)-XN(M+1,1)))
      RETURN
      END
      SUBRØUTINE SQMIN(XSQ,YSQ,ASQ,BSQ,ØSQ,NP)
C     SUBRØUTINE FØR MINIMUM AREA RECTANGLE
      DIMENSIØN X(50),Y(50)
      CØMMØN/SLAB1/X,Y
      PYE=3.1416
      AMIN=99999.
      AREA=0.0
      DØ 108 K=1,NP
      B1,B2,B3,B4=0.0
      IF(K.EQ.NP)GØ TØ 100
      I1=K
      I2=K+1
      GØ TØ 101
100   I1=NP
      I2=1
101   IF(ABS(X(I1)-X(I2)).GT.0.0001)GØ TØ 104
102   B1=X(I1)
      B2=X(I2)
      B3=Y(I1)
      B4=Y(I2)
      DØ 103 J=1,NP
      IF(X(J).LT.B1)B1=X(J)
      IF(X(J).GT.B2)B2=X(J)
      IF(Y(J).LT.B3)B3=Y(J)
      IF(Y(J).GT.B4)B4=Y(J)
103   CØNTINUE
      AA=ABS(B1-B2)
      BB=ABS(B3-B4)
      CC=0.0
      DD=(B1+B2)/2
      EE=(B3+B4)/2
      GØ TØ 107
104   IF(ABS(Y(I1)-Y(I2)).LT.0.0001)GØ TØ 102
      S1=(Y(I2)-Y(I1))/(X(I2)-X(I1))
      IF(S1.GT.0)CC=(ATAN(S1))*360/(2.0*PYE)
      S3=Y(I1)-(S1*X(I1))
      B4=0.0
      B9=S3
      DØ 105 J=1,NP
      B1=Y(J)-S1*X(J)
```

```
      IF(B1.LT.B9)B9=B1
      B2=ABS(S3-B1)
      IF(B2.LT.B4)GØ TØ 105
      B4=B2
      JJ=J
 105  CØNTINUE
      THETA=ABS(ATAN(S1))
      IF(S1.GT.0)BB=B4*(CØS(THETA))
      IF(S1.LT.0)AA=B4*(CØS(THETA))
      S10=S1
      S1=TAN((PYE/2.0)-(ATAN(ABS(S1))))
      IF(S10.GT.0)S1=-S1
      B7=Y(JJ)-X(JJ)*S1
      B5=B7
      DØ 106 J=1,NP
      B1=Y(J)-X(J)*S1
      IF(B1.LT.B7)B7=B1
      IF(B1.GT.B5)B5=B1
 106  CØNTINUE
      B2=B5-B7
      IF(S1.LT.0)AA=B2*(SIN(THETA))
      IF(S1.GT.0)BB=B2*(SIN(THETA))
      EE=((B9+0.5*B4)/S10-((B7+B5)/2)/S1)/(1/S10-1/S1)
      DD=(EE-(B9+0.5*B4))/S10
 107  AREA=AA*BB
      IF(AREA.GT.AMIN)GØ TØ 108
      AMIN=AREA
      ASQ=AA
      BSQ=BB
      ØSQ=CC
      XSQ=DD
      YSQ=EE
 108  CØNTINUE
      RETURN
      END
C
C     FINALISED 31 ØCTØBER 1974  AUTHØR J.DRISCOLL
C
      FINISH
****
```

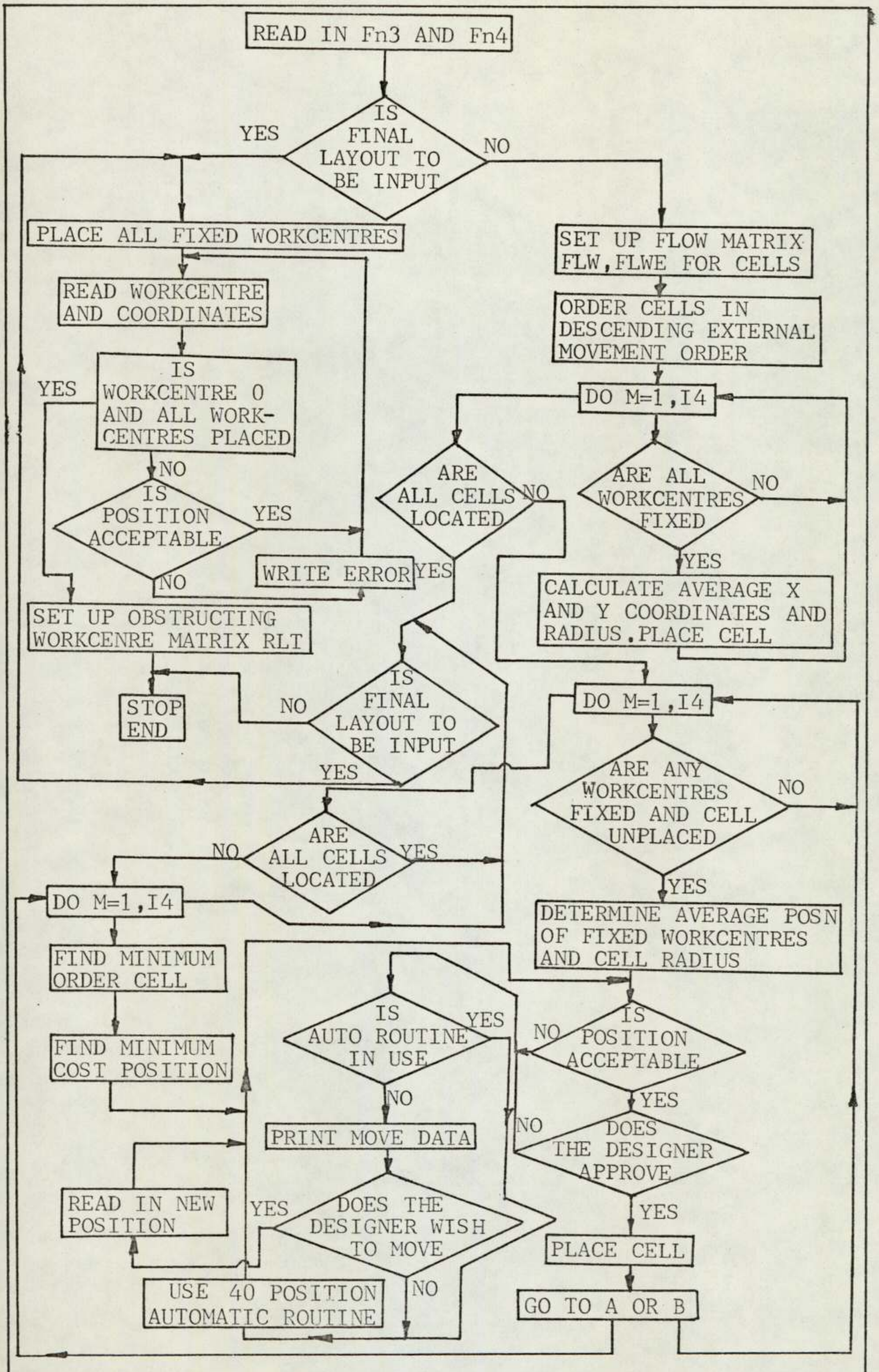


FIG B6 UA2 GENERAL FLOW CHART

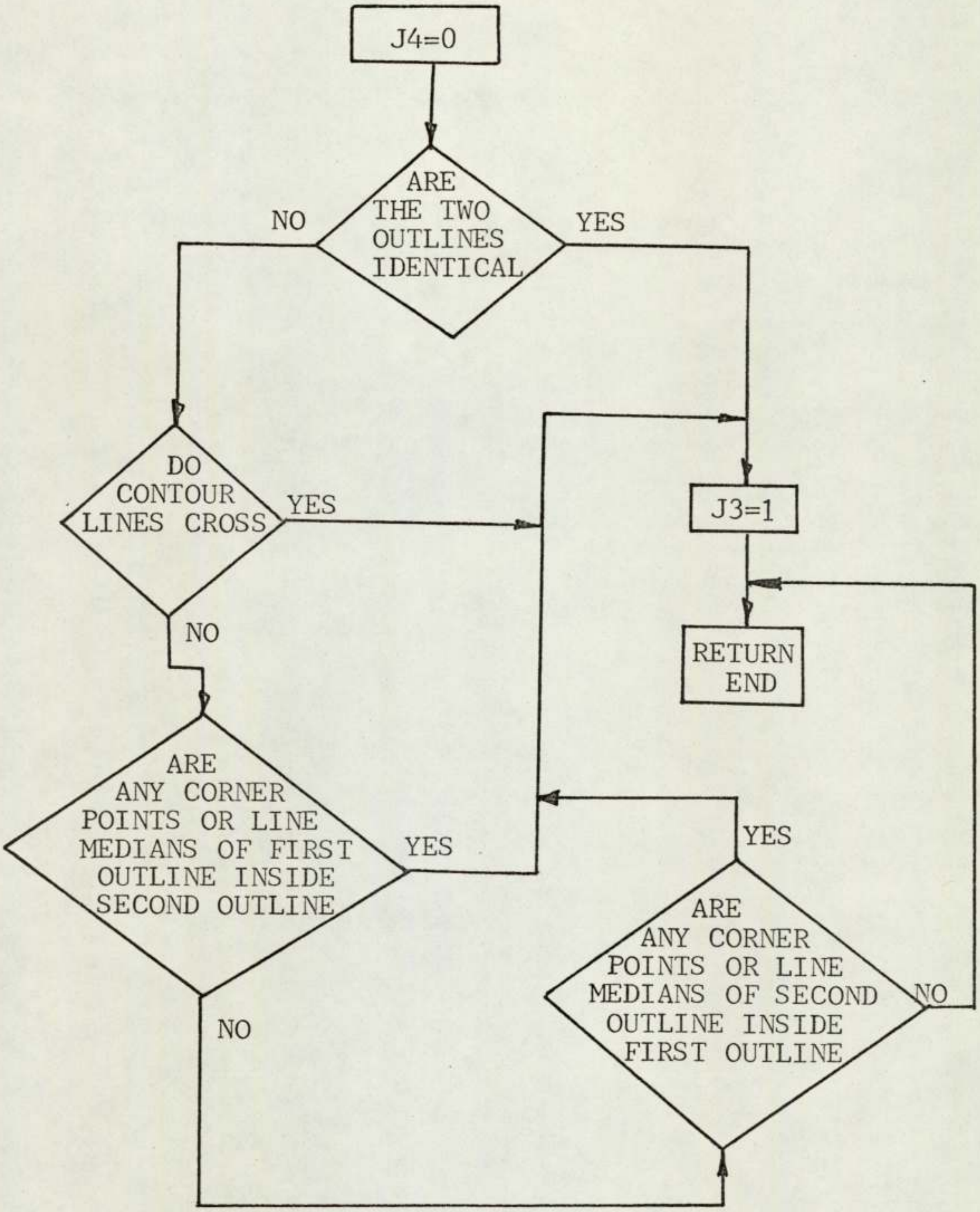


FIG B7 GENERAL FLOW DIAGRAM FOR SUBROUTINE OVLP1

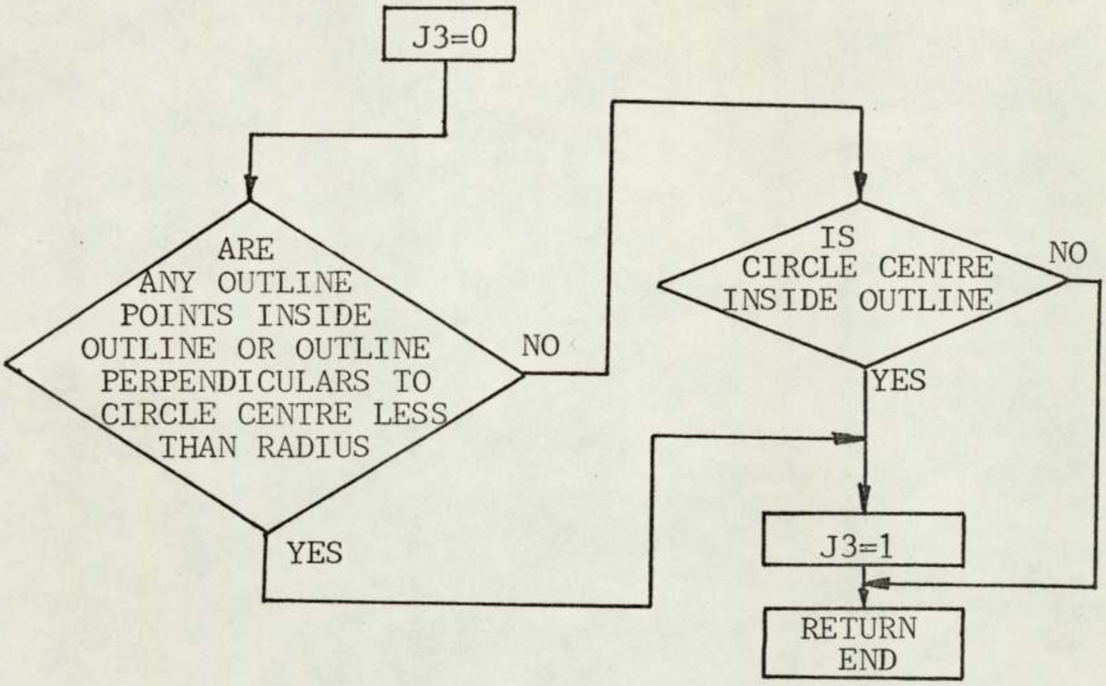


FIG B8 GENERAL FLOW CHART FOR SUBROUTINE OVLP2

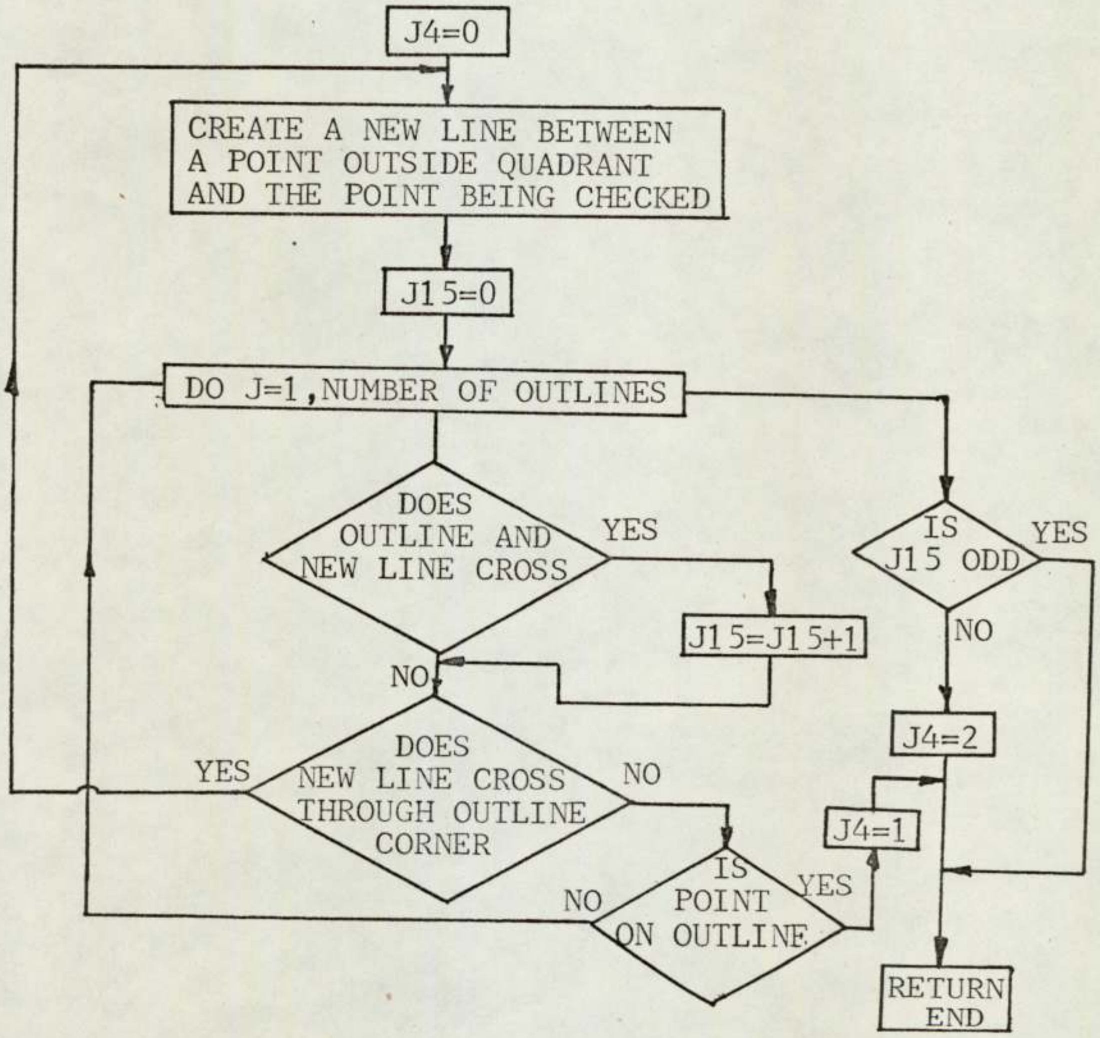


FIG B9 GENERAL FLOW CHART FOR SUBROUTINE OVLP3

PROGRAM UA2

```
      LIST (LP)
      PROGRAM(FXXX)
      INPUT 1=CR1
      INPUT 3=CR3
      INPUT 4=CR4
      ØUTPUT 2=LP2
      ØUTPUT 7=CP7
      CØMPRESS INTEGER AND LØGICAL
      CØMPACT
      END
      MASTER UA2
      INTEGER FID,WI,WC,WR,CI,PI,PW,CØ,CØ2,RLT
      DIMENSIØN PI(100),PM(100,3),PW(100,30),WI(150),WC(150),WR(150),F(1
     150,10),FID(150),CI(50,3),C(50,2),AØA(50,2),AIA(80,10,2),TITLE(5),D
     21(50,2),D2(50,2),RLT(150,6),CX(50),CY(50),CR(50),CØ(50),CC(8),CA(8
     3),IA(150),FLW(50,50),FLWE(50),CØ2(50),IL4(150)
      DATA IYES/3HYES/
      PYE=3.1416
      MK1,MK=1
      MK4=4
      DØ 50 I=1,8
   50 CA(I)=45.0*(I-1)
      WRITE(2,827)
C
C                                  INPUT ØF DATA
C
      READ(3,801)(TITLE(I),I=1,5)
      READ(3,808)D22
      READ(4,802)I3
      READ(4,806)((FID(I),WI(I),(F(I,IE),IE=1,5),WR(I),WC(I),F(I,9),F(I,
     110)),I=1,I3)
      READ(3,802)I4
      READ(3,807)(((CI(I,ID),ID=1,3),(C(I,IE),IE=1,2)),I=1,I4)
      READ(3,802)I5,I6,I7
      READ(3,808)(AØA(I,1),I=1,I5)
      READ(3,808)(AØA(I,2),I=1,I5)
      IF(I6.EQ.0)GØ TØ 52
      DØ 51 I=1,I6
      READ(3,823)IA(I),(AIA(I,ID,1),ID=1,10)
   51 READ(3,808)(AIA(I,ID,2),ID=1,10)
   52 Z=I5*2/15
      I8=INT(Z)
      IF((I8*15).NE.(I5*2))I8=I8*1
      I8=I8*I6*3
      READ(3,804)(BLK,I=1,I8)
   53 IF(I7.EQ.0)GØ TØ 55
      DØ 54 I=I6*1,I6+I7
      READ(3,808)(AIA(I,ID,1),ID=1,4)
      READ(3,808)(AIA(I,ID,2),ID=1,4)
   54 IA(I)=4
      Z=I7*I7/15
      I10=INT(Z)
      IF((I10*15).NE.(I7*I7))I10=I10+1
      I10=I10+I7
      READ(3,804)(BLK,I=1,I10)
   55 READ(3,802)I8
      DØ 56 I=1,I8
      READ(3,810)(PI(I)),(PM(I,ID),ID=1,3),(PW(I,IE),IE=1,10)
   56 IF(PW(I,10).GT.0)READ(3,802)(PW(I,IE),IE=11,30)
C
```

```
C                           END ØF DATA INPUT
C
      WRITE(2,803)
      READ(1,804)IANS
      IF(IANS.EQ.IYES)GØ TØ 94
      WRITE(2,828)
C     SETTING UP FLØW MATRIX FØR CELLS
      DØ 59 M=1,I8
      DØ 58 MA=2,30
      IF(PW(M,MA).EQ.0)GØ TØ 58
      DØ 57 MB=1,I3
      IF(PW(M,MA).EQ.WI(MB))M1=WC(MB)
      IF(PW(M,(MA-1)).EQ.WI(MB))M2=WC(MB)
   57 CØNTINUE
      IF(M1.LE.M2)FLW(M1,M2)=FLW(M1,M2)+PM(M,1)*PM(M,3)
      IF(M1.GT.M2)FLW(M2,M1)=FLW(M2,M1)+PM(M,1)*PM(M,3)
      IF(M1.EQ.M2)GØ TØ 58
      FLWE(M1)=FLWE(M1)+PM(M,1)*PM(M,3)/2
      FLWE(M2)=FLWE(M2)+PM(M,1)*PM(M,3)/2
   58 CØNTINUE
   59 CØNTINUE
C     ØRDERING CELLS
      DØ 61 M=1,I4
      VALUE=-10.0
      DØ 60 MA=1,I4
      IF(CØ(MA).GT.0.ØR.FLWE(MA).LT.VALUE)GØ TØ 60
      MB=MA
      VALUE=FLWE(MA)
   60 CØNTINUE
   61 CØ(MB),CØ2(MB)=M
C     PLACING PREFIXED CELLS
      WRITE(2,800)
      MP=1
      MTP,MT=0
      DØ 62 M=1,I4
      IF(CI(M,2).NE.CI(M,3))GØ TØ 62
      CR(M)=SQRT(C(M,1)/2)
      MTP=MTP+MP
      MT=MT+1
      CØ(M),MV=0
      DØ 62 MA=1,I3
      IF(WC(MA).NE.M)GØ TO 62
      CX(M)=CX(M)+F(MA,1)
      CY(M)=CY(M)+F(MA,2)
      MV=MV+1
      IF(MV.NE.CI(M,3))GØ TØ 62
      CX(M)=CX(M)/CI(M,3)
      CY(M)=CY(M)/CI(M,3)
      WRITE(2,809)CI(M,1),CX(M),CY(M),CR(M),MP,MTP
   62 CØNTINUE
      IF(MT.EQ.I4)GØ TØ 90
   63 MC,MP=1
      MV,M=52
      DØ 64 MA=1,I4
      IF(CØ(MA).EQ.0.ØR.CI(MA,3).EQ.0.ØR.CØ(MA).GT.MV)GØ TØ 64
      MV=CØ(MA)
      M=MA
   64 CØNTINUE
      IF(M.EQ.52)GØ TØ 83
      CR(M)=SQRT(C(M,1)/2)
```

```
      DØ 65 MA=1,I3
      IF(WC(MA).NE.M.ØR.FID(MA).LT.3)GØ TØ 65
      CX(M)=CX(M)+FID(MA,1)
      CY(M)=CY(M)+FID(MA,2)
   65 CØNTINUE
C     CHECKING PØSITIØN
      CX(M)=CX(M)/CI(M,3)
      CY(M)=CY(M)/CI(M,3)
   66 CST4=0.0
      DØ 67 N=1,I4
      IF(CØ(N).GT.0)GØ TØ 67
      IF(M.EQ.N)GØ TØ 67
      IF(I7.LE.0)DST4=SQRT((CX(N)-CX(M))**2+(CY(N)-CY(M))**2)
      IF(I7.GT.0)DST4=ABS(CX(N)-CX(M))+ABS(CY(N)-CY(M))
      CST4=CST4+DST4*(FLW(M,N)+FLW(N,M))
   67 CØNTINUE
      DØ 68 N=1,I4
      IF(CØ(N).GT.0)GØ TØ 68
      XN=SQRT((CX(M)-CX(N))**2+(CY(M)-CY(N))**2)
      IF(XN.LT.(CR(N)+CR(M)))GØ TØ 72
   68 CØNTINUE
      CALL ØVLP3(CX(M),CY(M),AØA,I5,J4)
      IF(J4.NE.2)GØ TØ 72
      IF((I6+I7).EQ.0)GØ TØ 71
      DØ 70 N=1,(I6+I7)
      DØ 69 NA=1,IA(N)
      D2(NA,1)=AIA(N,NA,1)
   69 D2(NA,2)=AIA(N,NA,2)
      CALL ØVLP3(CX(M),CY(M),D2,IA(N),J4)
      IF(J4.NE.0)GØ TØ 72
   70 CØNTINUE
   71 MTP=MTP+MP
      IF(CI(M,3).GT.0)WRITE(2,813)CI(M,1),CX(M),CY(M),CR(M),MP,MTP,CST4
      IF(CI(M,3).EQ.0)WRITE(2,811)CI(M,1),CX(M),CY(M),CR(M),MP,MTP,CST4
      MCØ=CØ(M)
      MT=MT+1
      CØ(M)=0
      IANS=IYES
      IF(CI(M,2).NE.CI(M,3))READ(1,804)IANS
      IF(IANS.EQ.IYES)GØ TØ (63,83)MK
      CØ(M)=MCØ
      MT=MT-1
      MTP=MTP-MP
      GØ TØ (82,0)MK
   72 IF(MC.EQ.2)GØ TØ 75
      DØ 73 N=1,8
      XR=CX(M)+5.0*CØS(PYE*(N-1)/4)
      YR=CY(M)+5.0*SIN(PYE*(N-1)/4)
      CC(N)=0.0
      DØ 73 NA=1,I4
      IF(CØ(NA).GT.0)GØ TØ 73
      IF(NA.EQ.M)GØ TØ 73
      IF(I7.GT.0)DST4=ABS(CX(NA)-XR)+ABS(CY(NA)-YR)
      IF(I7.LE.0)DST4=SQRT((CX(NA)-XR)**2+(CY(NA)-YR)**2)
      CC(N)=CC(N)+DST4*(FLW(NA,M)+FLW(M,NA))
   73 CØNTINUE
   74 WRITE(2,817)CX(M),CY(M),CR(M),CI(M,1),CST4,(CA(N),N=1,4),(CC(N),N=
     11,4),(CA(N),N=5,8),(CC(N),N=5,8)
      READ(1,804)IANS
      IF(IANS.EQ.IYES)GØ TØ 82
```

