

**MODULAR FACILITIES LAYOUT USING INTEGRATED CAD  
AND DATABASE SOFTWARE**

Thesis submitted in accordance with the requirements  
of the University of Liverpool for the degree of  
Doctor in Philosophy

By

**Nazir Ahmed Sangi**

The Department of Industrial Studies

Faculty of Engineering

January 1989 - Liverpool, England

**BEST COPY**

**AVAILABLE**

Variable print quality



**MISSING**

**PRINT**

## ACKNOWLEDGEMENTS

So the difficult time has arrived, i.e. to express my sincere thanks, in a few words, to the people who have directly and indirectly contributed in support of this work.

May I first thank the Government of Pakistan for providing financial support and Professor J S Halliday for providing an opportunity to undertake this research in the Department of Industrial Studies, Liverpool University.

My respects and gratitude goes to Dr J Driscoll, my research supervisor, for his interest and encouragement in carrying out this research work and other publications.

My thanks to all the staff members and research students of the Industrial Studies Department. Special thanks to Mr Ray Ball for checking the manuscript and giving valuable advice and encouragement. My thanks to Mrs. Shirley Smith and Mrs. Pauline Hobson for typing the thesis.

I express my sincere thanks to Miss Mary Thorp, and Dr S Morgan of the Computer Laboratory, who guided me through the difficult software tasks associated with the University's CADAM and CATIA CAD facilities.

I wish to thank Lucas Automotive, Bromborough, in particular Mr. L Quinn, Product General Manager, for allowing the construction of layout and facilities drawings and permitting the use of general product information.

A long and deeply felt separation from my family was the most difficult loss of all during my period of research. I humbly pay my respects to my parents and brothers who continuously encouraged me. The support and love I have received from them is truly inexpressible. My successful return, is perhaps the only way to make them happy.

Last, but very special thanks to my wife, whose personal support and care has added a flavour to my research work.

## **MODULAR FACILITIES LAYOUT USING INTEGRATED CAD AND DATABASE SOFTWARE**

**Nazir A. Sangi**

This thesis makes a contribution to the subject of Computer Aided Facilities Layout (CAFL) in two main areas; advancing state-of-the-art knowledge through a major international software survey, and secondly developing a CAD based CAFL software philosophy.

The thesis initially identifies the importance of combining advanced graphics and CAFL analysis and re-examines the design process specific to facilities layout problems. The review of Computer Aided Facilities Planning is made firstly through an examination of recently published layout procedures and secondly via a comprehensive international survey of CAFL software.

This detailed survey was conducted over a two year period and has identified 101 pieces of software developed and used by CAFL researchers and users internationally. The survey contained six sections and covered 69 major questions.

Section A of the survey examined the people involved in CAFL and Section B detailed the extent of their involvement. This provides an up-to-date profile of CAFL development.

Fifty six pieces of software were available for detailed scrutiny in Section C of the survey. Examination of the computational characteristics, working mode, data verification problem representation and graphics, layout design and evaluation procedures is performed. This section comprehensively examines technical features and approaches used in software and represents the most detailed international review completed to date.

Sections D and E, identify the commercial interest in CAFL and user evaluation of packages respectively. The user evaluations section identified 64 package evaluations consisting of 26 unique packages. Section D on commercial CAFL software, indicated a poor level of industrial interest and the need for improved CAFL software. Respondent comments, the final section, were found to contain a number of supportive statements regarding the philosophy developed in the second part of this work.

Together with the survey findings and literature review, the specification for an ideal CAFL package is proposed and followed by a conceptual framework for this CAD-CAFL philosophy. The framework employs proprietary CAD and DBMS software as the basis of graphics and data handling. The need for structured databases and specialist interface software have been identified for this approach.

The MEHRAN model is developed which makes use of two CAD packages; 3-D solid modelling CATIA and 2-D design and drafting CADAM. In parallel SQL/DS, a relational database package, is employed for manufacturing data manipulation.

The work on the design of the MEHRAN graphics database for generating layouts is fully described. Four CAD-CAFL interface programs (globally referred to as MEHRAN software) were developed to test the potential of MEHRAN graphics database application in layout design work. The initial development and testing was performed on a prototype 10 facilities test case and followed by a 37 facility industrial test case.

The MEHRAN model has demonstrated superior performance in providing effective, structured and quality graphics for layout design work in an industrial environment. The initial geometry interface CAFL programs have identified an area for further development along the lines of the conceptual CAD-CAFL philosophy.