```
      MC,MD=2
      RAD=0.0
      CXM=CX(M)
      CYM=CY(M)
   75 IF(MD.EQ.3)GØ TØ 78
      MD=3
      RAD=RAD+2.0
      IF(RAD.GT.11.0)GØ TØ 81
      CMAX=0.0
      DØ 77 N=1,8
      XR=CXM+RAD*CØS(PYE*(N-1)/4)
      YR=CYM+RAD*SIN(PYE*(N-1)/4)
      CC(N)=0.0
      DØ 77 NA=1,I4
      IF(CØ(NA).GT.0)GØ TØ 77
      IF(I7.GT.0)GØ TØ 76
      CC(N)=CC(N)+(FLW(M,NA)+FLW(NA,M))*SQRT((XR-CX(NA))**2+(YR-CY(NA))*
     1*2)
      GØ TØ 77
   76 CC(N)=CC(N)+(FLW(M,NA)+FLW(NA,M))*(ABS(XR-CX(NA))+ABS(YR-CY(NA)))
   77 IF(CC(N).GT.CMAX)CMAX=CC(N)
   78 CMIN=CMAX+5.0
      NB=9
      DØ 79 N=1,8
      IF(CC(N).LT.0.ØR.CC(N).GT.CMIN)GØ TØ 79
      NB=N
      CMIN=CC(N)
   79 CØNTINUE
      IF(NB.NE.9)GØ TØ 80
      MD=2
      GØ TØ 75
   80 CC(NB)=-1.0
      MP=MP+1
      CX(M)=CXM+RAD*CØS((NB-1)*PYE/4)
      CY(M)=CYM+RAD*SIN((NB-1)*PYE/4)
      GØ TØ 66
   81 WRITE(2,812)CI(M,1),CXM,CYM,MP
      CX(M)=CXM
      CY(M)=CYM
      MC=1
   82 READ(1,818)RR,DR
      DR=DR*PYE/180.0
      CX(M)=CX(M)+RR*CØS(DR)
      CY(M)=CY(M)+RR*SIN(DR)
      MP=MP+1
      GØ TØ 66
   83 IF(MT.EQ.I4)GØ TØ 90
      M,MV=52
      DØ 84 MA=1,I4
      IF(CØ(MA).EQ.0.ØR.CØ(MA).GT.MV)GØ TØ 84
      MV=CØ(MA)
      M=MA
   84 CØNTINUE
      CR(M)=SQRT(C(M,1)/2)
      XCTR,YCTR=-1.0
      CST1=9900000.0
      RAD=50.0
   85 DØ 87 N=1,8
      XM=XCTR+RAD*CØS((N-1)*PYE/4)
      YM=YCTR+RAD*SIN((N-1)*PYE/4)
```

```
      CC(N)=0.0
      DØ 87  MA=1,I4
      IF(CØ(MA).GT.0)GØ TØ 87
      IF(I7.GT.0)GØ TØ 86
      CC(N)=CC(N)+(FLW(M,MA)+FLW(MA,M))*SQRT((XM-CX(MA))**2+(YM-CY(MA))*
     1*2)
      GØ TØ 87
   86 CC(N)=CC(N)+(FLW(M,MA)+FLW(MA,M))*(ABS(XM-CX(MA))+ABS(YM-CY(MA)))
   87 CØNTINUE
      NA=9
      DØ 88 N=1,8
      IF(CC(N).GE.CST1)GØ TØ 88
      CST1=CC(N)
      NA=N
   88 CØNTINUE
      IF(NA.LT.9)GØ TØ 89
      RAD=RAD/4.0
      IF(RAD.GT.0.1)GØ TØ 85
      CX(M)=XCTR
      CY(M)=YCTR
      MC,MP=1
      MK=2
      GØ TØ 66
   89 XCTR=XCTR+RAD*CØS(PYE*(NA-1)/4)
      YCTR=YCTR+RAD*SIN(PYE*(NA-1)/4)
      GØ TØ 85
   90 WRITE(2,820)
      DØ 93 M=1,I4
      DØ 91 N=1,I4
   91 IF(CØ2(N).EQ.M)ICELL=CI(N,1)
      NA=1
      DØ 92 K=1,I3
      IF(WC(K).NE.ICELL)GØ TØ 92
      CØ(NA)=WI(K)
      NA=NA+1
   92 CØNTINUE
      NA=NA-1
      NB=NA
      IF(NA.GT.10)NB=10
      WRITE(2,821)CI(N,1),M,(CØ(NC),NC=1,NB)
      IF(NA.GT.10)WRITE(2,822)(CØ(NC),NC=11,NA)
   93 CØNTINUE
      WRITE(2,803)
      READ(1,804)IANS
      IF(IANS.NE.IYES)GØ TØ 500
C     FINAL LAYOUT INPUT
   94 WRITE(2,829)
      ICNT=0
      DØ 95 M=1,I3
      IF(FID(M).LT.3)GØ TØ 95
      F(M,6)=F(M,1)
      F(M,7)=F(M,2)
      F(M,8)=F(M,5)
      ICNT=ICNT+1
   95 CØNTINUE
   96 READ(1,819)I,X3,Y3,ANG
      IF(I.EQ.0.AND.ICNT.EQ.I3)GØ TØ 103
      DØ 100 M=1,I3
      IF(WI(M).NE.I)GØ TØ 100
      IF(FID(M).GT.2)GØ TØ 101
```

```
      CALL ØVLP3(X3,Y3,AØA,I5,J4)
      IF(J4.NE.2)GØ TØ 102
      IF((I6+I7).EQ.0)GØ TØ 99
      DØ 98 N=1,(I6+I7)
      DØ 97 NA=1,IA(N)
      D1(NA,1)=AIA(N,NA,1)
   97 D1(NA,2)=AIA(N,NA,2)
      CALL ØVLP3(X3,Y3,D1,IA(N),J4)
      IF(J4.NE.0)GØ TØ 102
   98 CØNTINUE
   99 F(M,6)=X3
      F(M,7)=Y3
      F(M,8)=ANG
      IF(IL4(M).EQ.0)ICNT=ICNT+1
      IL4(M)=1
      GØ TØ 96
  100 CØNTINUE
      WRITE(2,824)I
      GØ TØ 96
  101 WRITE(2,825)I
      GØ TØ 96
  102 WRITE(2,826)
      GØ TØ 96
C     CØMPLETIØN ØF RLT MATRIX
  103 DØ 109 M=1,I3
      IF(FID(M).GT.2)GØ TØ 109
      R1=SQRT(F(M,3)**2+F(M,4)**2)/2
      IF(FID(M).EQ.1)R1=F(M,3)
      MA=0
      MB=1
      DØ 108 N=1,I3
      IF(FID(N).GT.2.ØR.M.EQ.N)GØ TØ 108
      R2=SQRT(F(N,3)**2+F(N,4)**2)/2
      IF(FID(N).EQ.1)R2=F(N,3)
      R3=SQRT((F(M,6)-F(N,1))**2+(F(M,7)-F(N,2))**2)
      IF((R1+R2).LE.(R3+0.0001))GØ TØ 108
      IF((FID(M)+FID(N)).EQ.2)GØ TØ 107
      IF((FID(M)+FID(N)).EQ.4)GØ TØ 105
      IF(FID(M).EQ.2)GØ TØ 104
      CALL SETUP(D2,F(N,3),F(N,4),F(N,5),F(N,1),F(N,2))
      CALL ØVLP2(F(M,3),F(M,6),F(M,7),D2,MK4,J3)
      GØ TØ 106
  104 IF(MA.EQ.0)CALL SETUP(D2,F(M,3),F(M,4),F(M,8),F(M,6),F(M,7))
      MA=1
      CALL ØVLP2(F(N,3),F(N,1),F(N,2),D2,MK4,J3)
      GØ TØ 106
  105 CALL SETUP(D1,F(M,3),F(M,4),F(M,8),F(M,6),F(M,7))
      CALL SETUP(D2,F(N,3),F(N,4),F(N,5),F(N,1),F(N,2))
      CALL ØVLP1(D1,D2,MK4,MK4,J3)
  106 IF(J3.EQ.0)GØ TØ 108
  107 IF(MB.GT.6)WRITE(2,815)WI(M)
      IF(MB.GT.6)GØ TØ 109
      RLT(M,MB)=N
      MB=MB+1
  108 CØNTINUE
  109 CØNTINUE
      WRITE(7,802)I3
      WRITE(7,808)((F(M,MA),MA=1,10),M=1,I3)
      WRITE(7,802)(FID(M),WC(M),WR(M),WI(M),M=1,I3)
      WRITE(7,802)((RLT(M,MA),MA=1,6),M=1,I3)
```

```
 800  FØRMAT(1H1,//,52H CELL  X-CENTRE  Y-CENTRE  RADIUS  NO.PSNS  TTL.P
     1SNS,6H  CØST,/)
 801  FØRMAT(5A8)
 802  FØRMAT(20I4)
 803  FØRMAT(///,5X,36H WILL YOU PROVIDE THE FINAL LAYOUT ?,///)
 804  FØRMAT(A3)
 805  FØRMAT(/,I4,4X,F5.1,6X,F5.1,4X,I4,4X,I4,6X,I4)
 806  FØRMAT(2X,I2,I4,5F6.1,I4,I2,2F5.1)
 807  FØRMAT(5X,I2,8X,I3,10X,I3,6X,F6.1,4X,F7.1)
 808  FØRMAT(15F5.1)
 809  FØRMAT(/,I4,4X,F5.1,6X,F5.1,4X,F5.1,4X,I4,5X,I4,6H FIXED)
 810  FØRMAT(I4,F8.0,F9.6,F9.7,10I4)
 811  FØRMAT(/,I4,4X,F5.1,6X,F5.1,4X,F5.1,4X,I4,5X,I4,1X,F8.1)
 812  FØRMAT(/,6H CELL ,I4,19H UNASSIGNED AT X = ,F5.1,5H Y = ,F5.1,7H A
     1FTER ,I2,5H TRYS,/,14H CHANGE CENTRE)
 813  FØRMAT(/,I4,4X,F5.1,6X,F5.1,4X.F5.1,4X,I4,5X,I4,1X,F8.1,6H FIXED)
 814  FØRMAT(/,I4,4X,F5.1,6X,F5.1,4X,I4,4X,I4,6X,I4,9H NØT ASND)
 815  FØRMAT(5X,4H W/C,I4,35H HAS MØRE THAN SIX W/CS IN NEW PØSN)
 816  FØRMAT(14H ERRØR IN DATA)
 817  FØRMAT(/,14H MØVE GUIDE X=,F5.1,3H Y=,F5.1,5H RAD=,F5.1,6H CELL=,I
     14,6H CØST=,F8.1,/,9H ANGLE    ,4(F5.1,6X),/,5H CØST,4(F9.1,2X),/,9H
     2 ANGLE    ,4(F5.1,6X),/,5H CØST,4(F9.1,2X),//,15H WILL YØU MØVE?)
 818  FØRMAT(3F0.0)
 819  FØRMAT(I0,3F0.0)
 820  FØRMAT(//,11H CELL  CELL,17X,16HCELL WØRKCENTRES,/,11H  NØ  ØRDER)
 821  FØRMAT(/,I4,3X,I3,2X,10(I3,1X))
 822  FØRMAT(12X,10(I3,1X))
 823  FØRMAT(1X,I4,15F5.1)
 824  FØRMAT(12H WØRKCENTRE ,I4,12H NØNEXISTANT)
 825  FØRMAT(12H WØRKCENTRE ,I4,6H FIXED)
 826  FØRMAT(17H CØØRDINATE ERRØR)
 827  FØRMAT(/,35H UA2 - STATIC LAYOUT DESIGN PRØGRAM,/)
 828  FØRMAT(/,24H LAYOUT ØF CELLS SECTIØN,/)
 829  FØRMAT(/,22H INPUT ØF CELLS SECTIØN,/)
 500  STØP
      END
      SUBRØUTINE ØVLP1(D1,D2,J1,J2,J3)
      DIMENSIØN D1(50,2),D2(50,2)
      J3=0
      IF(J1.NE.J2)GØ TØ 52
      DØ 51 J=1,J1
      DØ 50 JA=1,J2
      S1=ABS(D1(J,1)-D2(JA,1))
      S2=ABS(D2(J,2)-D2(JA,2))
      IF(S1.LT.0.0001.AND.S2.LT.0.0001)GØ TØ 51
  50  CØNTINUE
      GØ TØ 52
  51  CØNTINUE
      GØ TØ 60
  52  DØ 56 J=1,J1
      JA=J+1
      IF(J.EQ.J1)JA=1
      S18=SQRT((D1(J,1)-D1(JA,1))**2+(D1(J,2)-D1(JA,2))**2)
      DØ 56 JB=1,J2
      JC=JB+1
      IF(JB.EQ.J2)JC=1
      S15=SQRT((D2(JB,1)-D2(JC,1))**2+(D2(JB,2)-D2(JC,2))**2)
      S1=ABS(D1(J,1)-D1(JA,1))
      S2=ABS(D2(JB,1)-D2(JC,1))
      IF(S1.LT.0.0001.AND.S2.LT.0.0001)GØ TØ 56
```

```
      IF(S1.LT.0.0001)GØ TØ 54
      IF(S2.LT.0.0001)GØ TØ 55
      S9=(D1(J,2)-D1(JA,2))/(D1(J,1)-D1(JA,1))
      S10=(D2(JB,2)-D2(JC,2))/(D2(JB,1)-D2(JC,1))
      IF(ABS(S9-S10).LT.0.0001)GØ TØ 56
      S11=((D2(JB,2)-D1(JA,2))+(D1(JA,1)*S9-D2(JB,1)*S10))/(S9-S10)
      S12=D1(JA,2)+(S11-D1(JA,1))*S9
   53 S13=SQRT((S11-D2(JB,1))**2+(S12-D2(JB,2))**2)
      S14=SQRT((S11-D2(JC,1))**2+(S12-D2(JC,2))**2)
      S16=SQRT((S11-D1(JA,1))**2+(S12-D1(JA,2))**2)
      S17=SQRT((S11-D1(J,1))**2+(S12-D1(J,2))**2)
      IF(S13.LT.0.0001.ØR.S14.LT.0.0001)GØ TØ 56
      IF(S17.LT.0.0001.ØR.S16.LT.0.0001)GØ TØ 56
      J14=0
      IF(S13.LT.S15.AND.S14.LT.S15)J14=J14+1
      IF(S16.LT.S18.AND.S17.LT.S18)J14=J14+1
      IF(J14.EQ.2)GØ TØ 60
      GØ TØ 56
   54 S11=D1(J,1)
      S12=D2(JB,2)+(D2(JB,2)-D2(JC,2))/(D2(JB,1)-D2(JC,1))*(D1(J,1)-D2(J
     1B,1))
      GØ TØ 53
   55 S11=D2(JB,1)
      S12=D1(J,2)+(D1(J,2)-D1(JA,2))/(D1(J,1)-D1(JA,1))*(D2(JB,1)-D1(J,1
     1))
      GØ TØ 53
   56 CØNTINUE
      J8=0
   57 J5,J6,J7=0
      DØ 58 M=1,J1
      MA=M+1
      IF(M.EQ.J1)MA=1
      CALL ØVLP3(D1(M,1),D1(M,2),D2,J2,J4)
      JJ4=J4
      X=(D1(M,1)+D1(MA,1))/2
      Y=(D1(M,2)+D1(MA,2))/2
      CALL ØVLP3(X,Y,D2,J2,J4)
      IF(JJ4.EQ.0)J5=J5+1
      IF(J4.EQ.0)J5=J5+1
      IF(JJ4.EQ.1)J6=J6+1
      IF(J4.EQ.1)J6=J6+1
      IF(JJ4.EQ.2)J7=J7+1
   58 IF(J4.EQ.2)J7=J7+1
      IF(J5.GT.0.AND.J7.GT.0)GØ TØ 60
      IF(J7.GT.0)GØ TØ 60
      IF(J8.GT.0)GØ TØ 61
      J9=J1
      IF(J2.GT.J1)J9=J2
      DØ 59 J=1,J9
      DØ 59 JA=1,2
      DX=D1(J,JA)
      D1(J,JA)=D2(J,JA)
   59 D2(J,JA)=DX
      J9,J8=J1
      J1=J2
      J2=J9
      GØ TØ 57
   60 J3=1
   61 RETURN
      END
      SUBRØUTINE ØVLP2(RD,D4,D5,D2,J2,J3)
```

```
      DIMENSIØN D2(50,2)
      J3=0
      DØ 52 J=1,J2
      RE=SQRT((D4-D2(J,1))**2+(D5-D2(J,2))**2)
      IF(RE.LT.(RD-0.0001))GØ TØ 53
      JJ=J+1
      IF(J.EQ.J2)JJ=1
      IF(ABS(D2(JJ,1)-D2(J,1)).LT.0.0001)GØ TØ 51
      S3=(D2(JJ,2)-D2(J,2))/(D2(JJ,1)-D2(J,1))
      S4=ABS((D5-D2(J,2)+(D2(J,1)-D4)*S3)*CØS(ATAN(S3)))
      IF(S4.GE.RD)GØ TØ 52
      S6=SQRT(RE**2-S4**2)
      S7=SQRT((D4-D2(JJ,1))**2+(D5-D2(JJ,2))**2)
      S8=SQRT(S7**2-S4**2)
      S7=SQRT((D2(J,1)-D2(JJ,2))**2+(D2(J,2)-D2(JJ,2))**2)
 50   IF(S8.LT.S7.AND.S6.LT.S7)GØ TØ 53
      GØ TØ 52
 51   S4=ABS(D4-D2(J,1))
      IF(S4.GT.RD)GØ TØ 52
      S7=ABS(D2(J,2)-D2(JJ,2))
      S6=ABS(D2(J,2)-D5)
      S8=ABS(D2(JJ,2)-D5)
      GØ TØ 50
 52   CØNTINUE
      JM=4
      CALL ØVLP3(D4,D5,D2,JM,J4)
      IF(J4.LT.2)GØ TØ 54
 53   J3=1
 54   RETURN
      END
      SUBRØUTINE ØVLP3(X,Y,D3,JA,J4)
      DIMENSIØN D3(50,2)
      J4=0
      X2,Y2=-20.0
 50   J15=0
      X2=X2+10.0
      S18=SQRT((X2-X)**2+(Y2-Y)**2)
      DØ 54 J=1,JA
      JB=J+1
      IF(J.EQ.JA)JB=1
      J14=0
      S1=ABS(D3(J,1)-D3(JB,1))
      IF(ABS(X-X2).LT.0.0001.AND.S1.LT.0.0001)GØ TØ 54
      S15=SQRT((D3(J,1)-D3(JB,1))**2+(D3(J,2)-D3(JB,2))**2)
      IF(ABS(X-X2).LT.0.0001)GØ TØ 52
      IF(S1.LT.0.0001)GØ TØ 53
      IF(ABS(D3(J,1)-D3(JB,1)).LT.0.0001)GØ TØ 53
      S9=(Y-Y2)/(X-X2)
      S10=(D3(J,2)-D3(JB,2))/(D3(J,1)-D3(JB,1))
      IF(ABS(S9-S10).LT.0.0001)GØ TØ 54
      S11=((D3(JB,2)-Y2)+(X2*S9-D3(JB,1)*S10))/(S9-S10)
      S12=Y2+(S11-X2)*S9
 51   S13=SQRT((S11-D3(J,1))**2+(S12-D3(J,2))**2)
      S14=SQRT((S11-D3(JB,1))**2+(S12-D3(JB,2))**2)
      S16=SQRT((S11-X)**2+(S12-Y)**2)
      S17=SQRT((S11-X2)**2+(S12-Y2)**2)
      IF(S17.LT.0.0001.ØR.S16.LT.0.0001)GØ TØ 55
      IF(S13.LT.0.0001.ØR.S14.LT.0.0001)GØ TØ 50
      IF(S16.LT.S18.AND.S17.LT.S18)J14=J14+1
```

```
      IF(S13.LT.S15.AND.S14.LT.S15)J14=J14+1
      GØ TØ 54
 52   S11=X2
      S12=D3(J,2)+(D3(J,2)-D3(JB,2))/(D3(J,1)-D3(JB,1))*(X2-D3(J,1))
      GØ TØ 51
 53   S11=D3(J,1)
      S12=Y2+(Y2-Y)/(X2-X)*(D3(J,1)-X2)
      GØ TØ 51
 54   IF(J14.EQ.2)J15=J15+1
      Z=J15/2
      J16=INT(Z)*2
      IF(J15.NE.J16)J4=2
      GØ TØ 56
 55   J4=1
 56   RETURN
      END
      SUBRØUTINE SETUP(D3,D4,D5,D6,D7,D8)
      DIMENSIØN D3(50,2)
      PYE=3.1416
      Z43=ATAN(D5/D4)
      Z41=Z43+D6*PYE/180.0
      Z40=PYE+Z41-2.0*Z43
      IF(Z41.GE.(2.0*PYE))Z41=Z41-2.0*PYE
      IF(Z40.GE.(2.0*PYE))Z40=Z40-2.0*PYE
      Z42=SQRT(D4**2+D5**2)
      D3(1,1)=D7-Z42*CØS(Z41)
      D3(2,1)=D7+Z42*CØS(Z40)
      D3(3,1)=D7+Z42*CØS(Z41)
      D3(4,1)=D7-Z42*CØS(Z40)
      D3(1,2)=D8-Z42*SIN(Z41)
      D3(2,2)=D8+Z42*SIN(Z40)
      D3(3,2)=D8+Z42*SIN(Z41)
      D3(4,2)=D8-Z42*SIN(Z40)
      RETURN
C
C     FINALISED 30 JANUARY 1975    AUTHØR J.DRISCØLL
C
      END
      FINISH
****
```

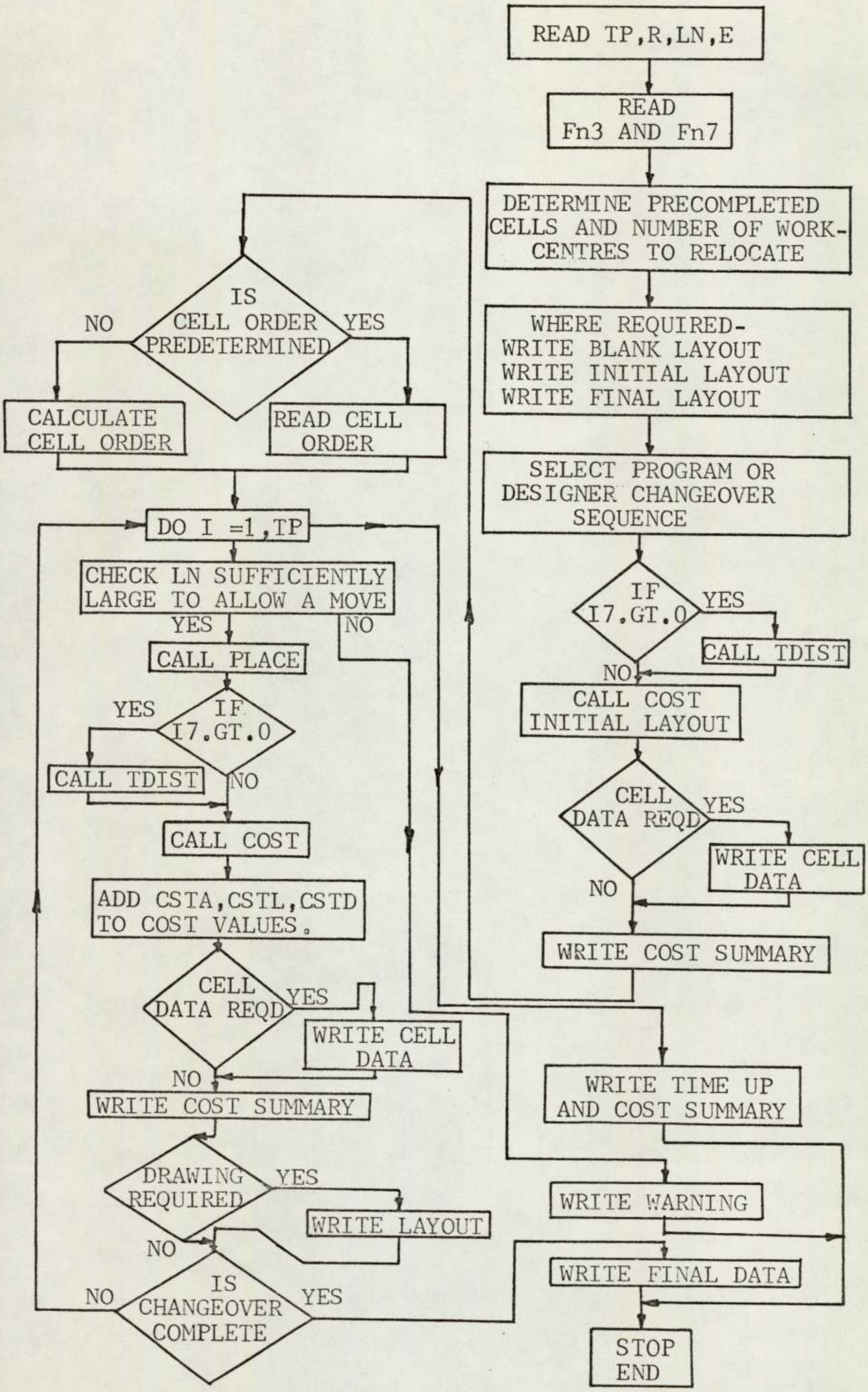


FIG B10 UA3 GENERAL FLOW CHART

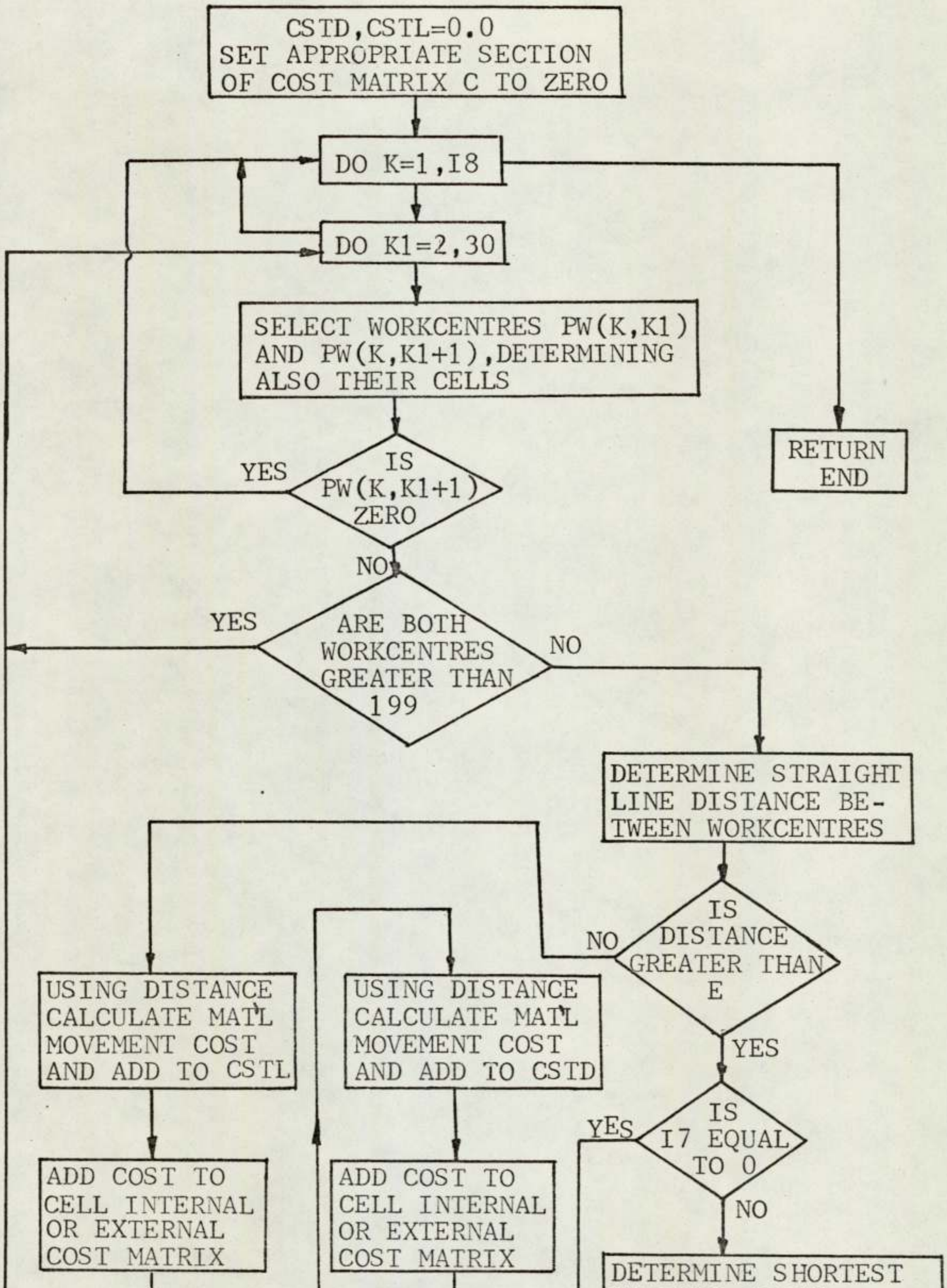


FIG B11 GENERAL FLOW DIAGRAM FOR SUBROUTINE COST

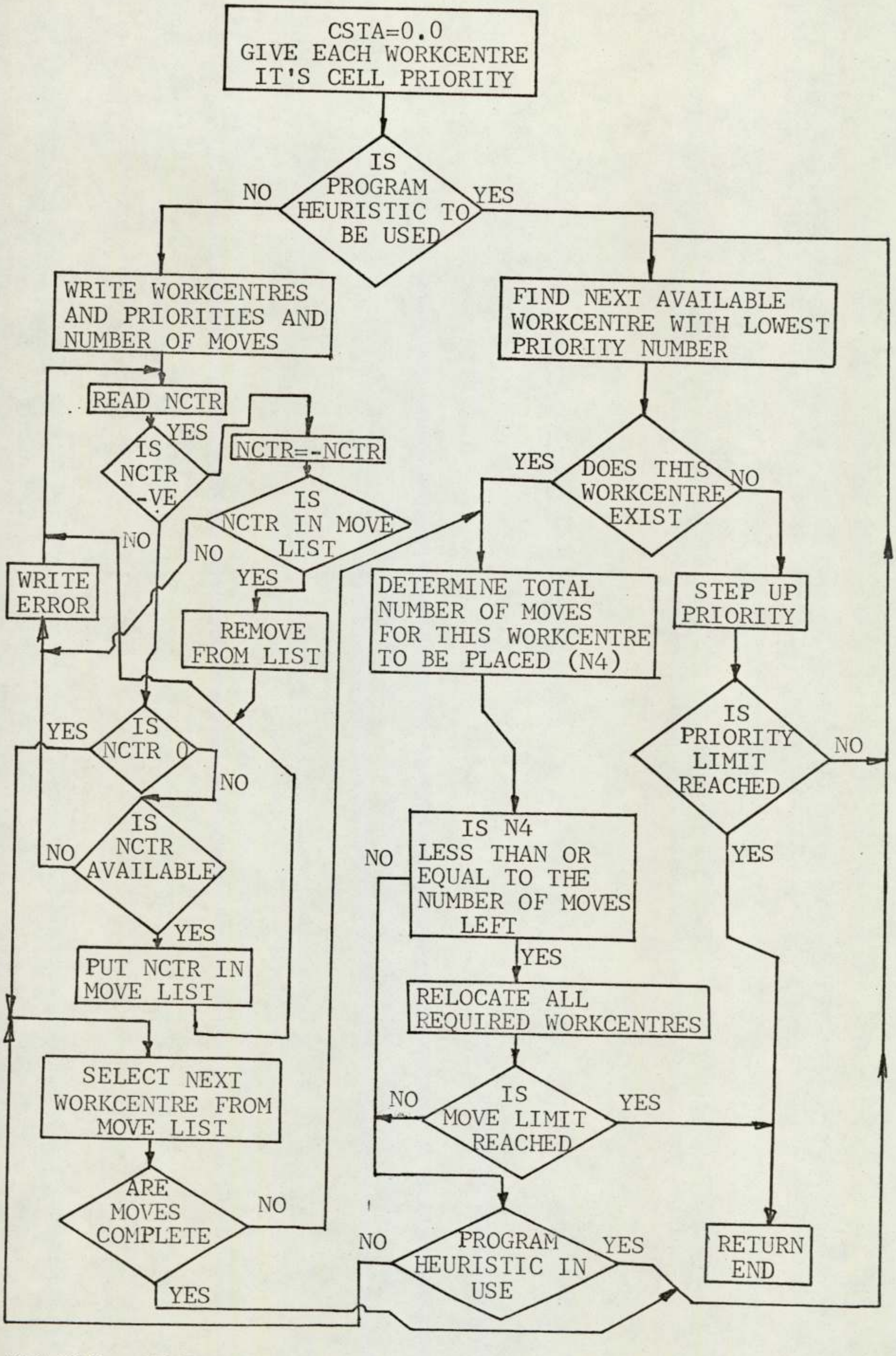


FIG B12 GENERAL FLOW DIAGRAM FOR SUBROUTINE PLACE

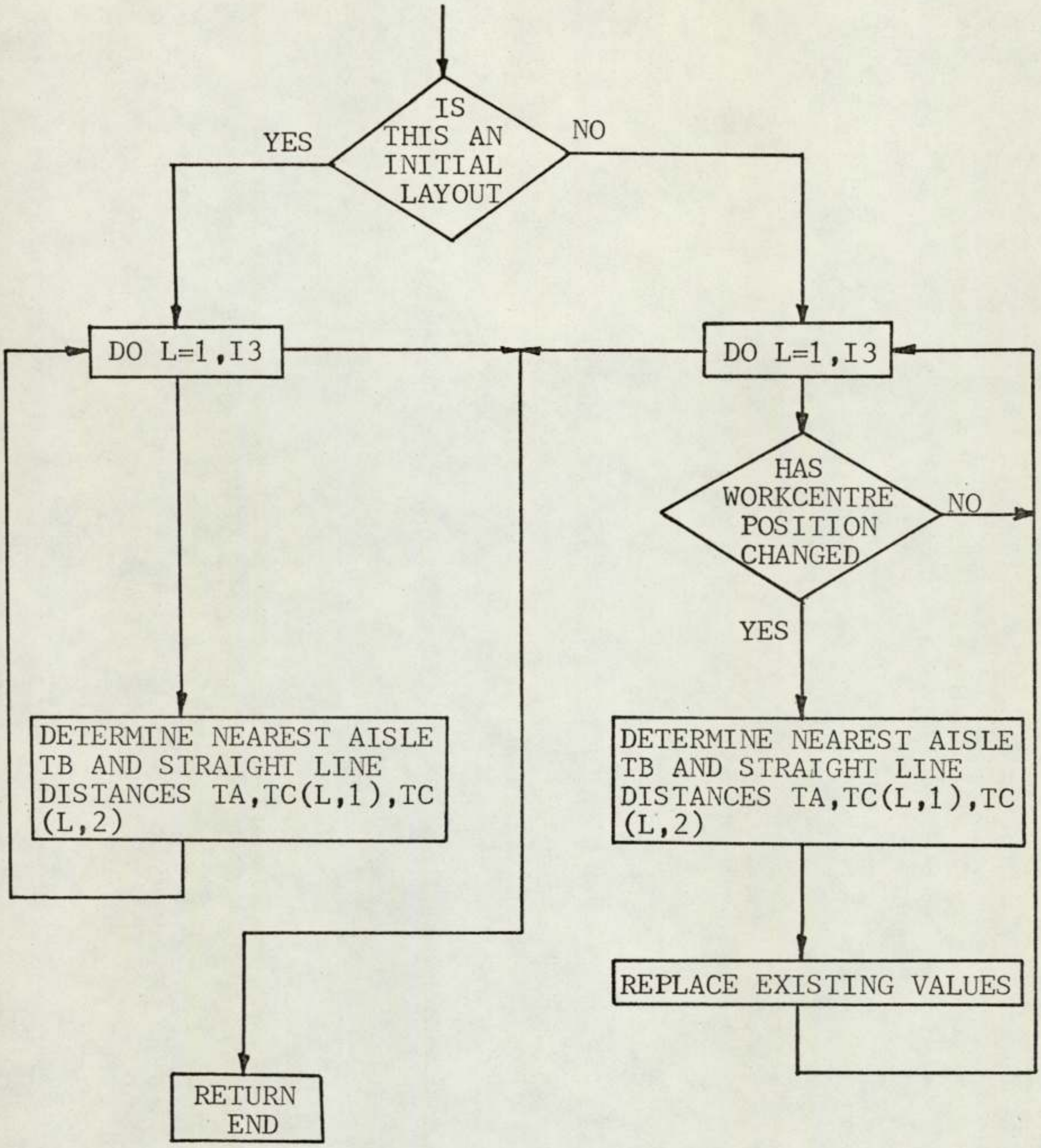


FIG B13
GENERAL FLOW CHART FOR SUBROUTINE TDIST

PROGRAM UA3

```
      LIST (LP)
      PRØGRAM(FXXX)
      INPUT 1=CR1
      INPUT 3=CR3
      INPUT 7=CR7
      ØUTPUT 2=LP2
      ØUTPUT 9=CP9
      CØMPRESS INTEGER AND LØGICAL
      CØMPACT
      END
      MASTER UA3
      INTEGER FID,WI,WC,WR,CI,TT,PI,PW,TP,CØ,TB,RLT
      DIMENSIØN TITLE(5),PI(100),PM(100,3),PW(100,30),WI(150),WC(150),WR
     1(150),F(150,10),FID(150),T(30,30),TA(150),TB(150),TC(150,2),TT(30,
     22),TR(30,4),CI(50,3),CR(50),CV(50),CØ(50),C(50,8),RLT(150,6),CLE(3
     30),NL1(150)
      CØMMØN/SLAB1/E,I3,I5,I6,I7,I8/SLAB2/F,FID/SLAB3/PI,PM,PW/SLAB4/C,C
     1I/SLAB5/WI,WC,WR/SLAB6/T,TA,TB,TC/SLAB7/CØ,RLT,CR/SLAB8/TR,TT
      DATA IYES/3HYES/
C     DATA INPUT SECTIØN
      WRITE(2,833)
   50 READ(1,800)TP,R,LN,E
      IF(TP.GT.0.AND.LN.GT.0.AND.R.GT.0)GØ TØ 51
      WRITE(2,825)
      GØ TØ 50
   51 READ(3,808)(TITLE(I),I=1,5)
      WRITE(2,803)(TITLE(I),I=1,5),TP,R,LN,E
      R=R/100.0
      READ(3,807)D22
      READ(3,801)I4
      READ(3,806)(CI(I,1),I=1,I4)
      READ(3,801)I5,I6,I7
      Z=I5/15
      I8=INT(Z)
      IF((I8*15).NE.I5)I8=I8+1
      Z=I5*2/15
      I9=INT(Z)
      IF((I9*15).NE.(I5*2))I9=I9+1
      I5=I8*2+I9+I7*2+I6*5
      READ(3,824)(BLK,I=1,I5)
      IF(I7.GT.0)READ(3,814)(((TR(I,ID),ID=1,4),(TT(I,J),J=1,2)),I=1,I7)
      IF(I7.GT.0)READ(3,807)((T(I,ID),ID=1,I7),I=1,I7)
      READ(3,801)I8
      DØ 52 I=1,I8
      READ(3,810)PI(I),(PM(I,ID),ID=1,3),(PW(I,IE),IE=1,10)
   52 IF(PW(I,10).GT.0)READ(3,801)(PW(I,IE),IE=11,30)
      READ(7,801)I3
      READ(7,807)((F(M,MA),MA=1,10),M=1,I3)
      READ(7,801)((FID(M),WC(M),WR(M),WI(M)),M=1,I3)
      READ(7,801)((RLT(M,MA),MA=1,6),M=1,I3)
      DØ 53 I=1,I3
      IF(FID(I).GT.2)GØ TØ 53
      IF(ABS(F(I,1)-F(I,6)).GT.0.0001)GØ TØ 53
      IF(ABS(F(I,2)-F(I,7)).GT.0.0001)GØ TØ 53
      IF(ABS(F(I,5)-F(I,8)).GT.0.0001)GØ TØ 53
      FID(I)=FID(I)+2
   53 CØNTINUE
      NZ=0
      DØ 55 I=1,I3
      IF(FID(I).GT.2)GØ TØ 54
```

```
      NZ=NZ+1
      GØ TØ 55
54    CI(WC(I),3)=CI(WC(I),3)+1
55    CI(WC(I),2)=CI(WC(I),2)+1
      DØ 56 I=1,I4
      IF(CI(I,2).EQ.CI(I,3))WRITE(2,802)CI(I,1)
      CI(I,2)=CI(I,2)-CI(I,3)
56    CI(I,3)=0
C     MAIN INTERACTIØN SECTIØN
      I,I99,I97,N98,N99=0
      WRITE(2,826)
      READ(1,824)IANS
      IF(IANS.EQ.IYES)I99=2
      IF(I99.NE.2)GØ TØ 61
      WRITE(2,827)
      I98=1
      READ(1,824)IANS
      IF(IANS.EQ.IYES)WRITE(9,801)I98,I97,I97,I3
      READ(1,824)IANS
      IF(IANS.EQ.IYES)I98=2
      IF(I98.NE.2)GØ TØ 58
      WRITE(9,801)I98,I97,I96,I3
      DØ 57 I=1,I3
57    WRITE(9,807)F(I,1),F(I,2),F(I,5),F(I,3),F(I,4),F(I,9),F(I,10)
58    WRITE(2,828)
      READ(1,824)IANS
      IF(IANS.EQ.IYES)I98=4
      I97=0
      IF(I98.NE.4)GØ TØ 60
      WRITE(9,801)I98,I97,TP,I3
      DØ 59 I=1,I3
59    WRITE(9,807)F(I,6),F(I,7),F(I,8),F(I,3),F(I,4),F(I,9),F(I,10)
60    READ(1,824)IANS
      IF(IANS.EQ.IYES)I99=5
61    WRITE(2,819)
      READ(1,824)IANS
      IF(IANS.EQ.IYES)N98=3
      WRITE(2,820)
      READ(1,824)IANS
      IF(IANS.EQ.IYES)N99=1
      I=0
      I11=5
      I12=6
      IF(I7.GT.0)CALL TDIST(I12)
      CALL CØST(I4,I11,I,CSTF,CSTG)
      I11,I12=1
      IF(I7.EQ.0)GØ TØ 62
      CALL TDIST(I12)
      GØ TØ 64
62    DØ 63 IE=1,I3
63    FID(IE)=FID(IE)+4
64    CALL CØST(I4,I11,I,CSTF,CSTG)
      TRC,PVTRC=0.0
      TC1=CSTD*TP
      TL1=CSTL*TP
      PVTC1=CSTD*(((1+R)**TP-1)/((1+R)**TP*R)
      PVTL1=CSTL*(((1+R)**TP-1)/((1+R)**TP*R)
      WRITE(2,823)I
      WRITE(2,811)
      IF(N98.NE.3)GØ TØ 66
```

```
      DØ 65 IE=1,I4
   65 WRITE(2,812)CI(IE,1),C(IE,4),C(IE,2),CR(IE),CV(IE),CØ(IE),C(IE,3),
     1C(IE,1)
   66 IF(N98.NE.3)WRITE(2,830)
      WRITE(2,805)TRC,PVTRC,TC1,PVTC1,TL1,PVTL1
      DØ 67 I=1,I3
      I66=0
      IF(ABS(F(I,1)-F(I,6)).GT.0.0001)I66=1
      IF(ABS(F(I,2)-F(I,7)).GT.0.0001)I66=1
      IF(ABS(F(I,5)-F(I,8)).GT.0.0001)I66=1
      IF(I66.EQ.0)GØ TØ 67
      CR(WC(I))=CR(WC(I))+WR(I)
   67 CØNTINUE
      DØ 68 I=1,I4
   68 TRC,PVTRC=TRC+CR(I)
      DØ 69 I=1,I4
      CV(I)=(C(I,4)+0.5*(C(I,2)-C(I,6))-C(I,8))*TP
   69 IF((CV(I)-CR(I)).LT.CØRE)CØRE=CV(I)-(CR(I)+10.0)
      WRITE(2,804)
      READ(1,824)IANS
      IF(IANS.EQ.IYES)GØ TØ 72
      READ(1,801)(CØ(IG),IG=1,I4)
      DØ 71 I=1,I4
      DØ 70 IG=1,I4
      IF(CØ(IG).EQ.I)GØ TØ 71
   70 CØNTINUE
      WRITE(2,831)
   71 CØNTINUE
      GØ TØ 75
   72 DØ 74 IB=1,I4
      CØR=CØRE
      DØ 73 I=1,I4
      IF(CØ(I).GT.0.ØR.(CV(I)-CR(I)).LT.CØR)GØ TØ 73
      CØR=CV(I)-CR(I)
      ID=I
   73 CØNTINUE
   74 CØ(ID)=IB
   75 I=0
C
C     CHANGEØVER IMPLEMENTATIØN
C
      TMC,TML,PVTMC,PVTML,TRC,PVTRC=0.0
      I11=5
      IF(LN.GT.NZ)LN=NZ
      DØ 88 I=1,TP
      IF(N99.EQ.2)GØ TØ 90
      JK3=900
      DØ 82 JL1=1,I3
      IF(FID(JL1).GT.6)GØ TØ 82
      JK1=1
      DØ 76 JL2=1,I3
   76 NL1(JL2)=0
      NL1(JL1)=1
   77 DØ 79 JL3=1,I3
      IF(NL1(JL3).LE.0)GØ TØ 79
      DØ 78 JL4=1,6
   78 IF(RLT(JL3,JL4).GT.0)NL1(RLT(JL3,JL4))=1
   79 CØNTINUE
      JK2=0
      DØ 80 JL3=1,I3
```

```
80    IF(NL1(JL3).GT.0)JK2=JK2+1
      IF(JK2.LE.JK1)GØ TØ 81
      JK1=JK2
      GØ TØ 77
81    IF(JK3.GT.JK1)JK3=JK1
82    CØNTINUE
      IF(JK3.GT.LN)GØ TØ 91
      IC=0
      WRITE(2,823)I
      CALL PLACE(LN,I4,NZ,N99,I,CSTA)
      IF(N99.EQ.3)GØ TØ 92
      IF(I7.GT.0)CALL TDIST(I12)
      IF(I7.GT.0)GØ TØ 84
      DØ 83 IE=1,I3
83    IF(FID(IE).LT.5)FID(IE)=FID(IE)+4
84    CALL CØST(I4,I11,I,CSTD,CSTL)
      TRC=TRC+CSTA
      PVTRC=PVTRC+CSTA/(1+R)**(I-1)
      TMC=TMC+CSTD
      PVTMC=PVTMC+CSTD/(1+R)**(I)
      TML=TML+CSTL
      PVTML=PVTML+CSTL/(1+R)**(I)
      WRITE(2,811)
      DØ 86 IE=1,I4
      CV(IE)=CLE(IE)+(C(IE,4)+0.5*(C(IE,2)-C(IE,6))-C(IE,8))*(TP+1-I)
      CLE(IE)=CLE(IE)+C(IE,4)+0.5*(C(IE,2)-C(IE,6))-C(IE,8))*(TP+1-I)
      IF(N98.NE.3)GØ TØ 86
      IF(CØ(IE).EQ.0)GØ TØ 85
      WRITE(2,812)CI(IE,1),C(IE,8),C(IE,6),CR(IE),CV(IE),CØ(IE),C(IE,7),
     1C(IE,5)
      GØ TØ 86
85    WRITE(2,813)CI(IE,1),C(IE,8),C(IE,6),CR(IE),CV(IE),C(IE,7),C(IE,5)
86    CØNTINUE
      IF(N98.NE.3)WRITE(2,830)
      WRITE(2,832)TRC,PVTRC,TMC,PVTMC,TML,PVTML
      TPRTN=TC1-(TMC+CSTD*(TP-I)+TRC)
      PVRTN=PVTC1-(PVTRC+PVTMC+CSTD*((1+R)**(TP-I)-1)/(R*(1+R)**(TP)))
      WRITE(2,821)TPRTN,PVRTN
      IF(I99.NE.5)GØ TØ 88
      WRITE(2,829)
      READ(1,824)IANS
      IF(IANS.NE.IYES)GØ TØ 88
      I98=3
      I97=0
      WRITE(9,801)I98,I97,I,I3
      DØ 87 IB=1,I3
87    WRITE(9,807)F(IB,1),F(IB,2),F(IB,5),F(IB,3),F(IB,4),F(IB,9),F(IB,1
     10)
88    CØNTINUE
      WRITE(2,815)
      IC=0
      DØ 89 I=1,I4
      IF(CØ(I).LE.0)GØ TØ 89
      WRITE(2,816)CI(I,1)
      IC=2
89    CØNTINUE
      IF(IC.EQ.0)WRITE(2,817)
      GØ TØ 92
90    II=I-1
      WRITE(2,818)II
```

```
      TMC=TMC+CSTD*(TP+1-I)
      TML=TML+CSTL*(TP+1-I)
      PVTML=PVTML+CSTL*((1+R)**(TP+1-I)-1)/(R*(1+R)**TP)
      PVTMC=PVTMC+CSTD*((1+R)**(TP+1-I)-1)/(R*(1+R)**TP)
      WRITE(2,805)TRC,PVTRC,TMC,PVTMC,TML,PVTML
      WRITE(2,822)TPRTN,PVRTN
 800  FØRMAT(2X,I4,2X,F4.1,2X,I4,2X,F5.1)
 801  FØRMAT(20I4)
 802  FØRMAT(5H CELL,I4,9H CØMPLETE)
 803  FØRMAT(1H1,///,5A8,//,9X,24H LIFE SPAN ØF PRØJECT = ,I4,8H PERIØDS
     1,//,6X,27H EXPECTED RATE ØF RETURN = ,F4.1,8H PERCENT,//,4X,29H NU
     2MBER ØF ALLØWABLE MØVES = ,I4,11H PER PERIØD,//,3X,30H BØUNDARY MØ
     3VEMENT DISTANCE = ,F4.1,7H METRES)
 804  FØRMAT(/,5X,34H DØ YOU HAVE YØUR ØWN CELL ØRDER ?)
 805  FØRMAT(/,27H   TØTAL RELØCATIØN CØST = ,F12.1,5X,F12.1,/,27H    TØ
     1TAL DEPMT MVT CØST = ,F12.1,5X,F12.1,/,27H    TØTAL LØCAL MVT CØST
     2 = ,F12.1,5X,F12.1)
 806  FØRMAT(5X,I2)
 807  FØRMAT(15F5.1)
 808  FØRMAT(5A8)
 809  FØRMAT(1X,I4,15F5.1)
 810  FØRMAT(I4,F8.0,F9.6,F9.7,10I4)
 811  FØRMAT(/,55H CELL  INTERNAL  EXTERNAL  ESTIMATE  ESTIMATE  CEL
     1L,/,55H  NØ.  MVT.CST.  MVT.CST.  REL.CST.  MVT.RTN. ØRDER)
 812  FØRMAT(1X,I4,4(F9.1,2X),3X,I2,/,5X,F9.1,2X,F9.1)
 813  FØRMAT(1X,I4,4(F9.1,2X),5H   **,/,5X,F9.1,2X,F9.1)
 814  FØRMAT(4F5.1,5X,2I4)
 815  FØRMAT(1H1,/,31H PRØJECT TIME PERIØDS CØMPLETED,/,10X,21H ØUTSTAND
     1ING CELLS : )
 816  FØRMAT(31X,I4)
 817  FØRMAT(30X,5H NØNE)
 818  FØRMAT(1H1,37H RELØCATIØN PRØJECT CØMPLETED PERIØD ,I4)
 819  FØRMAT(/,5X,24H DØ YØU WANT CELL DATA ?)
 820  FØRMAT(/,5X,48H DØ YØU WANT TØ SPECIFY EACH INDIVIDUAL CHANGE ?,/,
     110X,36H NØTE - THIS WILL SUSPEND CELL ØRDER)
 821  FØRMAT(/,27H EXPECTED PRØJECT RETURN = ,F12.1,5X,F12.1)
 822  FØRMAT(/,27H    TØTAL PRØJECT RETURN = ,F12.1,5X,F12.1)
 823  FØRMAT(1H1,/,19X,15H TIME PERIØD = ,I3,/,19X,18H *****************
     1)
 824  FØRMAT(A3)
 825  FØRMAT(5X,23H ERRØR IN LN ØR TP ØR R)
 826  FØRMAT(/,5X,35H WILL YØU REQUIRE LAYØUT DRAWINGS ?)
 827  FØRMAT(/,17H DØ YØU REQUIRE -,/,15H A BLANK PLAN ?,/,20H AN INITIA
     1L LAYØUT ?)
 828  FØRMAT(/,14H DØ YØU WANT -,/,17H A FINAL LAYØUT ?,/,25H AN INTERME
     1DIATE LAYØUT ?)
 829  FØRMAT(/,14H DØ YØU WANT -,/,25H AN INTERMEDIATE LAYØUT ?)
 830  FØRMAT(/,5X,10H SUSPENDED)
 831  FØRMAT(/,21H CELL ØRDER INCØRRECT)
 832  FØRMAT(/,27H PRESENT RELØCATIØN CØST = ,F12.1,5X,F12.1,/,27H  PRES
     1ENT DEPMT MVT CØST = ,F12.1,5X,F12.1,/,27H  PRESENT LØCAL MVT CØST
     2 = ,F12.1,5X,F12.1)
 833  FØRMAT(//,34H UA3-CHANGEØVER SIMULATIØN PRØGRAM,/)
 834  FØRMAT(/,15H MØVE LIMIT ØF ,I4,22H TØ LØW - MIN REQD IS ,I4)
      GØ TØ 92
   91 WRITE(2,834)LN,JL3
   92 IF(I99.EQ.2)WRITE(9,801)IXYZ
      STØP
      END
      SUBRØUTINE PLACE(LN,I4,NZ,N99,I,CSTA)
```