## CONTENTS

	<b>Page</b>
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Introduction	1
1.2 Life Cycle Concepts in Facilities Planning	2
1.3 The Design Solution Approach	4
1.4 CAD and CAFL	10
1.5 DBMS and CAFL	13
1.6 The CAD-CAFL System	14
1.7 The Research Proposal	17
1.8 Chapter Style	17
<b>2. LITERATURE REVIEW</b>	<b>19</b>
2.1 Chapter Objectives	19
2.2 Design Methodologies	19
2.3 Relating CAD to CAFL Design	28
2.4 Predecessors to the Present Work	33
2.5 Identified Sources of Information on CAFL	37
2.6 Recent CAD-CAFL Publications	40
2.7 Summary	51
2.8 The Need For International Survey	52
<b>3. AN INTERNATIONAL SURVEY OF COMPUTER AIDED FACILITIES LAYOUT</b>	<b>53</b>
3.1 Chapter Objectives	53
3.2 Previous Survey Perspective	53
3.3 Summary Justification For the Survey	59
3.4 Survey Background	60
3.5 Survey Section A: Personal Information	64
3.6 Survey Section B : Development of CAFL Software	65

	<b>Page</b>
3.7 Survey Section C : Contents of CAFL Software	69
3.8 Survey Section D : Marketing of CAFL Software	98
3.9 Survey Section E : Users of CAFL Software	100
3.10 Survey Section F : User Comments	109
3.11 Comparison of Surveys	113
3.12 Collected Summary Comments and Conclusions	121
3.13 The Direction of Future Work	131
<b>4. INTEGRATING CAD AND CAFL</b>	<b>132</b>
4.1 Chapter Objectives	132
4.2 Attributes of an Ideal CAFL Package	132
4.3 The CAD-CAFL Philosophy	138
4.4 Conceptual CAD-CAFL Model Requirements	139
<b>5. THE DEVELOPMENT OF MEHRAN MODEL</b>	<b>153</b>
5.1 Chapter Objectives	153
5.2 Computer Resources Employed	155
5.3 The MEHRAN Model	166
5.4 Manufacturing Information	187
5.5 Interface Software	196
5.6 Experience of Initial Development Work	208
<b>6. AN INDUSTRIAL TEST CASE</b>	<b>220</b>
6.1 Objectives	220
6.2 The Industrial Application of MEHRAN	221
6.3 Redesigning the Bromborough Factory	224
6.4 Building up the MEHRAN Graphical Database	229
6.5 CADAM Geometry Interface	247
6.6 Learning Experience - Time	248

	<b>Page</b>
6.7 Learning Experience - Storage	256
6.8 Learning Experience - Geometry Interface	261
6.9 Summary Learning Experience	263
6.10 Manufacturing Data	264
6.11 The Industrial Designs	264
<b>7. FUTURE WORK</b>	<b>226</b>
7.1 Chapter Objectives	266
7.2 Computer System Changes	266
7.3 MEHRAN Model and CAD-CAFL Philosophy	269
7.4 Exploitation of MEHRAN Software	276
7.5 Miscellaneous Developments	277
7.6 Summary of Future Work	278
<b>8. CONCLUSIONS</b>	<b>279</b>
8.1 Chapter Objectives	279
8.2 General Conclusions	279
8.3 International Survey	281
8.4 CAD-CAFL Model	282
8.5 The MEHRAN Model	284
8.6 Summary Conclusions	287
<b>APPENDICES</b>	
A. MEHRAN Facilities Database	289
B. The MEHRAN Software Listing	316
C. The Users Manual	344
D. Test Case Results	361
E. The International Survey	384
<b>REFERENCES</b>	<b>440</b>
<b>BIBLIOGRAPHY</b>	<b>444</b>

## LIST OF FIGURES

Figure	Title	Page
1.1	Facilities Life Cycle Concepts	2
1.2	Evolution of Layout Design with Computers	10
2.1	Design Process, CAD and Designer	24
2.2	Layout Design Process and CAFL	30
2.3	Steps in Design and CAFL Design	32
2.4	CAD-CAFL Design Process	32
2.5	Design Process Extended to Facilities Life Cycle	33
3.1	Answers Received by Section	63
3.2	Software Development Time	67
3.3	Research Team Size	67
3.4	Commercial Support Software	74
3.5	Tasks Undertaken	74
3.6	Data Verification	77
3.7	Layout Area Representation	77
3.8	Facilities Representation	80
3.9	Software Features	80
3.10	Layout Design Procedures	83
3.11A	Improvement Programs	83
3.11B	Improvement Programs continuation	85
3.11C	Improvement Programs continuation	85
3.12A	Construction Programs	88
3.12B	Construction Programs continuation	88
3.13	Layout Evaluation	92
3.14A	Closeness Desirability Models	92
3.14B	Closeness Desirability Models continuation	95
3.15A	Materials Movement Models	95