```
      INTERGER FID,WI,WC,WR,CØ,RLT,CI
      DIMENSIØN FID(150),F(150,10),WI(150),WC(150),WR(150),CØ(50),RLT(15
     10,6),C(50,8),CI(50,3),NL1(150),NL2(150),NL3(150),NL4(150),CR(50)
      CØMMØN/SLAB1/E,I3,I5,I6,I7/SLAB2/F,FID/SLAB4/C,CI/SLAB5/WI,WC,WR/S
     1LAB7/CØ,RLT,CR
      CSTA=0.0
      NX,N6=0
      IF(I.EQ.1)NY=0
      IF(N99.EQ.1)GØ TØ 75
      DØ 50 N=1,I3
      NL1(N)=0
   50 IF(FID(N).LT.7)NL1(N)=CØ(WC(N))
      WRITE(2,800)
C     CØMPUTER CHØICE
      N5=0
      N1=N5
   51 N1=N1+1
      IF(N1.GT.I4)GØ TØ 69
   52 N2=0
      DØ 61 N=1,I3
      NL2(N),NL3(N)=0
      IF(NL1(N).NE.N1)GØ TØ 61
      N2,NF=1
C     REQUIRED MØVES CALCULATIØN
   53 DØ 54 NA=1,I3
   54 NL4(NA)=0
      NL4(N),N3=1
   55 DØ 57 NA=1,I3
      IF(NL4(NA).EQ.0)GØ TØ 57
      DØ 56 NB=1,6
   56 IF(RLT(NA,NB).GT.0)NL4(RLT(NA,NB))=1
   57 CØNTINUE
      N4=0
      DØ 58 NA=1,I3
   58 IF(NL4(NA).GT.0)N4=N4+1
      IF(N4.LE.N3)GØ TØ 59
      N3=N4
      GØ TØ 55
   59 GØ TØ (0,65,91)NF
      DØ 60 NA=1,I3
      IF(NL4(NA).EQ.0)GØ TØ 60
      NL2(N)=NL2(N)+NL1(NA)
      NL3(N)=NL3(N)+1
   60 CØNTINUE
   61 CØNTINUE
      IF(N2.EQ.0)GØ TØ 51
      NMIN=200
      DØ 64 N=1,I3
      IF(NL3(N).GT.NMIN.ØR.NL3(N).EQ.0)GØ TØ 64
      IF(NL3(N).EQ.NMIN)GØ TØ 63
   62 NA=N
      NMIN=NL3(N)
      GØ TØ 64
   63 IF(NL2(N).LT.NL2(NA))GØ TØ 62
   64 CØNTINUE
      N=NA
      IF(NL3(NA).GT.(LN-NX))GØ TØ 51
      NX=NX+NL3(NA)
      NF=2
      GØ TØ 53
```

```
C     RELØCATING SECTIØN
 65   DØ 68 N=1,I3
      IF(NL4(N).EQ.0)GØ TØ 68
      FID(N)=FID(N)-2
      F(N,1)=F(N,6)
      F(N,2)=F(N,7)
      F(N,5)=F(N,8)
      CR(WC(N))=CR(WC(N))-WR(N)
      CSTA=CSTA+WR(N)
      NL1(N)=0
      N1,N6=N5+1
      WRITE(2,801)WI(N),WC(N),WR(N),CSTA
      DØ 67 NA=1,I3
      IF(FID(NA).GT.6)GØ TØ 67
      DØ 66 NB=1,6
 66   IF(RLT(NA,NB).EQ.N)RLT(NA,NB)=0
 67   CØNTINUE
 68   CØNTINUE
      IF(NX.EQ.LN)GØ TØ 69
      GØ TØ (52,52,92)NF
 69   IF(N6.EQ.0)GØ TØ 74
 70   DØ 71 N=1,I4
 71   CI(N,3)=0
      DØ 72 N=1,I3
 72   IF(FID(N).EQ.3.ØR.FID(N).EQ.4)CI(WC(N),3)=CI(WC(N),3)+1
      DØ 73 N=1,I4
      IF(CI(N,2).EQ.CI(N,3).AND.CI(N,3).GT.0)WRITE(2,807)CI(N,1)
 73   CI(N,2)=CI(N,2)-CI(N,3)
      NY=NY+NX
      IF(NY.EQ.NZ)N99=2
      GØ TØ 94
 74   N99=3
      GØ TØ 94
C     ØPERATØR CHØICE
 75   NK=1
      DØ 76 N=1,I3
      IF(FID(N).GT.6)GØ TØ 76
      NL1(NK)=N
      NK=NK+1
 76   CØNTINUE
      WRITE(2,802)
      NB=1
      NC=8
 77   IF((NK-1).LT.NC)NC=NK-1
      WRITE(2,808)(WI(NL1(N)),N=NB,NC)
      WRITE(2,806)(CØ(WC(NL1(N))),N=NB,NC)
      NB=NB+8
      NC=NC+8
      IF(NK.GT.NB)GØ TØ 77
      NF=3
      NJ=1
      N7=LN
      IF((NK-1).LT.LN)N7=NK-1
      WRITE(2,805)N7
 78   READ(1,803)NCTR
      IF(NCTR.EQ.0)GØ TØ 87
      IF(NCTR.LT.0)GØ TØ 83
      DØ 79 N=1,NK-1
 79   IF(NCTR.EQ.WI(NL1(N)))GØ TØ 81
 80   WRITE(2,804)NCTR
```

```
      GØ TØ 78
   81 DØ 82 N=1,NJ-1
   82 IF(NL2(N).EQ.NCTR)GØ TØ 80
      NL2(NJ)=NCTR
      NJ=NJ+1
      GØ TØ 78
   83 NCTR=IABS(NCTR)
      NC=0
      DØ 84 N=1,NJ-1
   84 IF(NCTR.EQ.NL2(N))NC=N
      IF(NC.EQ.0)GØ TØ 80
      IF(NC.EQ.NJ)GØ TØ 86
      DØ 85 N=NC,NJ-1
   85 NL2(N)=NL2(N+1)
   86 NJ=NJ-1
      GØ TØ 78
   87 WRITE(2,800)
   88 N8=0
   89 DØ 93 NH=1,NJ-1
      IF(NL2(NH).EQ.0)GØ TØ 93
      DØ 90 NM=1,I3
   90 IF(WI(NM).EQ.NL2(NH))N=NM
      IF(FID(N).LT.5)GØ TØ 93
      GØ TØ 53
   91 IF(N7.GE.N4)GØ TØ 65
      GØ TØ 93
   92 N8=1
      N7=N7-N4
      NY=NY+N4
      NL2(NH)=0
   93 CØNTINUE
      IF(N8.GT.0)GØ TØ 88
      GØ TØ 70
  800 FØRMAT(/,34H WØRKCENTRE CELL  CØST  TØTAL CØST)
  801 FØRMAT(6X,I3,4X,I2,3X,I4,3X,F8.0)
  802 FØRMAT(/,22H WØRKCENTRES AVAILABLE)
  803 FØRMAT(I4)
  804 FØRMAT(11H WØRKCENTRE,I4,14H NØT AVAILABLE)
  805 FØRMAT(20H NUMBER AVAILABLE = ,I4)
  806 FØRMAT(11H   PRIØRITY,8(2X,I4))
  807 FØRMAT(6H CELL ,I4,10H CØMPLETED)
  808 FØRMAT(/,11H WØRKCENTRE,8(2X,I4))
   94 DØ 95 N=1,I4
   95 IF(CI(N,2).EQ.0)CØ(N)=0
      DØ 96  N=1,I4
      IF(CØ(N).GT.0)GØ TØ 97
   96 CØNTINUE
      N99=2
   97 RETURN
      END
      SUBRØUTINE CØST(I4,I1,I,CSTD,CSTL)
      INTEGER CI,PI,PW,WI,WC,WR,TB,TT,FID
      DIMENSIØN PI(100),PM(100,3),PW(100,30),CI(50,3),C(50,8),WI(150),WC
     1(150),WR(150),F(150,10),FID(150),T(30,30),TA(150),TB(150),TC(150,2
     2),TT(30,2),TR(30,4)
      CØMMØN/SLAB3/PI,PM,PW/SLAB4/C,CI/SLAB5/WI,WC,WR/SLAB2/F,FID/SLAB6/
     1T,TA,TB,TC/SLAB1/E,I3,I5,I6,I7,I8/SLAB8/TR,TT
C     DETERMINATIØN ØF MTLS MVT CØST AT ANY PØINT IN TIME
      CSTD,CSTL=0.0
      DØ 50 K=1,I4
```

```
      DØ 50 K1=I1,I1+3
   50 C(K,K1)=0.0
      DØ 59 K=1,I8
      DØ 58 K1=2,30
      IF(PW(K,K1).EQ.0)GØ TØ 59
      IF(PW(K,K1).GE.200.AND.PW(K,(K1-1)).GE.200)GØ TØ 58
      DØ 51 K2=1,I3
      IF(PW(K,K1).EQ.WI(K2))K6=K2
   51 IF(PW(K,(K1-1)).EQ.WI(K2))K5=K2
      DØ 52 K2=1,I4
      IF(CI(K2,1).EQ.WC(K5))K3=K2
   52 IF(CI(K2,1).EQ.WC(K6))K4=K2
      I2=I1
      IF(I.GT.0)I2=1
      IF(I2.EQ.1)D=SQRT((F(K5,2)-F(K6,2))**2+(F(K5,1)-F(K6,1))**2)
      IF(I2.EQ.5)D=SQRT((F(K5,7)-F(K6,7))**2+(F(K5,6)-F(K6,6))**2)
      IF(I7.EQ.0.ØR.D.LE.E)GØ TØ 54
      D=TA(K5)+TA(K6)+ABS(TC(K5,1)-TC(K6,1))
      IF(TB(K5).EQ.TB(K6))GØ TØ 54
      D=9001.
      DØ 53 KA=1,2
      DØ 53 KB=1,2
      IF(TT(TB(K5),KA).EQ.0.ØR.TT(TB(K6),KB).EQ.0)GØ TØ 53
      DN=T(TT(TB(K5),KA),TT(TB(K6),KB))+TA(K5)+TA(K6)+TC(K5,KA)+TC(K6,KB
     1)
      IF(D.LT.DN)GØ TØ 53
      D=DN
   53 CØNTINUE
   54 IF(D.GT.E)GØ TØ 56
      CSTL=CSTL+PM(K,1)*(PM(K,2)+D*PM(K,3))
      IF(WC(K5).EQ.WC(K6))GØ TØ 55
      C(K4,I1)=C(K4,I1)+PM(K,1)*(PM(K,2)+PM(K,3)*D)
      C(K3,I1)=C(K3,I1)+PM(K,1)*(PM(K,2)+PM(K,3)*D)
      GØ TØ 58
   55 C(K3,I1+2)=C(K3,I1+2)+PM(K,1)*(PM(K,2)+D*PM(K,3))
      GØ TØ 58
   56 CSTD=CSTD+PM(K,1)*(PM(K,2)+D*PM(K,3))
      IF(WC(K6).EQ.WC(K5))GØ TØ 57
      C(K3,I1+1)=C(K3,I1+1)+PM(K,1)*(PM(K,2)+D*PM(K,3))
      C(K4,I1+1)=C(K4,I1+1)+PM(K,1)*(PM(K,2)+D*PM(K,3))
      GØ TØ 58
   57 C(K3,I1+3)=C(K3,I1+3)+PM(K,1)*(PM(K,2)+D*PM(K,3))
   58 CØNTINUE
   59 CØNTINUE
      RETURN
      END
      SUBRØUTINE TDIST(I1)
      INTEGER TT,TB,FID
      DIMENSIØN TR(30,4),TT(30,2),T(30,30),TA(150),TB(150),TC(150,2),F(1
     150,10),FID(150)
      CØMMØN/SLAB1/E,I3,I5,I6,I7,I8/SLAB6/T,TA,TB,TC/SLAB2/F,FID/SLAB8/T
     1R,TT
C     SUBRØUTINE TØ DETERMINE TRAFFIC RØUTE DATA
      PYE=3.1416
      DØ 56 L=1,I3
      IF(FID(L).GT.4)GØ TØ 56
      TA(L)=9001.0
      S11=0.0
      DØ 56 LA=1,I7
      S10=0.0
```

```
      IF(ABS(TR(LA,3)-TR(LA,1)).LT.0.0001)GØ TØ 51
      IF(ABS(TR(LA,2)-TR(LA,4)).LT.0.0001)GØ TØ 52
      S1=(TR(LA,4)-TR(LA,2))/(TR(LA,3)-TR(LA,1))
      S2=ABS(((TR(LA,2)-F(L,I1+1))-S1*(TR(LA,1)-F(L,I1)))*CØS(ATAN(S1)))
      S3=PYE/2.0+ATAN(S1)
      IF(S3.GE.(2.0*PYE))S3=S3-2.0*PYE
      S4=ABS(((TR(LA,2)-F(L,I1+1))-TAN(S3)*(TR(LA,1)-F(L,I1)))*CØS(S3))
      S5=ABS(((TR(LA,4)-F(L,I1+1))-TAN(S3)*(TR(LA,3)-F(L,I1)))*CØS(S3))
      GØ TØ 53
   51 S2=ABS(F(L,I1)-TR(LA,3))
      S4=ABS(TR(LA,2)-F(L,(I1+1)))
      S5=ABS(TR(LA,4)-F(L,(I1+1)))
      GØ TØ 53
   52 S2=ABS(F(L,(I1+1))-TR(LA,2))
      S4=ABS(TR(LA,1)-F(L,I1))
      S5=ABS(TR(LA,3)-F(L,I1))
   53 S6=SQRT((TR(LA,4)-TR(LA,2))**2+(TR(LA,3)-TR(LA,1))**2)
      S7=S4
      IF(S5.GT.S4)S7=S5
      IF(S7.LT.S6)GØ TØ 55
      S10=S2
      IF(ABS(S7-S5).LT.0.0001)GØ TØ 54
      S2=SQRT((TR(LA,4)-F(L,(I1+1)))**2+(TR(LA,3)-F(L,I1))**2)
      S5=0.0
      S4=S6
      GØ TØ 55
   54 S2=SQRT((TR(LA,2)-F(L,(I1+1)))**2+(TR(LA,1)-F(L,I1))**2)
      S4=0.0
      S5=S6
   55 IF(S2.GT.TA(L))GØ TØ 56
      IF(ABS(S2-TA(L)).LT.0.0001.AND.S10.LT.S11)GØ TØ 56
      S11=S10
      TA(L)=S2
      TB(L)=LA
      TC(L,1)=S4
      TC(L,2)=S5
   56 CØNTINUE
      IF(I1.EQ.6)GØ TØ 58
      DØ 57 L=1,I3
   57 IF(FID(L).LT.5)FID(L)=FID(L)+4
   58 RETURN
C
C     FINALISED 5 MARCH 1975    AUTHØR J. DRISCØLL
C
      END
      FINISH
****
```

GENERAL DESCRIPTION OF CONNECTING FILES

Fn 1

The main data input to the system Fn1 contains workcentre, layout area and production program data.

Fn 2

This file contains details of Fn10 and the permanent drawing features in a form convenient for the GHOST graph plotting subroutines.

Fn 3

This file will contain the permanent data on the layout area and production program that will not change throughout the project.

Fn 4

Workcentre information that will change throughout the exercise as facilities are relocated is initially stored in Fn4.

Fn 7

On completion of the static design stage information on traffic distances, workcentre relocation obstructions and initial and final workcentre co-ordinates are stored in Fn7.

Fn 9

As part of the simulation program UA3 layout drawings can be requested at any point in time. The actual co-ordinates of each workcentre at that interval and the type of drawing are stored in Fn9.

Fn 10

This file is used to input general information for layout drawings. This information consists of drawing labels, drawing scales and drawing size.

APPENDIX C

USERS GUIDE TO UA1, UA2 AND UA3.

USERS GUIDE
TO UA1, UA2 AND UA3.

Introduction

The programs UA1, UA2 and UA3 have been developed to examine the rearrangement of manufacturing facilities within a job shop to meet the requirements of a change in production program.

The three programs work on a progressive basis using intermediate file stores to connect the programs and the function of each program can be briefly described as:

UA1. Data checking and preparation

UA2. The interactive design of a new static layout arrangement to suit the new production program

UA3. The simulation of the dynamic changeover from the initial to final layout.

The overall relationship between files, programs UA1, UA2, UA3 and two ancillary drawing programs UA4 and UA5 is shown reproduced from chapter 6.

The majority of information is input into Fn1 using a metric rectangular co-ordinate system where the layout area is placed completely within the positive first quadrant. Alternative distance units can be accommodated with minor program changes.

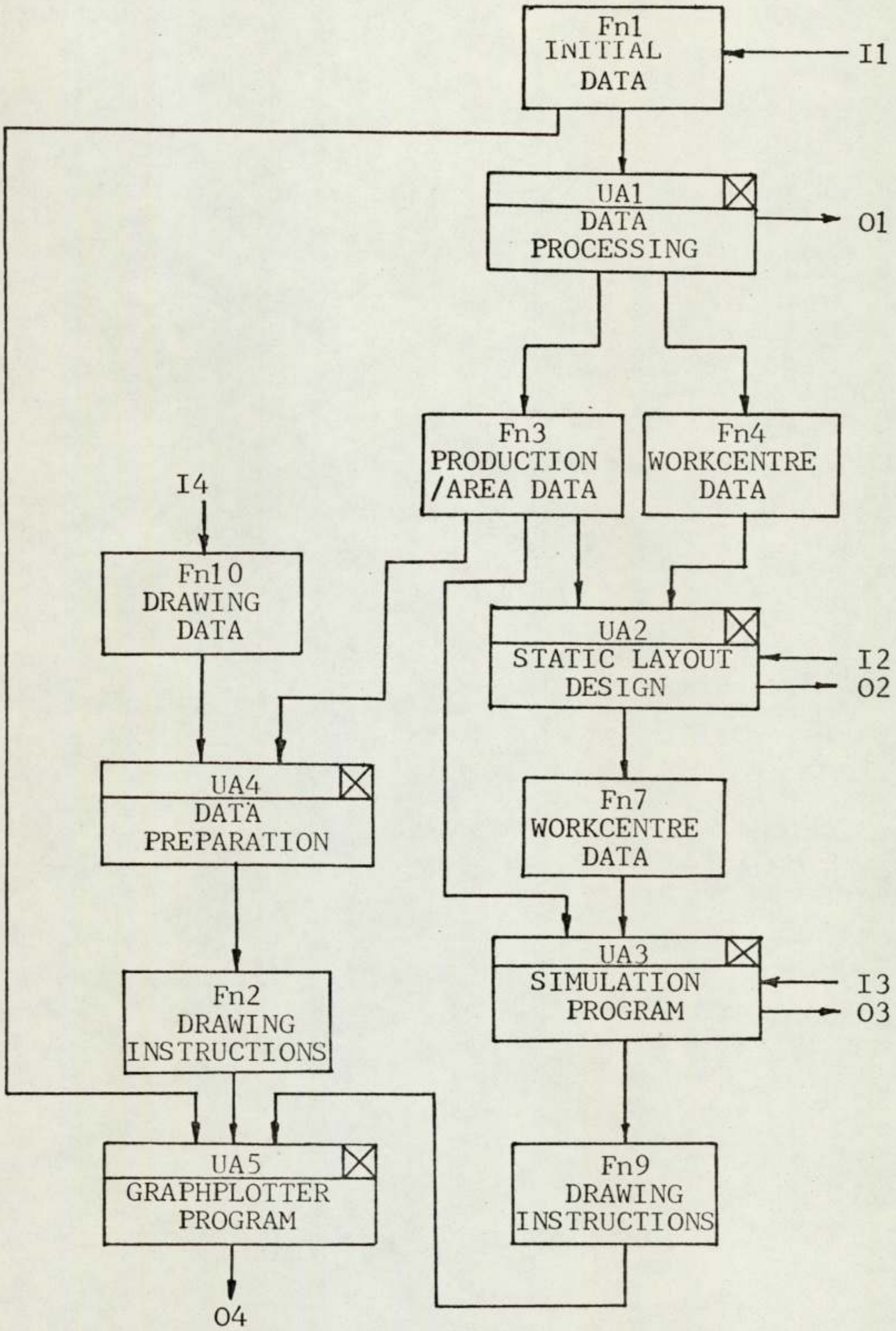


FIG C.1. PROGRAM AND FILE ARRANGEMENT

The following general limitations currently apply to the suite of programs which operate on an ICL 1905 computer at the University of Aston in Birmingham.

1.	Number of workcentres	$1 \leq I3 \leq 150$
2.	Number of workcentre cells	$0 < I4 \leq 50$
3.	Number of workcentres in each cell	$0 < \quad \leq 15$
4.	Layout area outline points	$2 < I5 \leq 50$
5.	Non-participation areas	$0 \leq I6 \leq 50$
	Number of points in each area	$2 < \quad \leq 10$
6.	Traffic routes	$0 \leq I7 \leq 30$
7.	Number of products	$1 \leq I8 \leq 150$

Inputing Information to Fnl

Fnl is a card image file containing the extensive information on workcentres,layout area and production program relevant to each problem. This information, illustrated with appropriate UA1 parameters, is input in the following manner:

CARD 1

TITLE

FORMAT 5A8

This card contains the test case title in columns 1 to 40.

CARD 2

D2

FORMAT F5.1

This card contains the distance by which the area outline is to be contracted and the non-participation areas expanded to check for obstructions.

CARD 3

I3

FORMAT I4

This card contains the number of workcentres in the problem.

NEXT I3 SETS OF CARDS

WI,WC,WT,WA,WB,W1,W2,W3,W4,WF,WX,WY,WO,WR

FORMAT 3X,I3,2(2X,I2),6(2X,F4.1),2X,I1,2X,2(F5.1,2X),
F4.1,2X,I4

WI Workcentre identity number in range 1-999. Each workcentre must have a unique number with normal workcentres in the range 1-199 and dummy workcentres at each entry and exit points in the range 200-999. This allows for movement outside the layout area to be discounted.

WC Workcentre cell number in range 1-99. The total number of different cells must be less than 51 and normal practice is to allocate one cell number to each entry and exit dummy workcentre.

WT Workcentre type is an indicator of the shape of each workcentre and is in the range 1-3 where:

1 = Circular shaped workcentre
2 = Rectangular shaped workcentre
3 = Miscellaneous shaped workcentre

WA These six parameters are used to input the dimen-
WB sions of each workcentre and are related to the
W1 workcentre type.
W2 Type 1 workcentres are circular in shape and
W3 the radius is stored under WA with all other
W4 parameters set at zero.

Type 2 workcentres are rectangular in shape and therefore use three of the six parameters. The base length is placed in WA, the vertical side length in WB and the orientation in WO.

Type 3 workcentres are those miscellaneous shapes that do not fit into circular or rectangular outlines. Miscellaneous outlines are entered in the following way. A smaller grid is placed around the outline shape and the X and Y co-ordinates noted with respect to this grid. Three sets of X and Y co-ordinates are then input at a time using the six parameters. This requires an additional card for each three outline points, a card which contains no other data. The input of points is stopped at the limit of 8 cards (24 points) or by zeros under W3 and W4. To assist finding the workcentre area the initial point should be the point nearest the Y axis with the lowest X value. Each of these values must be less than 99.9.

WF This parameter indicates whether the workcentre is fixed in position throughout the project and can be in two states:

0 Workcentre can be relocated

1 Workcentre fixed in position

WX
WY
WO These parameters contain the X and Y co-ordinates of each workcentre along with the orientation. For workcentres types 1 and 2 the X and Y co-ordinates are taken to the centre of the shape and for type 3

the X and Y co-ordinates locate the smaller grid. The limit on values is 999.9. The orientation which is limited to 89.9° normally will only apply to rectangular workcentres, circular and miscellaneous types being set to zero.

WR Workcentre relocation costs represent the cost of relocating each workcentre and includes disconnection and reconnection charges along with the cost of moving, with a limit of 9999.

This set of cards completes the workcentre data and an illustration of the three types of workcentre is given in Figure C.2.

NEXT 1 CARD

I5,I6,I7

FORMAT 3I4

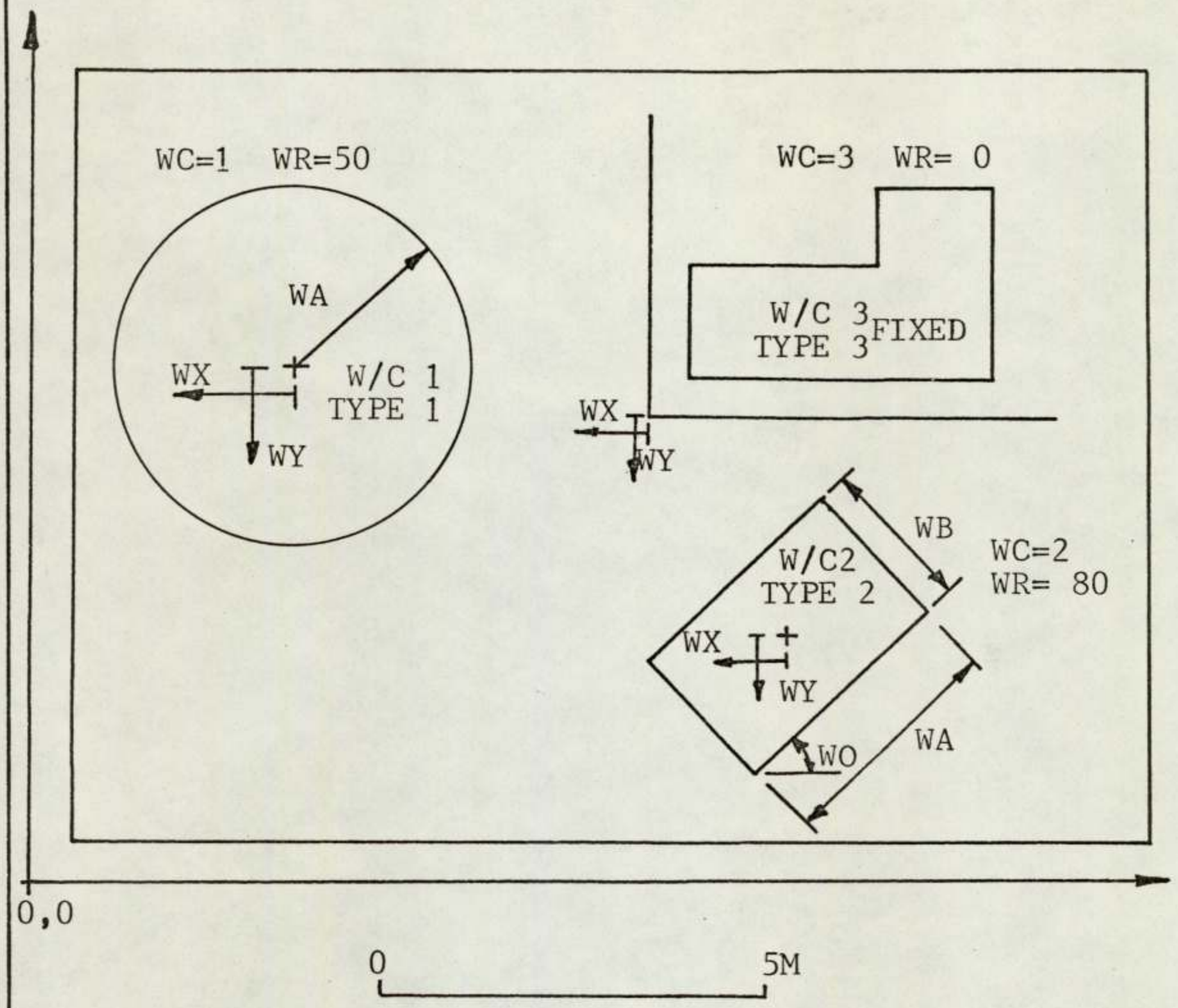
This card contains the number of points in the layout area outline (I5), the number of non-participation areas (I6) and the number of traffic routes, the limitations on which has been stated earlier.

NEXT MAXIMUM 4 CARDS

X(1-I5)

FORMAT 15F5.1

These cards contain the X co-ordinates of the layout area outline with up to 15 values on each card. To assist the subroutine for determinig area size the first point should be the point nearest the Y axis with the lowest X value and points are taken continuously around the outline.



WI	WC	WT	WA	WB	W1	W2	W3	W4	WF	WX	WY	WO	WR
1	1	1	2.3	0.0	0.0	0.0	0.0	0.0	0	3.5	6.1	0.0	50
2	2	2	3.0	2.0	0.0	0.0	0.0	0.0	0	9.5	3.2	45.0	80
3	3	3	0.5	0.5	0.5	2.0	3.0	2.0	1	8.0	6.5	0.0	0
			3.0	3.0	4.5	3.0	4.5	0.5					
			0.0	0.0	0.0	0.0	0.0	0.0					

FIG C.2. ILLUSTRATION OF WORKCENTRE DATA

NEXT MAXIMUM 4 CARDS

Y(1-I5)

FORMAT 15F5.1

These cards contain the corresponding Y co-ordinates to the previous outline X values with up to 15 values on each card.

NEXT I6 SETS OF CARDS

These cards contain the information on non-participation areas and consists of a number of two card sets shown below. In any one problem it is possible to have no non-participation areas in which case this section is omitted.

IA,X(1-10)

FORMAT 1X,I4,10F5.1

The first card contains the number of points in the non-participation area and the X co-ordinates of the outline, taken in a continuous manner with the first point being nearest the Y axis with the lowest X value. The maximum number of points for each non-participation area is 10.

Y(1-10)

FORMAT 5X,10F5.1

The second card in each set contains the Y values corresponding to the previous X values.The limit on these co-ordinates is 999.9.

NEXT I7 CARDS

TR(1-4),F7,TT(1-2)

FORMAT 5F5.1,2I4

Each card contains information on the traffic system for each problem. Where no traffic system exists this set of cards are omitted. Each section of traffic aisle is input on a separate card and is considered to be in a straight line with traffic junctions allowed only at each end.

TR Under TR is input the X and Y co-ordinates of each end of the traffic aisle in the order X1,Y1,X2 and Y2 with a limit of 999.9.

F7 This parameter contains the width of each traffic aisle.

TT This parameter contains the traffic junction number of each end of the aisle. With a maximum value of 30,traffic junctions function in the following manner. Each point at which two or more traffic aisles meet is given a junction number in order from 1. The two values of TT then correspond to the junction numbers of the TR values and where one end is unconnected the TT value is 0.

This completes the layout area imformation.

NEXT 1 CARD

I8

FORMAT I4

This parameter contains the number of products in the production program.

NEXT I8 SETS OF CARDS

PI,PQ,PB,PF,PV,PW(1-10)

FORMAT I3,1X,F8.0,1X,F5.0,1X,F9.6,1X,F9.7,2X,10I4

This information represents the details of the production program to be manufactured during the project life span, where:

PI	This parameter contains the identification number of the product and is in the range 0-999.
PQ	This is the total quantity of the product to be produced each time period. Range 0-9999999.
PB	Product batch size is the number of products to be moved each time. Range 0-9999.
PF	This is the fixed cost of raising and lowering one batch of the product and is in the range 0.0-99.999999.
PV	This is the variable cost of moving one batch of the product one unit distance. In the present program suite units of distance are metric and the range of values is 0.0-9.9999999.
PW	This parameter contains the sequence of workcentres through which each product travels and can consist of up to 30 workcentres. The first ten workcentre numbers are placed on the first card and if more than 9 workcentres are in the sequence an additional card is included using FORMAT 20I4 to input the remaining workcentres. An additional blank card has to be included for 10 workcentres in the sequence.

This completes the input of large data blocks into Fn1, the remaining information is input on an interactive basis.

Running program UA1

The program UA1 is loaded onto the ICL 1905 George system by using the following macro:

```
UAFORTRAN LOAD BUA1,OWNPD,*CR1 Fn1,*CP3 Fn3,*CP4 Fn4,*LP2
```

where:

BUA1	This parameter is the binary version of program UA1
*CR1	This is the input channel for Fn1
*CP3	This is the output channel for Fn3
*CP4	This is the output channel for Fn4
*LP2	This prints all output at the interactive terminal.

UA1 is not an interactive program but is used to prepare and check the large majority of data. In all 20 data checks are carried out, a summary of which is shown in Table C.1.

At the same time a listing is produced for the designers use throughout the test case, an example of which is shown in Figure C.3. From this output a number of useful guides can be obtained, four of which are illustrated in Figure C.3. and discussed below.

1. Type 3 workcentres are replaced by the nearest circular or rectangular shape. Where this occurs an indication of the increase in

	DATA CHECKS
1	Number of workcentres less than 150
2	Workcentre type in range 1 to 3 and correct data
3	Workcentre orientation less than 90 degrees
4	Workcentre cell in range 1 to 50 and minimum 1 fixed cell
5	Workcentre in fixed or unfixed position
6	Number of outline points in range 3 to 50
7	Number of non-participation areas less than 50
8	Number of traffic routes less than 30
9	No outline - non-participation area violation
10	No violation of non-participation areas
11	Workcentres inside modified outline
12	Workcentres outside modified non-participation areas
13	Initial area point on extreme left
14	Traffic system continuous and sequentially numbered
15	Each traffic point has minimum of two routes
16	Co-ordinates of each traffic point the same
17	Number of products in range 1 to 100
18	Product quantity and batch size greater than zero
19	At least two workcentres in workcentre sequence
20	No zero workcentre entry

TABLE C.1. DATA CHECKS BY PROGRAM UA1

```
UA1-DATA PROCESSING PROGRAM

 ILLUSTRATION EXAMPLE
                                          WORKCENTRE DATA
                                          ***************


PFX   W/C     X        Y      A/R      B     ANGLE  COST CELL


3    201    19.0     1.0     1.0     0.0     0.0      0   1

1    202    26.0     9.0     1.0     0.0     0.0     15   2

4      3    50.0     8.0     2.0     2.0     0.0      0   3

2      4    50.0    25.0     2.0     3.0    45.0     80   4

4      5    32.0    31.0     4.0     2.0     0.0      0   3
ORIGINAL TYPE =  3    AREA RATIO = 0.750

2      6    12.0    31.0     4.0     2.0     0.0     90   4
ORIGINAL TYPE =  3    AREA RATIO = 0.750                          ①

2      7     8.0     5.0     3.0     2.0    60.0     75   5

2      8     8.0    36.0     3.0     3.0     0.0     75   5
                TOTAL ORIGINAL AREA =      43.3
                     TOTAL NEW AREA =      47.3
                              RATIO =    0.9154                   ②
             NUMBER OF WORKCENTRES =      8
             TOTAL RELOCATION COST =     335.0


                 CELL DATA

  CELL      NO.W/CS     NO.FIXED      AREA       REL.COST

    1           1           1          3.1          0.0
    2           1           0          3.1         15.0
    3           2           2         12.0          0.0
          MORE THAN ONE FIXED W/C                                 ③
    4           2           0         14.0        170.0
    5           2           0         15.0        150.0
                                  LAYOUT AREA DATA
                                  ****************

    AREA OUTLINE X/Y VALUES
     0.0  0.0       0.0 40.0       40.0 40.0       40.0 30.0
    60.0 30.0      60.0  0.0


NON PARTICIPATION AREAS - X AND Y VALUES


 4     20.0 10.0      20.0 15.0      25.0 15.0      25.0 10.0


     TRAFFIC ROUTES

  X1      Y1      X2      Y2    WIDTH  TERMINATOR

 19.0     5.0    19.0    16.0    2.0      0   1
 19.0    35.0    19.0    16.0    2.0      0   1
 19.0    16.0    55.0    16.0    2.0      1   0

NON PARTICIPATION AREAS  QTY=  1  TOTAL AREA =      25.0

INTERNAL TRAFFIC ROUTES  QTY=  3  TOTAL AREA =     126.0

                                ****                *********
                  SUBTOTAL        4                     151.0

           TOTAL DEPARTMENT AREA =    2200.0

             NETT DEPARTMENT AREA =   2049.0                      ④

    WORKCENTRE/DEPT AREA RATIO = 0.0231    (0.0211 )
                                  PRODUCT INFORMATION
                                  *******************

  CODE   QUANTITY      B/SZ        FXD.CST        VAR.CST

    1          100.          5.     0.050000      0.0020000
       201     3    4     5 202

    2          200.          5.     0.050000      0.0020000
       201     4    6    7    8 202


                     *** END OF OUTPUT ***
```

FIG C.3. UA1 PROGRAM OUTPUT

area is given to show how close a representation is obtained.

2. The summary of workcentre data provides an indication of how the sum of all the workcentre changes affects realistic representation, allowing the problem to be re-examined when the ratio is low.
3. Where two or more fixed workcentres exist in any one cell a warning is printed. With one of the objectives to maintain if possible the close proximity of workcentres in each cell two fixed workcentres could cause problems, particularly if they are separated by an excessive distance. The warning therefore gives an indication of a possible problem with the static layout program UA2.
4. Included in the layout area summary along with the total and nett area available is the workcentre/area ratio. This ratio gives an indication of the extent of difficulty that will be encountered when arranging the layout of workcentres. A high ratio indicates that at a later stage the actual placing of individual workcentres may be too difficult for any automatic heuristic.

On completing a successful run UA1 will have also written to file Fn3 permanent area and product data along with workcentre data into Fn4.

Running program UA2

The program UA2 is loaded onto the ICL 1905 George system by using the following macro:

```
UAFORTRAN LOAD BUA2,OWNPD,*CR3 Fn3,*CR4 Fn4,*CP7 Fn7,*CR1,
        *LP2
```

where:

BUA2	This parameter is the binary version of program UA2
*CR1	This is the input channel for interactive decisions
*CR3	This is the input channel for Fn3
*CR4	This is the input channel for Fn4
*CP7	This is the output channel for data to Fn7
*LP2	This prints the output information at the interactive terminal.

UA2 functions in two separate sections on an interactive basis. The first section creates a new arrangement of workcentre cells using a heuristic procedure which works through three stages:

1. Cells containing workcentres that are all fixed are automatically located first.
2. Cells containing at least one fixed workcentre are located next in an interactive procedure with the designer.
3. Free cells with no fixed workcentres are

located next in order of external movement.

An illustration of program UA2 using the example shown in Figure C.3. is given in Figure C.4., the major parts of which have been indexed and are discussed further in the following section:

1. The first interactive question decides which section of the program is to be used. The answer to interactive questions is normally "yes" or "no" using FORMAT A3. A "no" answer runs the cell layout section.
2. The cells containing all fixed workcentres are located without reference to the designer.
3. The first partially fixed cell is located at the average fixed workcentre co-ordinates and printed out for the designer's approval. This printout, which is given each time the designers approval is required, consists of the co-ordinates and identity number of the cell, a two part count of the number of positions tried and the estimate materials movement cost. The illustration shows the result of rejecting a location. A move guide showing the potential increase in cost for various directions is printed to assist the designer.
4. The designer has two choices with regard to moving the suggested cell position. The first choice is to use the automatic routine for trying 40 locations around the

```
UA2 - STATIC LAYOUT DESIGN PROGRAM


     WILL YOU PROVIDE THE FINAL LAYOUT ?


- NO                                                                   ①
LAYOUT OF CELLS SECTION


CELL  X-CENTRE  Y-CENTRE  RADIUS  NO.PSNS  TTL.PSNS  COST

  1     19.0        1.0      1.2      1        1 FIXED
                                                                       ②
  3     41.0       19.5      2.4      1        2 FIXED

  4     38.0       10.0      2.6      1        3       3.2
- NO

MOVE GUIDE X= 38.0 Y= 10.0 RAD=  2.6 CELL=   4 COST=     3.2
ANGLE      0.0       45.0       90.0      135.0                        ③
COST       3.6        3.3        3.2        3.2
ANGLE    180.0      225.0      270.0      315.0
COST       3.2        3.2        3.2        3.3

WILL YOU MOVE?
- NO
                                                                       ④
  4     39.4       11.5      2.6      2        4       3.2
- YES

MOVE GUIDE X= 39.4 Y= 11.5 RAD=  2.7 CELL=   5 COST=     0.0
ANGLE      0.0       45.0       90.0      135.0
COST       0.4        0.6        0.4        0.6
ANGLE    180.0      225.0      270.0      315.0
COST       0.4        0.6        0.4        0.6

WILL YOU MOVE?
- YES                                                                  ⑤
-  5.0 180.0

MOVE GUIDE X= 34.4 Y= 11.5 RAD=  2.7 CELL=   5 COST=     0.4
ANGLE      0.0       45.0       90.0      135.0
COST       0.0        0.4        0.8        1.0
ANGLE    180.0      225.0      270.0      315.0
COST       0.8        1.0        0.8        0.4

WILL YOU MOVE?
- YES
- 3.0 270.0

  5     34.4        8.5      2.7      3        7       0.6
- YES

MOVE GUIDE X= 34.6 Y=  8.6 RAD=  1.2 CELL=   2 COST=     0.7
ANGLE      0.0       45.0       90.0      135.0
COST       0.9        1.0        0.9        1.3
ANGLE    180.0      225.0      270.0      315.0
COST       1.3        1.5        1.3        1.3

WILL YOU MOVE?
- NO

  2     34.6       12.6      1.2     10       17       0.9
- YES

CELL  CELL                  CELL WORKCENTRES
 NO  ORDER

  4     1    4   6

  5     2    7   8

  3     3    3   5                                                     ⑥

  2     4  202

  1     5  201


     WILL YOU PROVIDE THE FINAL LAYOUT ?
                                                                       ⑦

- NO
```

FIG C.4. UA2 PROGRAM OUTPUT

present position. In the illustrated example the first position tried at a radius of 2.0 metres was acceptable and therefore proposed to the designer. If rejected again the procedure will continue proposing locations until all 40 are exhausted and at that point will ask the designer to make a compulsory move.

5. The second choice is to make a move to an alternative location using the move guide. This is achieved by firstly replying "yes" to the move question and then by inputting the distance to be moved (RR) and the direction in degrees (DR) using FORMAT 2F0.0.
6. When each cell has been located using the interactive designer-heuristic procedure a brief listing of cells and their workcentres is printed.
7. Finally should the designer wish to input the final layout at this point the initial question is repeated.

The second section of UA2 is used to input the final locations of each workcentre and is entered by answering "Yes" to the first question. Discounting fixed workcentres which are automatically transferred from the initial to final layout data each final workcentre position is entered by using the following data input:

```
I,X3,Y3,ANG
FORMAT I0,3F0.0
```

Each workcentre is checked to ensure that it is in the available area and has a correct identity number. Where an error has occurred an appropriate message is printed. At any point in time the location of a workcentre can be changed simply by re-entering the new values. When all the free workcentres have been entered the input is terminated by the use of a zero workcentre:

```
0   0.0   0.0   0.0
```

At this stage the program completes the necessary calculations to create Fn7 and writes off this data to the appropriate file. This completes the use of program UA2.

Running program UA3

In a similar manner to UA2 this program works on an interactive basis and therefore can not be described in a defined sequence of events. Within this section of the guide instructions are included for loading the program and the various interactive stages are discussed.

The program is loaded onto the ICL 1905 George system by using the following macro:

```
UAFORTRAN LOAD BUA3,OWNPD,*CR1,*CR3 Fn3,*CR7 Fn7,*CP9 Fn9,
        *LP2
```

where:

BUA3	This is the binary version of program UA3
*CR1	This is the input channel for interactive decisions
*CR3	This is the input channel for Fn3
*CR7	This is the input channel for Fn7
*CP9	This is the output channel for drawing instructions held in Fn9
*LP2	This prints the output information at the interactive terminal.

The use of UA3 can be divided into three sections:

1. Drawing and data output
2. Designer selected changeover
3. Using the changeover heuristic

The first two parts are illustrated in Figure C.5.. For each run of the program the first input is

TP,R,LN,E

FORMAT 2X,I4,2X,F4.1,2X,I4,2X,F5.1

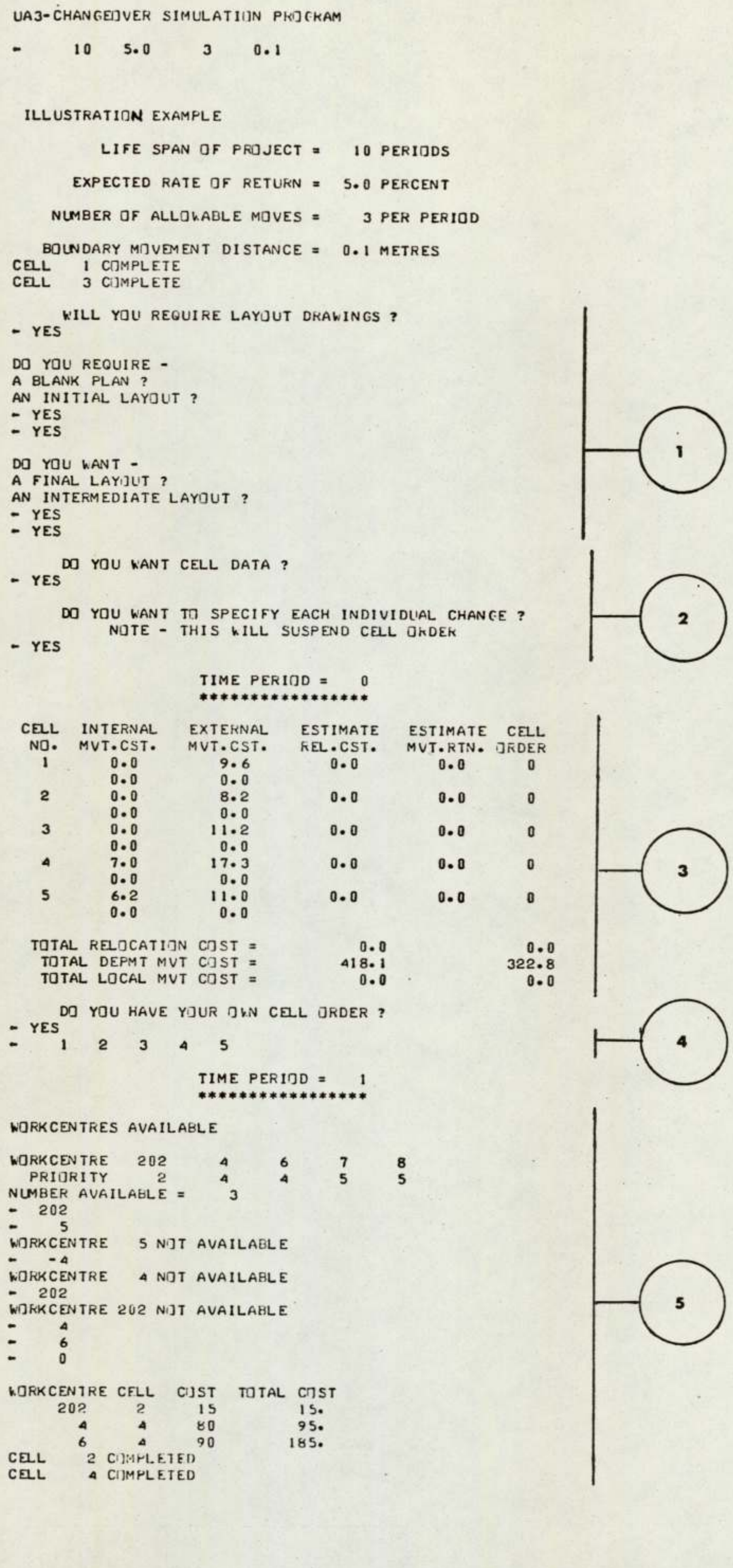
where:

TP	This is the life span of the project in time periods
R	This is the expected rate of return
LN	This is the maximum number of workcentres that can be relocated each time period
E	This is the boundary distance between local and departmental movement.

From Figure C.5. the following program steps are then continued for designer selected changeover,

1. The fist interaction deals with the question of layout drawings. Interactive questions are answered by using "Yes" or "No" with FORMAT A3 unless otherwise indicated. Four types of drawing are available:
    - A Blank layout
    - B Initial layout
    - C Final layout
    - D Intermediate layouts

   Answering "No" to the initial question will eliminate the remaining layout questions. Answering "Yes" to the intermediate layout question will produce a repeat question during each time period.
2. The next question deals with cell data. For each time interval a listing of the materials movement costs, relocation costs, estimate movement cost return and cell order is given. Where a problem involves a number of cells printing this data may consume excessive time and therefore the ability to suspend this data is included by answering "No" at this point. At this point the choice between using the program heuristic or selecting an alternative changeover sequence is also made.
3. Before starting the changeover the initial



```
UA3-CHANGEOVER SIMULATION PROGRAM

-     10    5.0     3     0.1


 ILLUSTRATION EXAMPLE

          LIFE SPAN OF PROJECT =    10 PERIODS

       EXPECTED RATE OF RETURN =   5.0 PERCENT

    NUMBER OF ALLOWABLE MOVES =     3 PER PERIOD

   BOUNDARY MOVEMENT DISTANCE =   0.1 METRES
CELL    1 COMPLETE
CELL    3 COMPLETE

     WILL YOU REQUIRE LAYOUT DRAWINGS ?
- YES

DO YOU REQUIRE -
A BLANK PLAN ?
AN INITIAL LAYOUT ?
- YES
- YES

DO YOU WANT -
A FINAL LAYOUT ?
AN INTERMEDIATE LAYOUT ?
- YES
- YES

      DO YOU WANT CELL DATA ?
- YES

      DO YOU WANT TO SPECIFY EACH INDIVIDUAL CHANGE ?
           NOTE - THIS WILL SUSPEND CELL ORDER
- YES

                      TIME PERIOD =    0
                      *****************

 CELL  INTERNAL    EXTERNAL    ESTIMATE    ESTIMATE  CELL
  NO.  MVT.CST.    MVT.CST.    REL.CST.    MVT.RTN.  ORDER
   1      0.0         9.6         0.0         0.0       0
          0.0         0.0
   2      0.0         8.2         0.0         0.0       0
          0.0         0.0
   3      0.0        11.2         0.0         0.0       0
          0.0         0.0
   4      7.0        17.3         0.0         0.0       0
          0.0         0.0
   5      6.2        11.0         0.0         0.0       0
          0.0         0.0

  TOTAL RELOCATION COST =             0.0                0.0
   TOTAL DEPMT MVT COST =           418.1              322.8
   TOTAL LOCAL MVT COST =             0.0                0.0

      DO YOU HAVE YOUR OWN CELL ORDER ?
- YES
-    1   2   3   4   5

                      TIME PERIOD =    1
                      *****************

WORKCENTRES AVAILABLE

WORKCENTRE   202      4      6      7      8
  PRIORITY     2      4      4      5      5
NUMBER AVAILABLE =      3
-  202
-    5
WORKCENTRE    5 NOT AVAILABLE
-   -4
WORKCENTRE    4 NOT AVAILABLE
-  202
WORKCENTRE 202 NOT AVAILABLE
-    4
-    6
-    0

WORKCENTRE CELL   COST   TOTAL COST
     202     2     15         15.
       4     4     80         95.
       6     4     90        185.
CELL    2 COMPLETED
CELL    4 COMPLETED
```

FIG C.5. (A) UA3 PROGRAM OUTPUT

```
 CELL  INTERNAL   EXTERNAL   ESTIMATE   ESTIMATE  CELL
 NO.   MVT.CST.   MVT.CST.   REL.CST.   MVT.RTN. ORDER
  1      0.0        8.0        0.0         7.6     **
         0.0        0.0
  2      0.0        8.7        0.0        -2.4     **
         0.0        0.0
  3      0.0       11.0        0.0         1.0     **
         0.0        0.0
  4      3.2       15.8        0.0        45.6     **
         0.0        0.0
  5      6.2       11.7      150.0        -3.4      5
         0.0        0.0

PRESENT RELOCATION COST =        185.0             185.0
 PRESENT DEPMT MVT COST =         37.0              35.2
 PRESENT LOCAL MVT COST =          0.0               0.0

EXPECTED PROJECT RETURN =       -136.6            -147.6

DO YOU WANT -
AN INTERMEDIATE LAYOUT ?                                          ⑥
- YES

                    TIME PERIOD =   2
                    *****************

WORKCENTRES AVAILABLE

WORKCENTRE      7     8
  PRIORITY      5     5
NUMBER AVAILABLE =    2
-    7
-    8
-    0

WORKCENTRE CELL   COST   TOTAL COST
       7     5     75         75.
       8     5     75        150.
CELL     5 COMPLETED

 CELL  INTERNAL   EXTERNAL   ESTIMATE   ESTIMATE  CELL
 NO.   MVT.CST.   MVT.CST.   REL.CST.   MVT.RTN. ORDER
  1      0.0        8.0        0.0         7.6     **
         0.0        0.0
  2      0.0        6.1        0.0         9.0     **
         0.0        0.0
  3      0.0       11.0        0.0         1.0     **
         0.0        0.0
  4      3.2       13.3        0.0        56.8     **
         0.0        0.0
  5      3.6        6.7        0.0        41.9     **
         0.0        0.0