<b>Figure</b>	<b>Title</b>	<b>Page</b>
3.15B	Materials Movement Models continuation	101
3.16	Software Usability Rating	101
3.17A	Input and Execution Features	104
3.17B	Design and Evaluation Features	104
3.17C	Output and Graphics Features	107
4.1	Attributes of an Ideal CAFL Package	135
4.2	A Conceptual Framework for CAFL	140
5.1	Hardware Configuration for MEHRAN	156
5.2	CAD Data Base Organisation	160
5.3	MEHRAN Model within Conceptual Framework	167
5.4	3-D Solid Model Image of SOLON-1 Machining Centre	171
5.5	Four View Screen Image of SOLON-1 Machining Centre	172
5.6	Graphical Data Transfer from CATIA to CADAM	174
5.7	Five Levels of Facility Representation in CADAM	176
5.8	MEHRAN Facilities Database Record (Level 3)	179
5.9	Layout Area Organisation in MEHRAN Database	179
5.10	Illustrated Example of Layout Area Composition	181
5.11	Composing Master Overlay Image	185
5.12	Prototype Test Case Composite Layout	186
5.13	Relational File Structure for the MEHRAN CAFL-Database	189
5.14	Overall MEHRAN Software Design Activity	205
5.15	Structured Menu Options in MEHRAN	206



<b>Figure</b>	<b>Title</b>	<b>Page</b>
5.16	Example of Facility Location Data Extracted by ATTRES Program	207
5.17	Comparative Storage Requirements of 10 Prototype Facilities	213
6.1	Lucas Automotives, Bromborough Site Plan -1985	222
6.2	An Example of A Disc Brake Manufactured at the Site	225
6.3A	Proposed Layout Plan Prepared at the Site	230
6.3B	Lucas Girling Proposed Layout 1987	231
6.4	Spray Booth	234
6.5	Photograph of the Matrix Churchill V50 Machining Centre	236
6.6	MEHRAN Solid Model Isometric Image of The Matrix Churchill V50 Machining Centre	237
6.7	Four View MEHRAN Screen Image of the Matrix Churchill V50 Machining Centre	238
6.8	Site Drawing without Partitions	240
6.9	Stripped out Manufacturing Area and Partitions	241
6.10	Test Case Version of Original Layout	242
6.11	Disc Module Installed	243
6.12	Components Module Installed	245
6.13	Caliper Module Installed	246
6.14	Comparison of Times	250
6.15	CADAM and CATIA Storage Comparison	251
6.16	MEHRAN Facility and "Transferred Facility" Storage Comparison	252

## LIST OF TABLES

Table	Title	Page
1.1	Multiple Criteria in Layout Planning.	7
1.2	Factors Illustrating Complexity and Diversity in Layout Problems.	8
2.1	Identified Published Paper Reviews	38
2.2	Identified Theses Reviews	39
2.3	Identified Book Reviews	40
3.1	Previous Surveys Perspective	54
3.2	CAFL Software Receiving Professional Support	69
3.3	Programs Identified in Section D	100
3.4	Reassessment of CAFL Software Effectiveness	105
3.5	User Listed Shortcomings and Additional Features	108
3.6	Comparison of Current, Moore and Hales Surveys	115
3.7	Comparison of Current and Muther and Phillips Surveys	115
3.8	Comparison of Program Types	116
3.9	Comparison of Program Languages	117
3.10	Comparison of Output Devices	118
3.11	Selection of Problems Encountered by CAFL Users	119
3.12	Popularity of First Generation CAFL Programs	119
3.13	Comparison of Usefulness of CAFL Software	120
5.1	Installation Computing Boundaries	167
5.2	Ten Facilities Used in Example Test Case	170
5.3	Products Data Files	190
5.4	Prodseqs View File	191
5.5	Machine Data File	193
5.6	Layout Area Information	194

<b>Table</b>	<b>Title</b>	<b>Page</b>
5.7	Material Handling Equipment Data File	195
5.8	Overall Project Information File	195
5.9	CADMACGM Enhancement in CADAM Release 20	216
6.1	Lucas Automotives Test Case Facilities	233
6.2	Estimated Design Times	256
6.3	Average Storage of Facilities	257
6.4	Storage Comparison of CATIA Solid Model Primitives	258

## CHAPTER 1

### INTRODUCTION

## CHAPTER 1

### INTRODUCTION

#### 1.1 INTRODUCTION

Since the introduction of early computer packages for facilities planning in the 1960's, the subject of Computer Aided Facilities Layout (to be referred to as CAFL) has always been dependent upon the quality of computer hardware and software available. The early attempts at CAFL were based on low memory batch oriented processes, whose output frequently was produced in simple line printer form as typified by the programs CRAFT [6] and CORELAP [32]. The second generation of CAFL packages made use of greater processing power and dealt with graphics or spatial layout through the use of purpose written high level graphics routines, typified by the GINO (Graphical Input Output) routines. The present state of the art, however, is based on very powerful mainframe and micro computers supported by well established professional software, particularly in the fields of Computer Aided Design (to be referred to as CAD), Data Base Management System (to be referred to as DBMS) and mathematical analysis.