PRESENT RELOCATION COST =        335.0             327.9
 PRESENT DEPMT MVT COST =         66.4              61.9
 PRESENT LOCAL MVT COST =          0.0               0.0

EXPECTED PROJECT RETURN =       -218.7            -239.4

DO YOU WANT -
AN INTERMEDIATE LAYOUT ?
- YES

RELOCATION PROJECT COMPLETED PERIOD    2

  TOTAL RELOCATION COST =        335.0             327.9
   TOTAL DEPMT MVT COST =        301.8             234.4
   TOTAL LOCAL MVT COST =          0.0               0.0        ⑦

   TOTAL PROJECT RETURN =       -218.7            -239.4
```

FIG C.5. (B) UA3 PROGRAM OUTPUT

layout is evaluated and the data summary printed. This summary is used throughout the exercise.

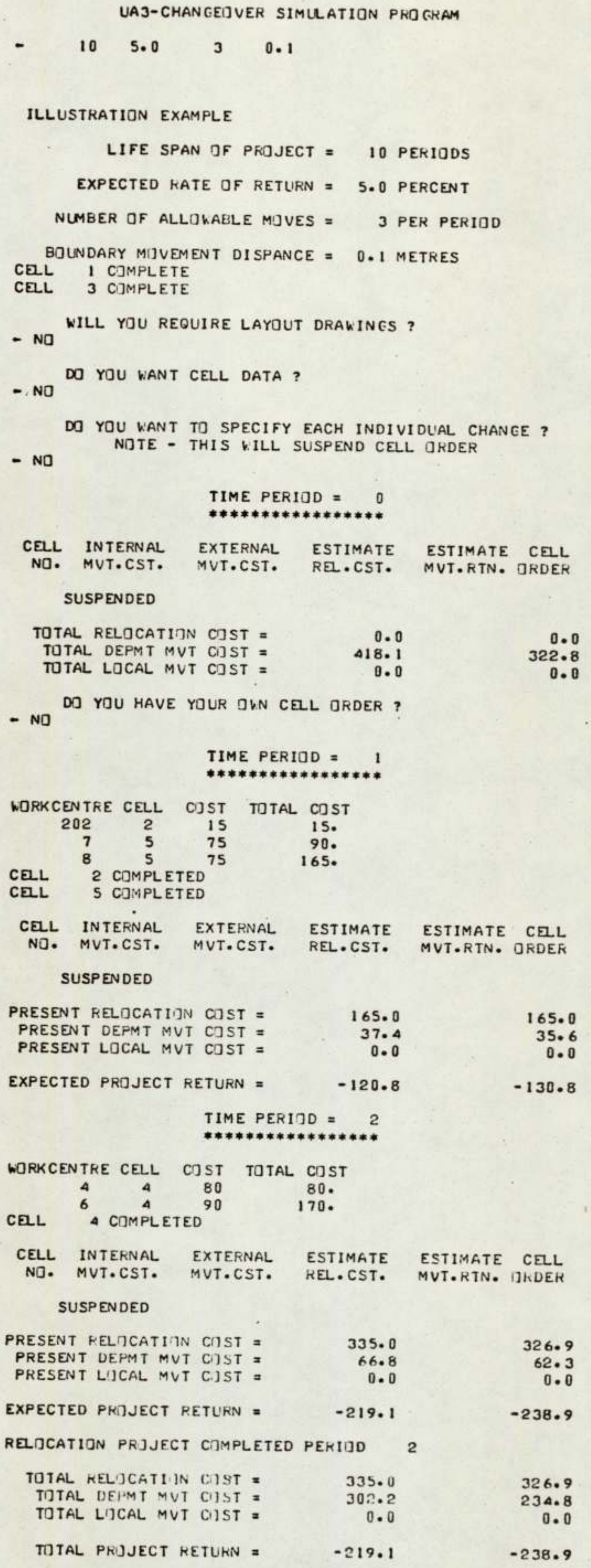
4. During the changeover each workcentre is given a priority related to its cell. The cell priority can either be determined automatically as a function of the potential return from each cell or can be input separately by the designer. This is achieved by firstly answering "Yes" to the cell order question and then by inputting each cell's priority (CO) using FORMAT 20I4. The priorities are input in order with up to 20 at a time.
5. Having selected a designer based changeover for each time period a list of candidate workcentres is produced and printed at the terminal, including the number available for relocation. Three choices are then available, firstly a workcentre can be added to the relocation list by inputting the identity number, secondly a workcentre can be removed from the relocation list using the negative of the number and thirdly the relocation list can be completed by entering a zero value. Each of these values are input using FORMAT I4. After the list is closed each workcentre is relocated in order in-

cluding all dependant workcentres. If an error is made during the compilation of the relocation list an error message is printed.

6. As indicated in the first point, where an intermediate layout drawing is required a "Yes" reply at this stage will write off to Fn9 the appropriate data.
7. On completion of the relocation of all workcentres a summary of project costs and financial return is printed. Alternatively the life span of the project may run out before the completion of workcentre relocation, for which an appropriate message will be printed.

Figure C.6. illustrates an abbreviated listing along with the use of the automatic changeover heuristic. One further general point remains concerning the maximum number of workcentres that can be relocated each time period (LN). The relocation of each workcentre may involve the movement of other workcentres to vacate the final position. This may result in an accumulation of changes requiring a certain minimum number of relocation moves. Where LN is less than this minimum number the relocation project can not be completed and therefore a warning is printed before stopping.

This completes the users guide to programs UA1,UA2



```
                  UA3-CHANGEOVER SIMULATION PROGRAM
-       10    5.0      3     0.1


  ILLUSTRATION EXAMPLE

              LIFE SPAN OF PROJECT =    10 PERIODS

          EXPECTED RATE OF RETURN =  5.0 PERCENT

       NUMBER OF ALLOWABLE MOVES =     3 PER PERIOD

     BOUNDARY MOVEMENT DISPANCE =  0.1 METRES
CELL    1 COMPLETE
CELL    3 COMPLETE

      WILL YOU REQUIRE LAYOUT DRAWINGS ?
- NO

      DO YOU WANT CELL DATA ?
-.NO

      DO YOU WANT TO SPECIFY EACH INDIVIDUAL CHANGE ?
           NOTE - THIS WILL SUSPEND CELL ORDER
- NO
                         TIME PERIOD =    0
                         *****************

  CELL  INTERNAL    EXTERNAL    ESTIMATE    ESTIMATE  CELL
   NO.  MVT.CST.    MVT.CST.    REL.CST.    MVT.RTN. ORDER

      SUSPENDED

   TOTAL RELOCATION COST =              0.0                  0.0
    TOTAL DEPMT MVT COST =            418.1                322.8
    TOTAL LOCAL MVT COST =              0.0                  0.0

      DO YOU HAVE YOUR OWN CELL ORDER ?
- NO

                         TIME PERIOD =    1
                         *****************

WORKCENTRE CELL   COST  TOTAL COST
     202     2     15       15.
       7     5     75       90.
       8     5     75      165.
CELL    2 COMPLETED
CELL    5 COMPLETED

  CELL  INTERNAL    EXTERNAL    ESTIMATE    ESTIMATE  CELL
   NO.  MVT.CST.    MVT.CST.    REL.CST.    MVT.RTN. ORDER

      SUSPENDED

PRESENT RELOCATION COST =             165.0                165.0
 PRESENT DEPMT MVT COST =              37.4                 35.6
 PRESENT LOCAL MVT COST =               0.0                  0.0

EXPECTED PROJECT RETURN =            -120.8               -130.8
                         TIME PERIOD =    2
                         *****************

WORKCENTRE CELL   COST  TOTAL COST
       4     4     80       80.
       6     4     90      170.
CELL    4 COMPLETED

  CELL  INTERNAL    EXTERNAL    ESTIMATE    ESTIMATE  CELL
   NO.  MVT.CST.    MVT.CST.    REL.CST.    MVT.RTN. ORDER

      SUSPENDED

PRESENT RELOCATION COST =             335.0                326.9
 PRESENT DEPMT MVT COST =              66.8                 62.3
 PRESENT LOCAL MVT COST =               0.0                  0.0

EXPECTED PROJECT RETURN =            -219.1               -238.9

RELOCATION PROJECT COMPLETED PERIOD     2

   TOTAL RELOCATION COST =            335.0                326.9
    TOTAL DEPMT MVT COST =            302.2                234.8
    TOTAL LOCAL MVT COST =              0.0                  0.0

    TOTAL PROJECT RETURN =           -219.1               -238.9
```

FIG C.6. ABBREVIATED UA3 PROGRAM OUTPUT

and UA3.

Before closing an insight into the philosophy behind the program suite will set the guide in perspective. The layout of workcentres in a job shop situation is a complex problem requiring consideration of both subjective and quantitative factors. In order to realistically model materials movement and layout changes the programs therefore involve a more than usual degree of detail. The approach adopted is one of an interactive, quantitative examination between designer and computer programs, an approach which will inevitably require the designer to have a working knowledge of each program and consequently the use of these detailed programs will not prove as difficult as first appears.

APPENDIX D

EXAMINATION OF LAYOUT PARAMETERS

UA1 OUTPUT TEST CASE A1

VARIATION IN PRODUCT BATCHES FOR TEST CASES A1-A4

VARIATION IN MATERIALS MOVEMENT FOR TEST CASES A1-A4

UA1 OUTPUT TEST CASE A5

CELL CENTRE CO-ORDINATES FOR TEST CASES A1-A4

CELL DIAGRAMS FOR TEST CASES A1-A4

WORKCENTRE CO-ORDINATES FOR TEST CASES A1-A4

LAYOUT ARRANGEMENTS FOR TEST CASES A1-A5

DISTANCES FROM WORKCENTRES TO CELL CENTRES

PROJECT RETURN RATIO AGAINST FIXED COST PER BATCH

TOTAL COST (FINAL LAYOUT) AGAINST BOUNDARY DISTANCE

PROJECT RETURN AGAINST BOUNDARY DISTANCE

PROJECT RETURN AGAINST RATE OF RETURN

PROJECT RETURN AGAINST TIME PERIODS

DYNAMIC PROJECT RETURN THROUGHOUT LIFE SPAN

PRESENT VALUE PROJECT RETURN THROUGHOUT LIFE SPAN

PROJECT RETURN AGAINST MOVES PER PERIOD AND RATE OF RETURN

```
UA1-DATA PROCESSING PROGRAM

 MACHINE SHOP TEST LAYOUT ONE


                              WORKCENTRE DATA
                              ***************


PFX   W/C     X      Y      A/R     B    ANGLE   COST CELL

 2     1     1.6    1.8    3.0    3.0    0.0      0    8

 2     2     4.8    1.8    3.0    3.0    0.0      0    9

 2     3     8.0    1.8    3.0    3.0    0.0      0   10

 2     4    11.2    1.8    3.0    3.0    0.0      0   11

 2     5    14.4    1.8    3.0    3.0    0.0      0   12

 2     6    17.6    1.8    3.0    3.0    0.0      0   13

 2     7    21.8    2.0    1.8    2.4    0.0      0    6

 2     8    24.0    2.4    2.5    2.2    0.0      0    6

 2     9    26.3    2.0    1.8    2.4    0.0      0    6

 2    10     3.0    7.4    3.3    2.6    0.0      0   13

 2    11     3.0   10.0    3.3    2.6    0.0      0    8

 2    12     3.0   14.3    3.3    2.6    0.0      0    9

 2    13     3.0   16.9    3.3    2.6    0.0      0   10

 2    14     3.0   20.3    3.3    2.6    0.0      0   11

 2    15     3.0   22.9    3.3    2.6    0.0      0   12

 2    16     6.0   25.8    2.1    3.0    0.0      0   10

 2    17    10.5   10.2    3.8    2.4    0.0      0   11

 2    18     9.9    6.9    4.2    2.2    0.0      0   12

 2    19    16.8    6.9    4.2    2.2    0.0      0   13

 2    20    16.8   10.5    2.5    2.6    0.0      0   12

 2    21     9.9   14.1    2.1    1.8    0.0      0    8

 2    22     9.9   15.9    2.1    1.8    0.0      0    9

 2    23    16.8   14.1    2.1    1.8    0.0      0   10

 2    24    16.8   15.9    2.1    1.8    0.0      0   11

 2    25     9.7   25.7    2.1    2.9    0.0      0    8

 2    26    11.9   25.7    2.1    2.9    0.0      0    8

 2    27    16.1   25.7    2.1    2.9    0.0      0    9

 2    28    14.1   25.7    3.4    2.2   45.0      0    9

 2    29     9.3   21.0    2.4    3.0    0.0      0    7

 4    30    23.7   20.1    6.3    4.5    0.0      0   14
ORIGINAL TYPE =  3    AREA RATIO = 0.783

 4    31    23.7   16.1    6.3    4.5    0.0      0   14
ORIGINAL TYPE =  3    AREA RATIO = 0.783

 2    32    23.7   10.2    5.9    2.0    0.0      0   10

 2    33    23.7    7.0    5.9    2.0    0.0      0   11

 2    34    23.7    4.8    5.9    2.0    0.0      0   12

 3   201     0.6    4.3    0.1    0.0    0.0      0    1

 3   202    19.8    0.6    0.1    0.0    0.0      0    2

 3   203    27.0   23.2    0.1    0.0    0.0      0    3

 3   204    19.8   23.7    0.1    0.0    0.0      0    4

 3   205    19.6   20.0    0.1    0.0    0.0      0    5


                TOTAL ORIGINAL AREA =      288.0
                     TOTAL NEW AREA =      300.3
                              RATIO =     0.9589
             NUMBER OF WORKCENTRES =     39
             TOTAL RELOCATION COST =        0.0
```

UA1 OUTPUT

TEST CASE A1 (A)

```
                 CELL DATA

CELL      NO.W/CS      NO.FIXED       AREA     REL.COST

  1          1             1           0.0         0.0
  2          1             1           0.0         0.0
  3          1             1           0.0         0.0
  4          1             1           0.0         0.0
  5          1             1           0.0         0.0
  6          3             0          14.1         0.0
  7          1             0           7.2         0.0
  8          5             0          33.5         0.0
  9          5             0          34.9         0.0
 10          5             0          39.5         0.0
 11          5             0          42.3         0.0
 12          5             0          45.1         0.0
 13          3             0          26.8         0.0
 14          2             2          56.7         0.0
        MORE THAN ONE FIXED W/C


                                LAYOUT AREA DATA
                                ****************

      AREA OUTLINE X/Y VALUES
       0.0  0.0        0.0 27.6      18.6 27.6      18.6 24.3
      27.6 24.3       27.6  0.0


NON PARTICIPATION AREAS - X AND Y VALUES


 4        7.9  7.9       7.9  9.1       9.1  9.1       9.1  7.9

 4        7.9 16.4       7.9 17.6       9.1 17.6       9.1 16.4

 4        7.9 24.9       7.9 26.1       9.1 26.1       9.1 24.9

 4       16.4  7.9      16.4  9.1      17.6  9.1      17.6  7.9

 4       16.4 24.9      16.4 26.1      17.6 26.1      17.6 24.9

 4       24.9  7.9      24.9  9.1      26.1  9.1      26.1  7.9

 4       24.9 16.4      24.9 17.6      26.1 17.6      26.1 16.4

 8       10.7 12.5      10.7 17.9      11.5 17.9      11.5 22.9
         19.5 22.9      19.5 16.9      16.2 16.9      16.2 12.5


      TRAFFIC ROUTES

   X1      Y1      X2      Y2    WIDTH   TERMINATOR

   0.0     4.3     6.8     4.3    1.6       0    1
   6.8     4.3     6.8    23.2    1.6       1    2
   6.8    23.2    19.8    23.2    1.6       2    3
  19.8    23.2    19.8     4.3    1.6       3    4
   6.8     4.3    19.8     4.3    1.6       1    4
  19.8    23.2    27.6    23.2    1.6       3    0
  19.8     4.3    19.8     0.0    1.6       4    0


NON PARTICIPATION AREAS  QTY=  8  TOTAL AREA =     55.1

INTERNAL TRAFFIC ROUTES  QTY=  7  TOTAL AREA =    123.4

                                ****                *********
                     SUBTOTAL    15                     178.4

            TOTAL DEPARTMENT AREA =    732.1

               NETT DEPARTMENT AREA =    553.6

       WORKCENTRE/DEPT AREA RATIO = 0.5425   (0.5202 )
```

UA1 OUTPUT

TEST CASE A1 (B)

```
                        PRODUCT INFORMATION
                        *******************

CODE   QUANTITY      P/SZ       FXD.CST       VAR.CST

 1       20000.      300.       0.000000      0.0018500
     204  16  23   3  13  32  29 205

 2       12000.      250.       0.000000      0.0018500
     204   3  16  13  23  32 203 203  29 205

 3        8400.      150.       0.000000      0.0018500
     204   1  25  11  21  26  29   7   8 205

 4      270000.     1500.       0.000000      0.0018500
     204   6  10  19  29 205

 5       20000.      100.       0.000000      0.0018500
     204   4  14  24  33  17  30 205

 6       11100.       50.       0.000000      0.0018500
     204  24   4  14  33  17 202 202 205

 7        4000.       50.       0.000000      0.0024000
     204  31  29  10 205

 8        3300.       50.       0.000000      0.0024000
     204   6  10  19  29 205

 9        9000.      150.       0.000000      0.0024000
     204  25  11   1  21  11  30  29 205

10        8100.      150.       0.000000      0.0018500
     204  25   1  26  11  21  30  29 205

11        6300.      100.       0.000000      0.0018500
     204  20  15  18  34   5  30 205

12        4000.      100.       0.000000      0.0018500
     204  34  20  15  18   5 201 202 205

13        5000.       50.       0.000000      0.0018500
     204  16  23  32   3  13 205

14        4000.       50.       0.000000      0.0018500
     204  31  29  10 205

15        1900.       50.       0.000000      0.0024000
     204  31  29  12 205

16        3300.       30.       0.000000      0.0024000
     204  31  29  12 205

17        2000.       30.       0.000000      0.0024000
     204  30  29  15 205

18        1500.       30.       0.000000      0.0038230
     204  30  29  15 205

19        1000.       30.       0.000000      0.0038230
     204   4  14  17  24  33  31 205

20        1000.       30.       0.000000      0.0038230
     204   4  17  14  24  33  31 205

21        1000.       30.       0.000000      0.0038230
     204   5  15  18  34  20 205

22         800.       30.       0.000000      0.0038230
     204   2  12  22  27  28  30 205

23         800.       25.       0.000000      0.0038230
     204  27   2  12  22  28  30 201 202  29 205

24         800.       25.       0.000000      0.0038230
     204  19  10   6  29 205

25         800.       25.       0.000000      0.0038230
     204  20  18  34   5  15  31 205

26         600.       25.       0.000000      0.0038230
     204   6  10  19 202 202  29 205

27         600.       25.       0.000000      0.0038230
     204   3  13  23  32  16   7   8 205

28         600.       25.       0.000000      0.0038230
     204   1  11  21  25  26 203 203  29 205

29        1600.      250.       0.000000      0.0024000
     204  12  28   2  27  22   9   8 205

30        8000.      200.       0.000000      0.0024000
     204  12  28

                   *** END OF OUTPUT ***
```

UA1 OUTPUT

TEST CASE A1 (C)

PRODUCT	TEST CASE A1	A2	A3	A4
1	67	67	67	67
2	48	100	48	48
3	56	50	56	56
4	180	18	180	180
5	200	20	500	500
6	222	22	222	222
7	80	80	80	80
8	67	100	67	67
9	60	60	60	60
10	54	54	54	54
11	63	63	5000	10000
12	40	40	40	40
13	100	100	100	100
14	80	80	80	80
15	38	38	38	38
16	110	11	110	110
17	67	20	67	67
18	50	50	50	50
19	34	100	34	34
20	34	100	34	34
21	34	800	200	800
22	27	27	200	800
23	32	32	32	32
24	32	4	32	32
25	32	32	32	32
26	24	24	24	24
27	24	24	24	24
28	24	24	24	24
29	7	7	7	7
30	40	100	40	40

COEFFICIENT OF VARIATION

81.1	187.8	360.9	397.2

BATCH QUANTITIES AND VARIATION - TEST EXAMPLES A1-A4

TABLE D1

WORKCENTRE	TEST CASE A1	 A2	 A3	 A4
1	0.87580	0.85630	8.78504	8.79504
2	0.67671	0.96471	19.99472	65.87072
3	0.97900	1.17140	9.79004	9.79004
4	2.08133	1.68460	31.91328	31.91328
5	0.88574	6.74257	204.21872	435.09472
6	1.41098	0.76069	14.10976	14.10976
7	0.39080	0.36850	3.90704	3.90704
8	0.42430	0.40210	4.24304	4.24304
9	0.03360	0.03360	0.33600	0.33600
10	2.09098	1.44069	20.90976	20.90976
11	1.16650	1.14430	11.66504	11.66044
12	1.38711	1.19991	27.09872	72.97472
13	0.97900	1.17140	9.79004	9.79004
14	2.08133	1.68460	31.91328	31.91328
15	1.58964	7.22087	211.25772	442.13372
16	0.97900	1.17140	9.79004	9.79004
17	2.08133	1.68460	31.91328	31.91328
18	0.88574	6.74257	204.21872	435.09472
19	1.41098	0.76069	14.10976	14.10976
20	0.88574	6.74257	204.21872	435.09472
21	0.87850	0.85630	8.78504	8.78504
22	0.67651	0.96471	19.99472	65.87072
23	0.97900	1.17140	9.79004	9.79004
24	2.08133	1.68460	31.91328	31.91328
25	0.87850	0.85630	8.78504	8.78504
26	0.59050	0.56830	5.90504	5.90504
27	0.67671	0.96471	19.99472	65.87072
28	0.67671	0.96471	19.99472	65.87072
29	5.24595	4.35306	52.45952	53.45952
30	2.61591	1.72431	233.15572	464.03172
31	2.15500	2.68907	21.55000	21.55000
32	0.97900	1.17140	9.79004	9.79004
33	2.08133	1.68460	31.91328	31.91328
34	0.88574	6.74254	204.21872	435.09472
201	0.39267	0.39267	3.92672	3.92672
202	2.40248	0.92248	24.02480	24.02480
203	0.72221	1.10701	7.22208	7.22208
204	4.50328	6.78689	154.87728	293.25328
205	4.93146	7.10802	159.15904	297.53504

COEFFICIENT OF VARIATION

80.21	104.01	139.56	155.82

WORKCENTRE MATERIALS MOVEMENT COST AND VARIATION

(COST = BATCH QUANTITIES X COST PER UNIT DISTANCE)

TABLE D2

```
UA1-DATA PROCESSING PROGRAM

 MACHINE SHOP TEST LAYOUT ONE


                              WORKCENTER DATA
                              ****************


PEX   W/C    X      Y     A/R     P    ANGLE  COST CELL

2      1    1.6    1.8    3.0    3.0    0.0    80   8

2      2    4.8    1.8    3.0    3.0    0.0    80   9

2      3    8.0    1.8    3.0    3.0    0.0    80  10

2      4   11.2    1.8    3.0    3.0    0.0    80  11

2      5   14.4    1.8    3.0    3.0    0.0    80  12

2      6   17.6    1.8    3.0    3.0    0.0    80  13

2      7   21.8    2.0    1.8    2.4    0.0    30   6

2      8   24.0    2.4    2.5    2.2    0.0   150   6

2      9   26.3    2.0    1.8    2.4    0.0    30   6

2     10    3.0    7.4    3.3    2.6    0.0    90  13

2     11    3.0   10.0    3.3    2.6    0.0    90   8

2     12    3.0   14.3    3.3    2.6    0.0    90   9

2     13    3.0   16.9    3.3    2.6    0.0    90  10

2     14    3.0   20.3    3.3    2.6    0.0    90  11

2     15    3.0   22.9    3.3    2.6    0.0    90  12

2     16    6.0   25.8    2.1    3.0    0.0    80  10

2     17   10.5   10.2    3.8    2.4    0.0    80  11

2     18    9.9    6.9    4.2    2.2    0.0    80  12

2     19   16.8    6.9    4.2    2.2    0.0    80  13

2     20   16.8   10.5    2.5    2.6    0.0    60  12

2     21    9.9   14.1    2.1    1.8    0.0    40   8

2     22    9.9   15.9    2.1    1.8    0.0    40   9

2     23   16.8   14.1    2.1    1.8    0.0    40  10

2     24   16.8   15.9    2.1    1.8    0.0    40  11

2     25    9.7   25.7    2.1    2.9    0.0     5   8

2     26   11.9   25.7    2.1    2.9    0.0    50   8

2     27   16.1   25.7    2.1    2.9    0.0    50   9

2     28   14.1   25.7    3.4    2.2   45.0    50   9

2     29    9.3   21.0    2.4    3.0    0.0     5   7

4     30   23.7   20.1    6.3    4.5    0.0     0  14
ORIGINAL TYPE =  3    AREA RATIO = 0.783

4     31   23.7   16.1    6.3    4.5    0.0     0  14
ORIGINAL TYPE =  3    AREA RATIO = 0.783

2     32   23.7   10.2    5.9    2.0    0.0    70  10

2     33   23.7    7.0    5.9    2.0    0.0    70  11

2     34   23.7    4.8    5.9    2.0    0.0    70  12

3    201    0.6    4.3    0.1    0.0    0.0     0   1

3    202   19.8    0.6    0.1    0.0    0.0     0   2

3    203   27.0   23.2    0.1    0.0    0.0     0   3

3    204   19.8   23.7    0.1    0.0    0.0     0   4

3    205   19.6   20.0    0.1    0.0    0.0     0   5


                 TOTAL ORIGINAL AREA =      284.0
                      TOTAL NEW AREA =      300.3
                               RATIO =    0.7589
             NUMBER OF WORKCENTRES =    39
             TOTAL RELOCATION COST =    2140.0
```

UA1 OUTPUT

TEST CASE A5 (A)

```
                CELL DATA

CELL        NO.W/CS       NO.FIXED        AREA      REL.COST

  1            1              1            0.0          0.0
  2            1              1            0.0          0.0
  3            1              1            0.0          0.0
  4            1              1            0.0          0.0
  5            1              1            0.0          0.0
  6            3              0           14.1        210.0
  7            1              0            7.2          5.0
  8            5              0           33.5        265.0
  9            5              0           34.9        310.0
 10            5              0           39.5        360.0
 11            5              0           42.3        360.0
 12            5              0           45.1        380.0
 13            3              0           26.8        250.0
 14            2              2           56.7          0.0
          MORE THAN ONE FIXED W/C


                              LAYOUT AREA DATA
                              ****************

     AREA OUTLINE X/Y VALUES
      0.0  0.0        0.0 27.6        18.6 27.6        18.6 24.3
     27.6 24.3       27.6  0.0


NON PARTICIPATION AREAS - X AND Y VALUES

 4        7.9  7.9        7.9  9.1         9.1  9.1         9.1  7.9

 4        7.9 16.4        7.9 17.6         9.1 17.6         9.1 16.4

 4        7.9 24.9        7.9 26.1         9.1 26.1         9.1 24.9

 4       16.4  7.9       16.4  9.1        17.6  9.1        17.6  7.9

 4       16.4 24.9       16.4 26.1        17.6 26.1        17.6 24.9

 4       24.9  7.9       24.9  9.1        26.1  9.1        26.1  7.9

 4       24.9 16.4       24.9 17.6        26.1 17.6        26.1 16.4

 8       10.7 12.5       10.7 17.9        11.5 17.9        11.5 22.9
         19.5 22.9       19.5 16.9        16.2 16.9        16.2 12.5


      TRAFFIC ROUTES

   X1       Y1       X2       Y2    WIDTH   TERMINATOR

   0.0      4.3      6.8      4.3     1.6       0   1
   6.8      4.3      6.8     23.2     1.6       1   2
   6.8     23.2     19.8     23.2     1.6       2   3
  19.8     23.2     19.8      4.3     1.6       3   4
   6.8      4.3     19.8      4.3     1.6       1   4
  19.8     23.2     27.6     23.2     1.6       3   0
  19.8      4.3     19.8      0.0     1.6       4   0


NON PARTICIPATION AREAS  CTY=  8  TOTAL AREA =      55.1

INTERNAL TRAFFIC ROUTES  CTY=  7  TOTAL AREA =     123.4

                               ****                ********
                    SUBTOTAL    15                    178.4

             TOTAL DEPARTMENT AREA =     732.1

                 NETT DEPARTMENT AREA =     553.6

      WORKCENTRE/DEPT AREA RATIO = 0.5425    (0.5202 )
```

UA1 OUTPUT

TEST CASE A5 (B)

```
                            PRODUCT INFORMATION
                            *******************

CODE   QUANTITY      P/SZ        FXD.CST        VAR.CST

  1       20000.      300.        0.078000       0.0018500
    204  16  23   3  13  32  29 205

  2       12000.      250.        0.078000       0.0018500
    204   3  16  13  23  32 203 203  29 205

  3        8400.      150.        0.078000       0.0018500
    204   1  25  11  21  26  29   7   8 205

  4      270000.     1500.        0.078000       0.0018500
    204   6  10  19  29 205

  5       20000.      100.        0.078000       0.0018500
    204   4  14  24  33  17  30 205

  6       11100.       50.        0.078000       0.0018500
    204  24   4  14  33  17 202 202 205

  7        4000.       50.        0.160000       0.0024000
    204  31  29  10 205

  8        3300.       50.        0.160000       0.0024000
    204   6  10  19  29 205

  9        9000.      150.        0.078000       0.0024000
    204  25  11   1  21  11  30  29 205

 10        8100.      150.        0.078000       0.0018500
    204  25   1  26  11  21  30  29 205

 11        6300.      100.        0.078000       0.0018500
    204  20  15  18  34   5  30 205

 12        4000.      100.        0.078000       0.0018500
    204  34  20  15  18   5 201 202 205

 13        5000.       50.        0.078000       0.0018500
    204  16  23  32   3  13 205

 14        4000.       50.        0.160000       0.0018500
    204  31  29  10 205

 15        1900.       50.        0.160000       0.0024000
    204  31  29  12 205

 16        3300.       30.        0.160000       0.0024000
    204  31  29  12 205

 17        2000.       30.        0.316000       0.0024000
    204  30  29  15 205

 18        1500.       30.        0.316000       0.0038230
    204  30  29  15 205

 19        1000.       30.        0.316000       0.0038230
    204   4  14  17  24  33  31 205

 20        1000.       30.        0.316000       0.0038230
    204   4  17  14  24  33  31 205

 21        1000.       30.        0.316000       0.0038230
    204   5  15  18  34  20 205

 22         800.       30.        0.316000       0.0038230
    204   2  12  22  27  28  30 205

 23         800.       25.        0.316000       0.0038230
    204  27   2  12  22  28  30 201 202  29 205

 24         800.       25.        0.316000       0.0038230
    204  19  10   6  29 205

 25         800.       25.        0.316000       0.0038230
    204  20  18  34   5  15  31 205

 26         600.       25.        0.316000       0.0038230
    204   6  10  19 202 202  29 205

 27         600.       25.        0.316000       0.0038230
    204   3  13  23  32  16   7   8 205

 28         600.       25.        0.316000       0.0038230
    204   1  11  21  25  26 203 203  29 205

 29        1600.      250.        0.160000       0.0024000
    204  12  28   2  27  22   9   8 205

 30        8000.      200.        0.160000       0.0024000
    204  12  28  22  27   2  29 205

                          *** END OF OUTPUT ***
```

UA1 OUTPUT

TEST CASE A5 (C)

CELL	TEST CASE							
	A1		A2		A3		A4	
	X	Y	X	Y	X	Y	X	Y
1	0.6	4.3	0.6	4.3	0.6	4.3	0.6	4.3
2	19.8	0.6	19.8	0.6	19.8	0.6	19.8	0.6
3	27.0	23.2	27.0	23.2	27.0	23.2	27.0	23.2
4	19.8	23.7	19.8	23.7	19.8	23.7	19.8	23.7
5	20.6	20.0	20.6	20.0	20.6	20.0	20.6	20.0
6	2.7	9.9	3.2	6.4	3.7	10.5	3.7	10.5
7	24.5	9.7	24.5	9.7	24.5	9.7	24.0	1.3
8	9.2	7.4	1.4	21.4	2.5	23.3	2.5	23.3
9	9.5	15.9	10.3	16.2	17.2	10.5	24.2	8.4
10	0.9	23.6	10.4	7.1	7.8	16.6	7.8	16.6
11	24.2	2.1	24.5	2.3	24.0	2.9	14.6	10.0
12	10.2	26.0	11.9	25.1	11.9	25.0	11.9	25.0
13	18.6	9.7	18.6	9.7	12.1	1.2	15.0	1.5
14	23.7	18.1	23.7	18.1	23.7	18.1	23.7	18.1

TABLE D3 CELL CENTRE X AND Y CO-ORDINATES

PLACEMENT
ORDER
7
13
11
12
9
10
8
6

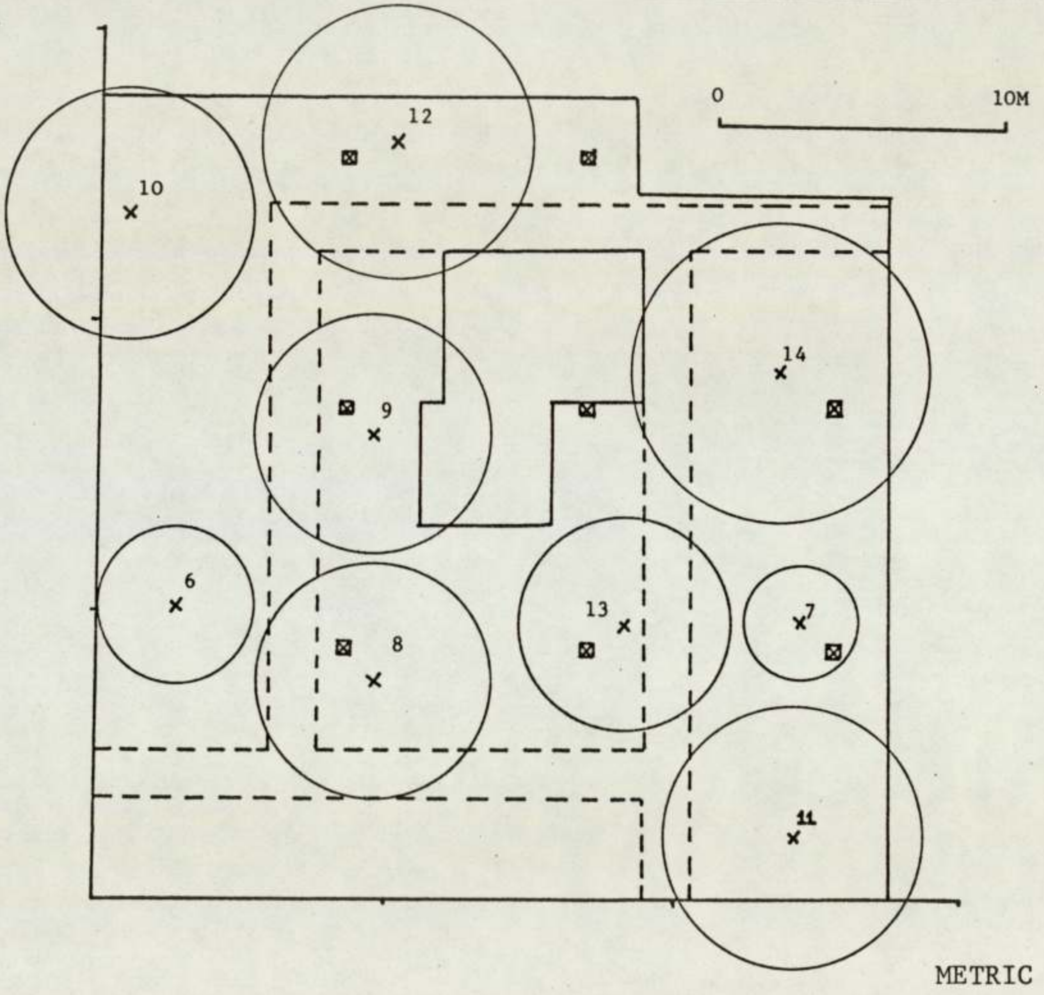


FIG D1 CELL DIAGRAM - TEST EXAMPLE A1

PLACEMENT
ORDER
12
7
11
13
9
10
8
6

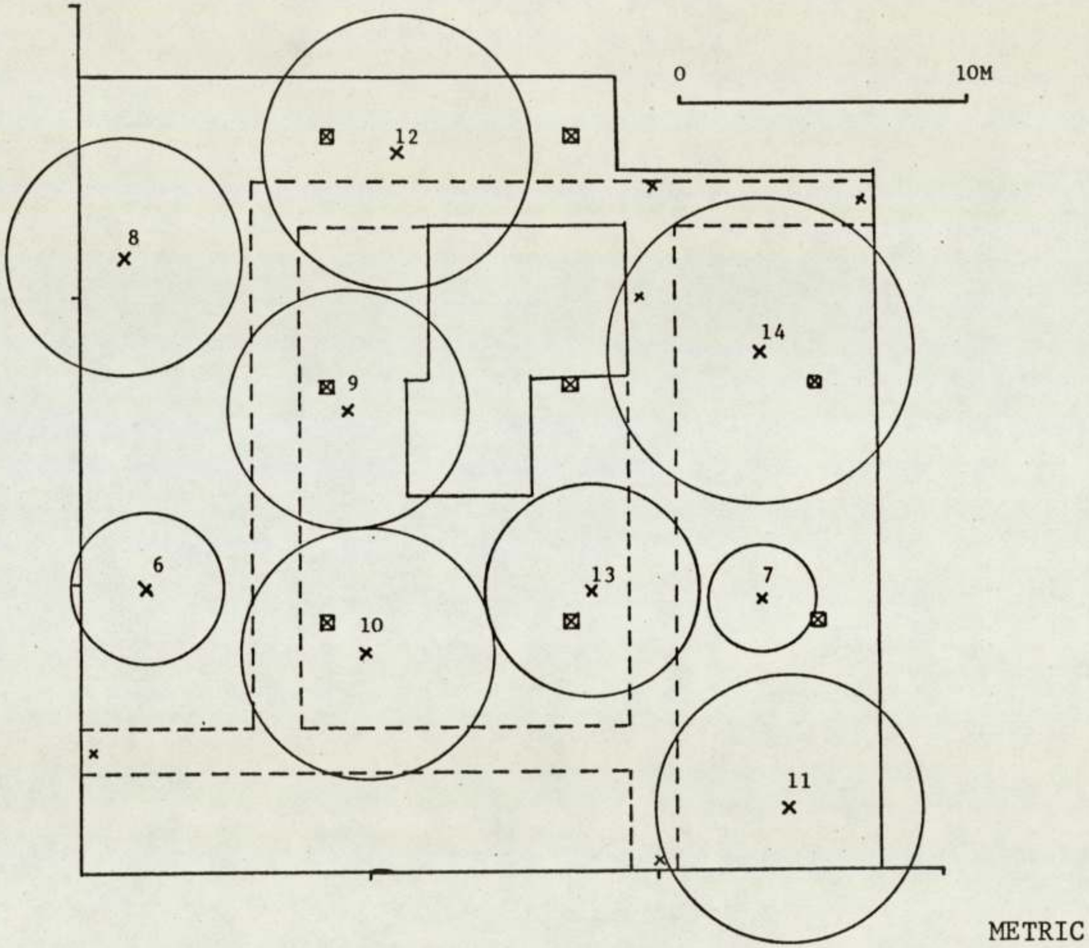
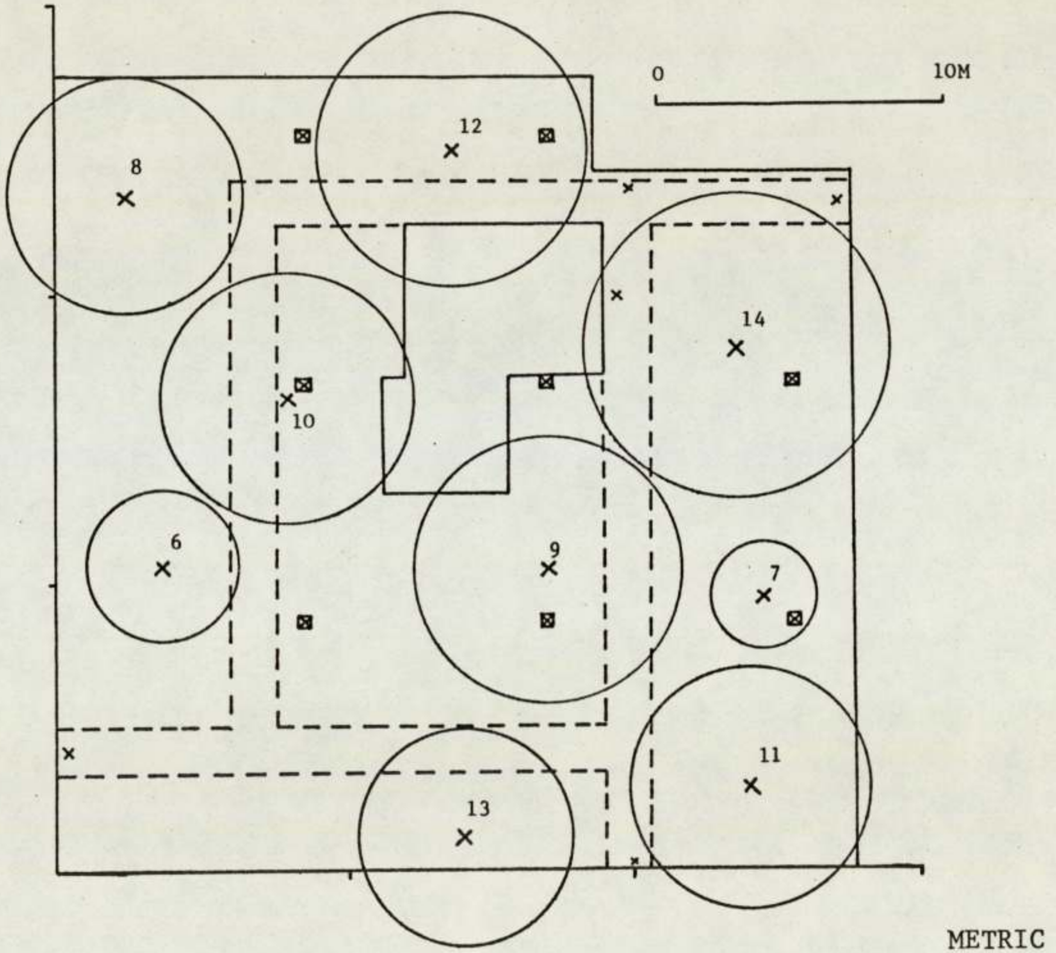


FIG D2 CELL DIAGRAM - TEST EXAMPLE A2



PLACEMENT
ORDER

12
7
11
9
13
10
8
6

FIG D3 CELL DIAGRAM - TEST EXAMPLE A3

PLACEMENT
ORDER
12
9
7
11
13
10
8
6

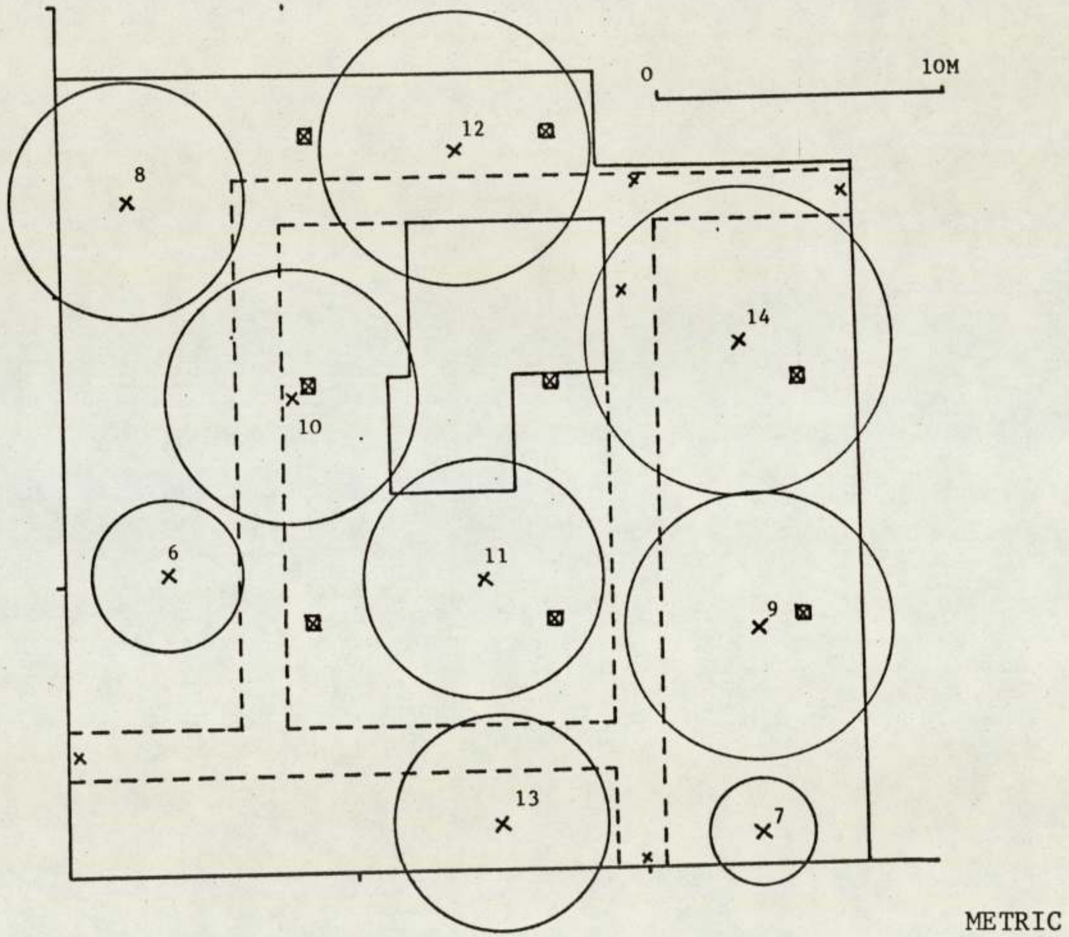


FIG D4 CELL DIAGRAM - TEST EXAMPLE A4

WORK		A1			A2	
CENTRE	X	Y	ANG	X	Y	ANG
1	9.5	6.5	0.0	1.7	19.4	0.0
2	9.3	14.9	0.0	9.3	14.9	0.0
3	1.7	18.0	0.0	9.1	6.8	0.0
4	25.7	1.8	0.0	25.7	1.8	0.0
5	1.7	23.3	0.0	1.7	23.3	0.0
6	17.5	10.8	0.0	17.5	14.5	0.0
7	4.6	9.8	90.0	4.0	7.5	90.0
8	1.7	8.4	90.0	1.7	9.0	90.0
9	4.6	7.2	90.0	4.0	10.5	90.0
10	17.4	15.0	90.0	17.7	10.7	90.0
11	12.7	6.3	0.0	1.7	16.2	90.0
12	9.6	20.8	0.0	9.6	20.8	0.0
13	2.0	15.1	0.0	14.5	11.6	0.0
14	22.3	1.5	0.0	22.3	1.5	0.0
15	10.6	25.5	0.0	10.6	25.5	0.0
16	1.7	20.7	90.0	14.5	9.1	90.0
17	22.8	7.3	0.0	22.8	7.3	0.0
18	14.6	25.3	0.0	14.6	25.3	0.0
19	16.8	6.9	0.0	16.8	6.9	0.0
20	4.7	23.0	0.0	4.7	23.0	0.0
21	13.4	11.5	90.0	1.3	13.2	90.0
22	8.9	9.8	0.0	8.9	9.8	0.0
23	1.5	12.5	90.0	11.8	12.0	0.0
24	26.1	7.1	0.0	26.1	7.1	0.0
25	14.5	9.4	90.0	4.8	16.2	0.0
26	11.5	9.4	90.0	4.7	19.7	0.0
27	9.1	12.0	90.0	9.1	12.0	90.0
28	9.5	18.3	0.0	9.5	18.3	0.0
29	22.5	10.5	0.0	22.5	11.0	0.0
30	23.7	20.1	0.0	23.7	20.1	0.0
31	23.7	15.1	0.0	23.7	15.1	0.0
32	4.7	17.1	90.0	11.8	8.1	90.0
33	23.8	4.8	0.0	23.8	4.8	0.0
34	4.9	25.8	170.0	4.9	25.8	170.0
201	0.6	4.3	0.0	0.6	4.3	0.0
202	19.8	0.6	0.0	19.8	0.6	0.0
203	27.0	23.2	0.0	27.0	23.2	0.0
204	19.8	23.7	0.0	19.8	23.7	0.0
205	19.6	20.0	0.0	19.6	20.0	0.0

TABLE D4 (A)

FINAL WORKCENTRE LOCATIONS TEST CASES A1 AND A2
(TEST CASE A5 SAME AS TEST CASE A1)

WORK CENTRE		A3			A4	
	X	Y	ANG	X	Y	ANG
1	1.7	19.4	0.0	1.7	19.4	0.0
2	10.2	6.8	0.0	22.5	9.9	0.0
3	10.3	20.8	0.0	10.3	20.8	0.0
4	25.7	1.8	0.0	9.2	6.8	0.0
5	1.7	23.3	0.0	1.7	23.3	0.0
6	17.6	1.8	0.0	17.6	1.8	0.0
7	4.0	7.5	90.0	4.0	7.5	90.0
8	1.7	9.0	90.0	1.7	9.0	90.0
9	4.0	10.5	90.0	4.0	10.5	90.0
10	9.5	1.7	0.0	9.5	1.7	0.0
11	1.7	16.2	90.0	1.7	16.3	90.0
12	17.7	6.9	90.0	22.1	5.4	90.0
13	9.2	14.8	90.0	9.2	14.8	90.0
14	22.3	1.5	0.0	17.7	6.9	90.0
15	10.6	25.5	0.0	10.6	25.5	0.0
16	9.3	18.2	90.0	9.3	18.2	90.0
17	22.8	7.3	0.0	14.1	6.6	0.0
18	14.6	25.3	0.0	14.6	25.3	0.0
19	13.9	1.7	0.0	13.9	1.7	0.0
20	4.7	23.0	0.0	4.7	23.0	0.0
21	1.3	13.2	90.0	1.3	13.2	90.0
22	14.3	9.5	0.0	25.2	10.0	0.0
23	8.8	9.8	0.0	8.8	9.6	0.0
24	26.1	7.1	0.0	11.3	9.5	0.0
25	4.8	16.2	0.0	4.8	16.2	0.0
26	4.7	19.7	0.0	4.7	19.7	0.0
27	17.0	10.0	90.0	25.2	7.0	90.0
28	14.4	6.6	0.0	25.2	4.7	0.0
29	22.5	10.5	0.0	22.3	1.6	90.0
30	23.7	20.1	0.0	23.7	20.1	0.0
31	23.7	15.1	0.0	23.7	15.1	0.0
32	10.8	11.8	0.0	10.8	11.6	0.0
33	23.8	4.8	0.0	15.8	10.1	15.0
34	4.9	25.8	170.0	4.9	25.8	170.0
201	0.6	4.3	0.0	0.6	4.3	0.0
202	19.8	0.6	0.0	19.8	0.6	0.0
203	27.0	23.2	0.0	27.0	23.2	0.0
204	19.8	23.7	0.0	19.8	23.7	0.0
205	19.6	20.0	0.0	20.6	20.0	0.0

TABLE D4 (B)

FINAL WORKCENTRE LOCATIONS TEST CASES A3 AND A4

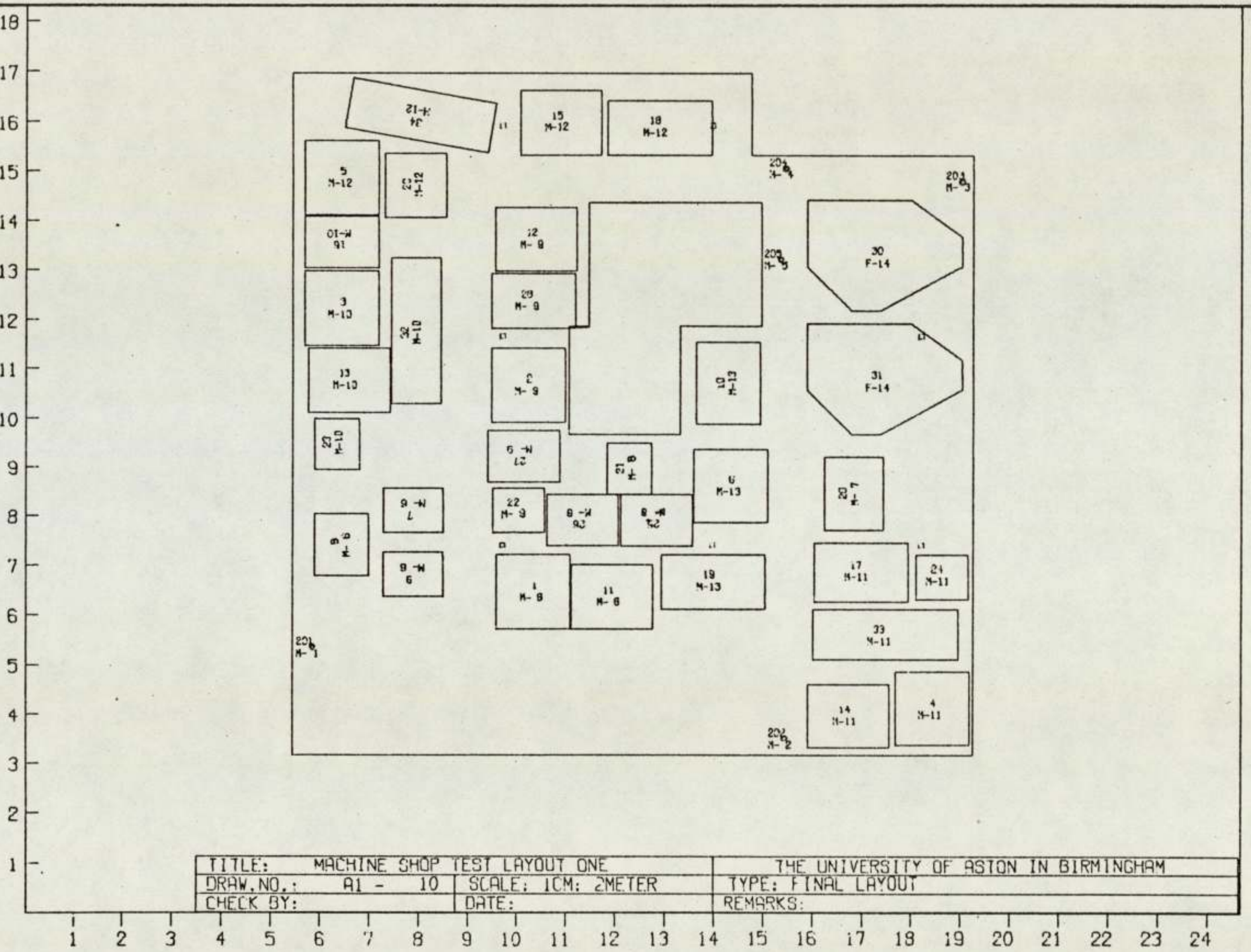


FIG D5 FINAL LAYOUT TEST CASE A1

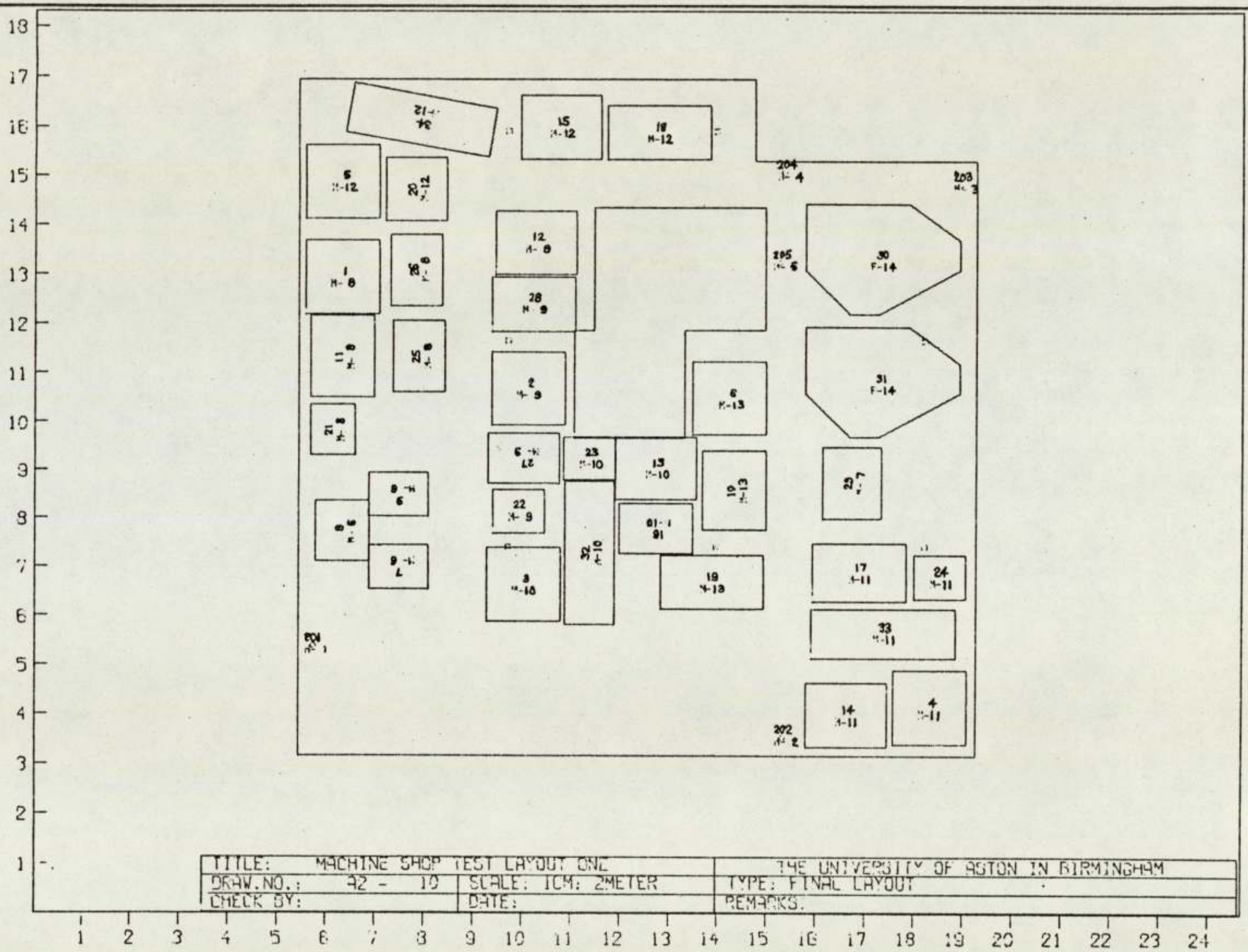
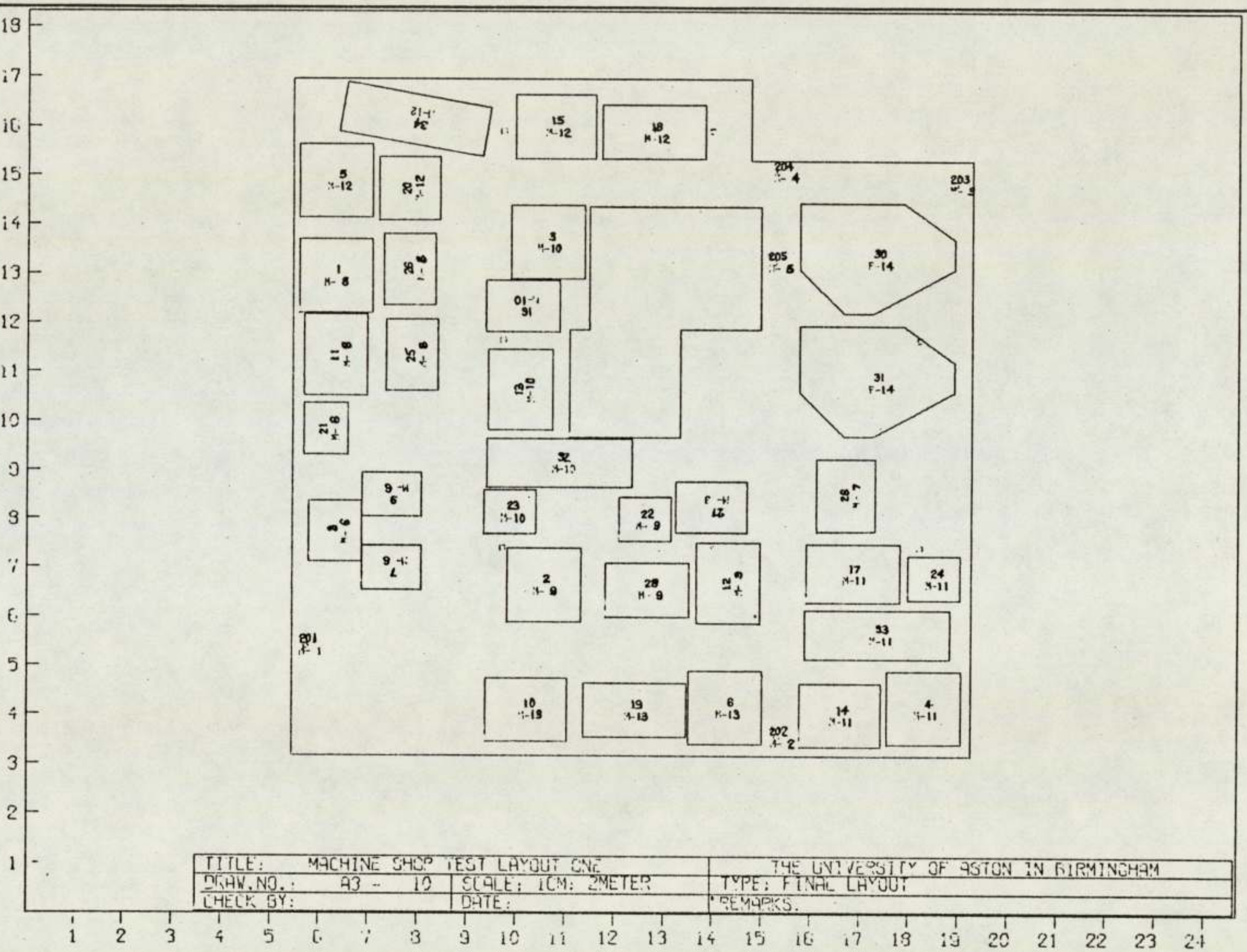


FIG D6 FINAL LAYOUT TEST CASE A2



TITLE: MACHINE SHOP TEST LAYOUT ONE
DRAW.NO.: A3 - 10
CHECK BY:
SCALE: 1CM: 2METER
DATE:
THE UNIVERSITY OF ASTON IN BIRMINGHAM
TYPE: FINAL LAYOUT
REMARKS.

FIG D7 FINAL LAYOUT TEST CASE A3

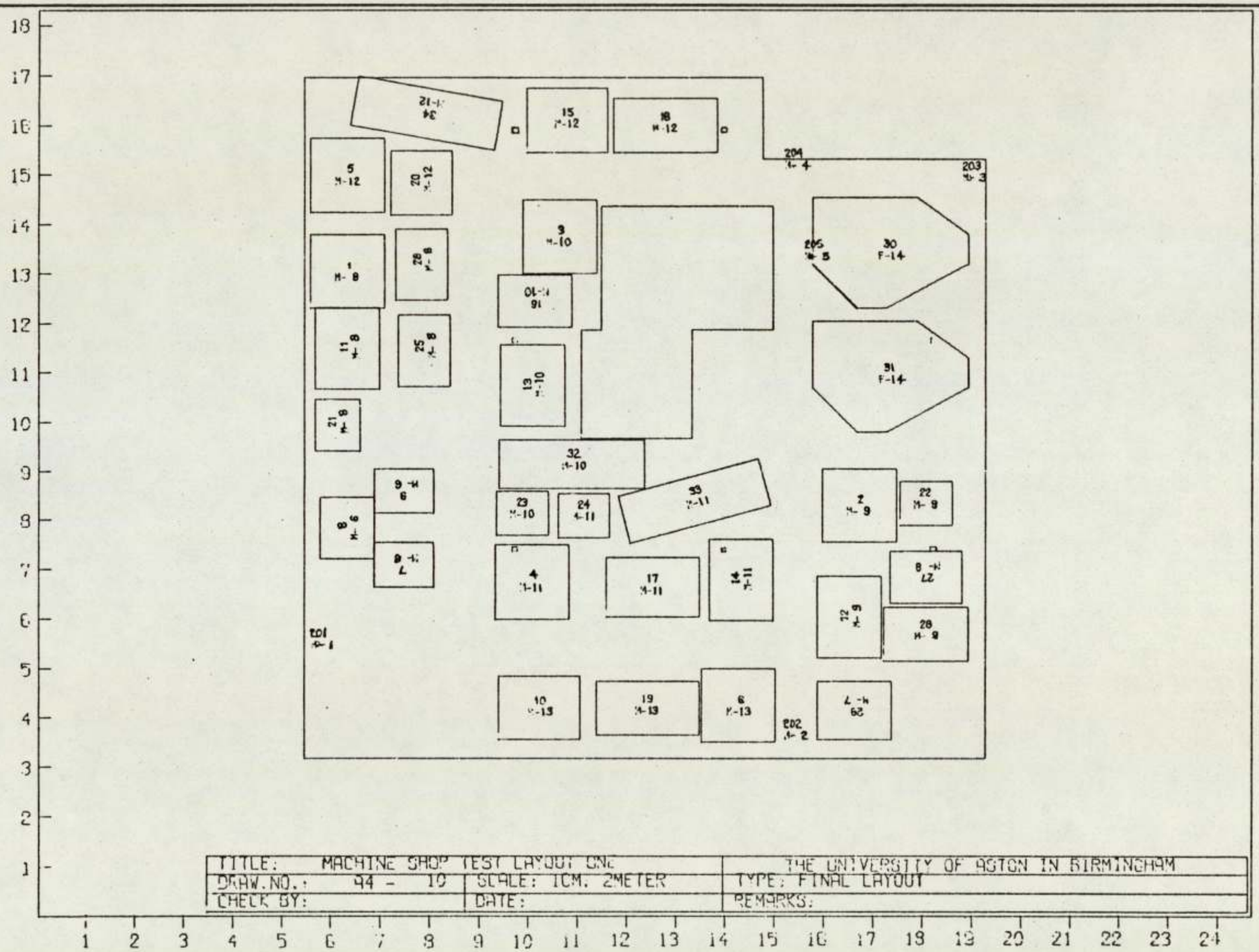


FIG D8 FINAL LAYOUT TEST CASE A4

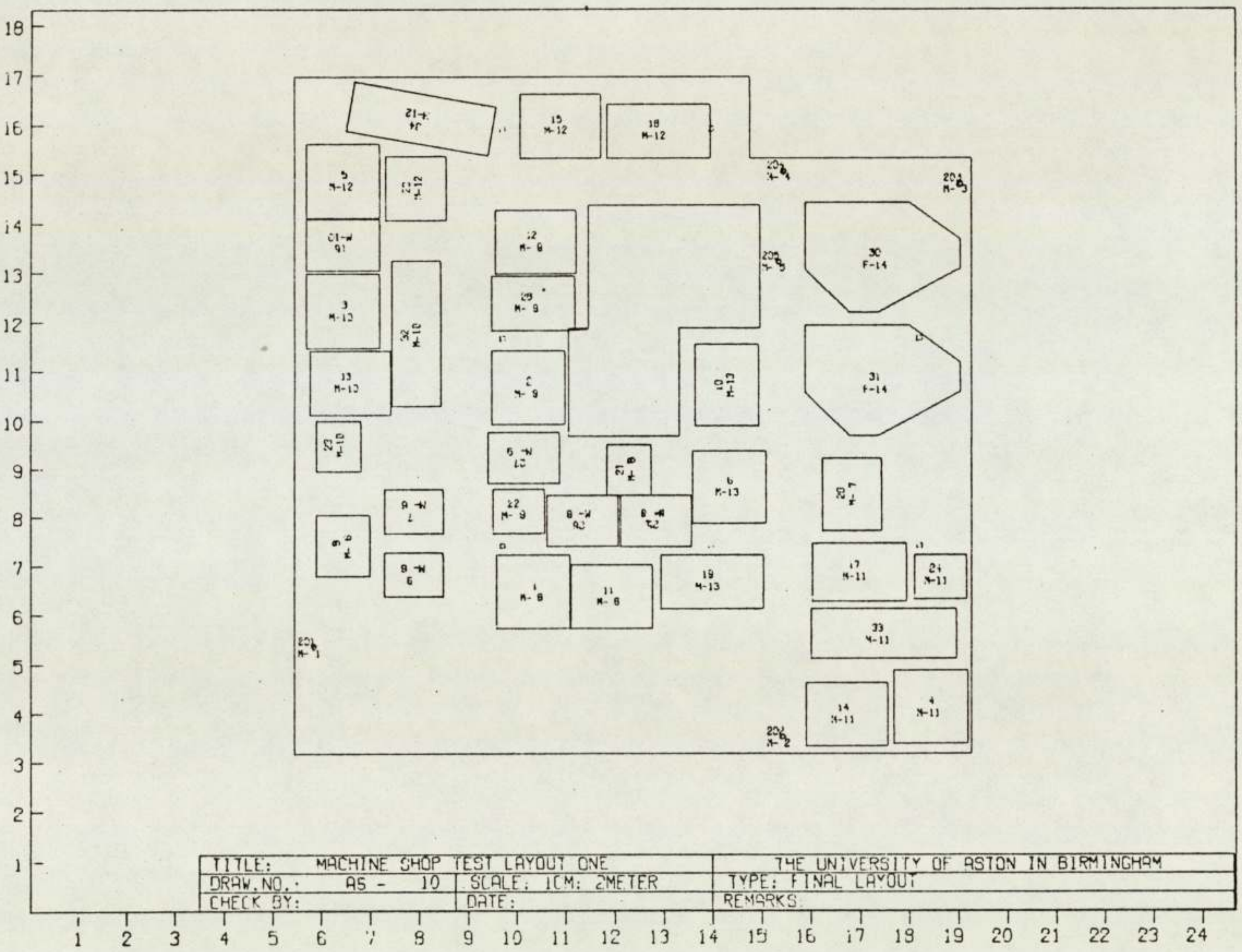


FIG D9 FINAL LAYOUT TEST CASE A5

CELL	CELL WORKCENTRE	DISTANCE			
		CASE A1	CASE A2	CASE A3	CASE A4
6	7	1.9	1.4	3.0	3.0
	8	1.8	3.0	2.5	2.5
	9	3.3	4.2	0.3	0.3
7	29	1.9	2.4	2.2	1.7
8	1	1.0	2.0	4.0	4.0
	11	3.7	5.2	7.1	7.0
	21	5.9	8.2	10.2	10.2
	25	5.7	6.2	7.5	7.5
	26	3.1	3.7	4.2	4.2
9	2	1.0	1.6	7.9	2.3
	12	4.9	4.7	3.6	3.7
	22	6.1	6.6	3.1	1.9
	27	3.9	4.4	0.5	1.7
	28	2.4	2.3	4.8	3.8
10	3	5.7	1.3	4.9	4.9
	13	8.6	6.1	2.3	2.3
	16	3.0	4.6	2.2	2.2
	23	11.1	5.1	6.9	7.1
	32	7.5	1.7	5.7	5.8
11	4	1.5	1.3	2.0	6.3
	14	2.0	2.3	2.2	4.4
	17	5.4	5.3	4.6	3.4
	24	5.3	5.1	4.7	3.3
	33	2.7	2.6	1.9	1.2
12	5	8.9	10.4	10.3	10.3
	15	0.6	1.4	1.4	1.4
	18	4.5	2.7	2.7	2.7
	20	6.3	7.5	7.5	7.5
	34	5.3	7.0	7.0	7.0
13	6	1.6	4.9	5.5	2.6
	10	5.4	1.4	2.6	5.5
	19	3.3	3.3	1.9	1.1

TABLE D5 DISTANCES FROM WORKCENTRES TO CELL CENTRES

TEST CASE	FIXED COST PER BATCH						
	0.00	0.01	0.02	0.05	0.10	0.20	0.40
A1	0.2838	0.2383	0.2054	0.1452	0.0976	0.0589	0.0329
A2	0.3016	0.2522	0.2166	0.1523	0.1019	0.0613	0.0341
A3	0.3510	0.2865	0.2421	0.1652	0.1080	0.0638	0.0351
A4	0.3398	0.2781	0.2354	0.1611	0.1056	0.0623	0.0344

TABLE D6 PROJECT RETURN RATIO AGAINST FIXED COST PER BATCH

TEST CASE	BOUNDARY DISTANCE (METRES)											
	0.1	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	12.0	16.0	20.0
A1	4360	4360	4360	4061	3715	3534	3019	2711	2020	1708	1145	463
A2	6320	6320	6320	6000	4641	4479	3701	3417	2891	2077	1624	1323
A3	14563	14563	14563	14129	13643	10507	10217	8897	6830	6484	4302	3201
A4	27770	27770	27770	26676	26119	19568	19065	17087	13083	12860	7530	5383

TABLE D7 TOTAL COST (FINAL LAYOUT) AGAINST BOUNDARY DISTANCE

TEST CASE	BOUNDARY DISTANCE (METRES)											
	0.1	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	12.0	16.0	20.0
A1	1727	1727	1720	2000	2344	2455	2906	3082	3302	3082	1540	1361
A2	2729	2729	2722	3021	4380	4507	5005	5169	3737	3563	2130	1746
A3	7875	7875	7821	8234	8720	10710	10935	12667	12379	11858	8355	2650
A4	14291	14291	14077	15150	15707	19912	20350	21945	22475	20974	16750	5813

TABLE D8 PROJECT RETURN AGAINST BOUNDARY DISTANCE

PERCENTAGE RATE OF RETURN	PROJECT RETURN
0.0	6910.9
1.0	5672.9
2.0	4726.3
5.0	2964.6
10.0	1689.6
20.0	863.3
40.0	431.9
80.0	216.0

VARIATION IN PROJECT RETURN AGAINST RATE OF RETURN

TABLE D9

TIME PERIODS	PROJECT RETURN	
	R=0%	R=2%
1	173	170
2	346	336
4	692	659
10	1730	1554
20	3460	2829
40	6920	4732
100	17300	7475

VARIATION IN PROJECT RETURN AGAINST TIME PERIODS

TABLE D10

TIME PERIOD	NUMBER OF MOVES PER PERIOD					
	32	16	8	4	2	1
0	-2060.0	-1145.0	-535.0	-290.0	-170.0	-80.0
1	172.8	-770.2	-487.7	-172.5	-89.0	-102.3
2	172.8	172.8	-375.2	-167.7	-77.5	-49.0
3	172.8	172.8	-227.4	-198.4	-22.1	28.3
4	172.8	172.8	172.8	-155.2	-47.7	2.6
5	172.8	172.8	172.8	-42.4	3.0	-10.5
6	172.8	172.8	172.8	-2.4	-28.5	-17.0
7	172.8	172.8	172.8	-32.4	-32.9	94.5
8	172.8	172.8	172.8	172.8	14.8	42.3
9	172.8	172.8	172.8	172.8	-5.3	35.2
10	172.8	172.8	172.8	172.8	87.6	42.9
11	172.8	172.8	172.8	172.8	48.2	79.5
12	172.8	172.8	172.8	172.8	52.5	51.6
13	172.8	172.8	172.8	172.8	118.4	58.3
14	172.8	172.8	172.8	172.8	-2.3	47.0
15	172.8	172.8	172.8	172.8	142.1	61.5
16	172.8	172.8	172.8	172.8	172.8	84.8
17	172.8	172.8	172.8	172.8	172.8	74.0
18	172.8	172.8	172.8	172.8	172.8	84.7
19	172.8	172.8	172.8	172.8	172.8	80.9
20	172.8	172.8	172.8	172.8	172.8	137.6
21	172.8	172.8	172.8	172.8	172.8	124.3
22	172.8	172.8	172.8	172.8	172.8	128.2
23	172.8	172.8	172.8	172.8	172.8	99.0
24	172.8	172.8	172.8	172.8	172.8	92.6
25	172.8	172.8	172.8	172.8	172.8	136.8
26	172.8	172.8	172.8	172.8	172.8	168.3
27	172.8	172.8	172.8	172.8	172.8	126.2
28	172.8	172.8	172.8	172.8	172.8	147.6
29	172.8	172.8	172.8	172.8	172.8	24.0
30	172.8	172.8	172.8	172.8	172.8	142.1
31	172.8	172.8	172.8	172.8	172.8	172.8
32	172.8	172.8	172.8	172.8	172.8	172.8

PROJECT RETURN THROUGHOUT LIFE SPAN

TABLE D11

TIME	NUMBER OF MOVES PER PERIOD					
PERIOD	32	16	8	4	2	1
0	-2060.0	-1145.0	-535.0	-290.0	-170.0	-80.0
1	157.7	-700.1	-443.3	-156.8	-80.9	-93.0
2	142.7	142.7	-309.9	-138.5	-63.8	-40.5
3	129.8	129.8	-145.1	-149.0	-16.6	21.3
4	118.0	118.0	118.0	-106.0	-32.6	1.8
5	107.3	107.3	107.3	-26.3	1.9	-6.5
6	97.5	97.5	97.5	-1.4	-16.1	-9.6
7	88.7	88.7	88.7	-16.6	-16.9	48.5
8	79.0	79.0	79.0	79.0	6.8	19.3
9	73.3	73.3	73.3	73.3	-2.2	14.9
10	66.7	66.7	66.7	66.7	33.8	16.6
11	60.5	60.5	60.5	60.5	16.9	27.8
12	55.1	55.1	55.1	55.1	16.7	16.5
13	50.1	50.1	50.1	50.1	34.3	16.9
14	45.5	45.5	45.5	45.5	-0.6	12.4
15	41.3	41.3	41.3	41.3	34.0	14.7
16	37.7	37.7	37.7	37.7	37.7	18.5
17	34.2	34.2	34.2	34.2	34.2	14.7
18	31.1	31.1	31.1	31.1	31.1	15.3
19	28.8	28.8	28.8	28.8	28.8	13.3
20	25.7	25.7	25.7	25.7	25.7	20.5
21	23.3	23.3	23.3	23.3	23.3	16.8
22	21.3	21.3	21.3	21.3	21.3	15.8
23	19.4	19.4	19.4	19.4	19.4	11.1
24	17.6	17.6	17.6	17.6	17.6	9.4
25	15.9	15.9	15.9	15.9	15.9	12.6
26	14.5	14.5	14.5	14.5	14.5	14.1
27	13.1	13.1	13.1	13.1	13.1	9.6
28	11.9	11.9	11.9	11.9	11.9	10.2
29	10.9	10.9	10.9	10.9	10.9	1.5
30	9.8	9.8	9.8	9.8	9.8	8.1
31	8.9	8.9	8.9	8.9	8.9	8.9
32	8.1	8.1	8.1	8.1	8.1	8.1

TABLE D12

PRESENT VALUE PROJECT RETURN THROUGHOUT LIFE SPAN

RATE OF RETURN	NUMBER OF MOVES PER PERIOD					
	1	2	4	8	16	32
0	3664.2	4310.8	4640.6	4782.3	4823.0	4850.9
2	2090.2	2414.2	2588.8	2654.2	2656.8	2666.3
4	1218.3	1345.2	1401.5	1400.6	1368.0	1359.6
5	934.5	993.5	1001.5	970.9	921.6	904.6
10	233.7	120.1	-36.3	-188.1	-312.7	-370.4

TABLE D13

EFFECT ON PROJECT RETURN OF MOVES PER PERIOD AND RATE OF RETURN

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