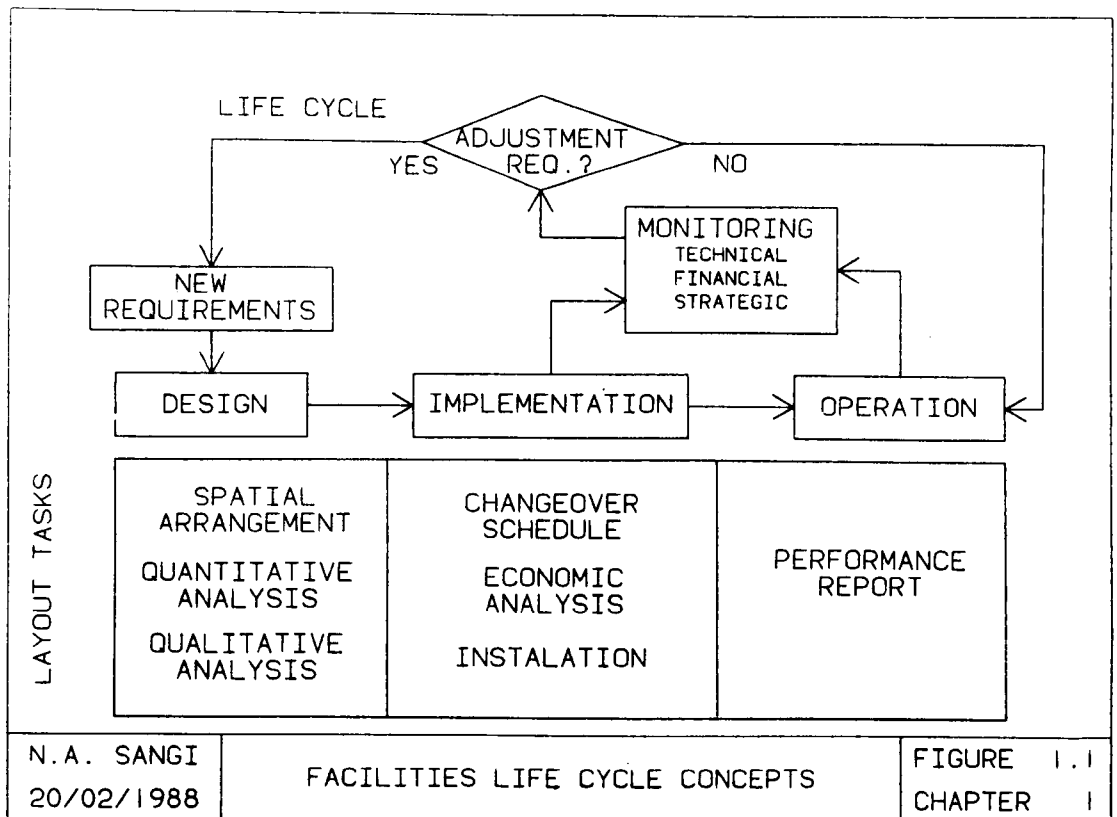
This has given the opportunity for a new generation of CAFL research along one of two streams (mainframe and micro computer) in which the role of advanced CAD in facilities planning can be extended. This thesis examines in particular how high level mainframe CAD systems can meet the needs of facility planners.

Before going on to examine and develop the subject of CAD-CAFL it is first appropriate to examine the components and strategies behind the facilities planning process itself. This chapter makes

this examination and prepares the ground for the review of the state of art in CAFL.

## 1.2 LIFE CYCLE CONCEPTS IN FACILITIES PLANNING

The facilities life cycle can be divided in to three phases; design, implementation and operation as illustrated in Figure 1.1. Computer applications assist the designer at all stages of planning and have been used to model all three stages of the facility life cycle. The following paragraphs introduce facilities planning tasks at the three stages and detailed discussion of each level is furnished in Chapter 2. The scope of the discussion is limited to manufacturing facilities only.



### **1.2.1 Design**

The design phase starts with defining the objectives of the facilities and focuses on spatial arrangement of layout objects, quantitative evaluation and qualitative merits of the arrangement. The design process is repeated in an iterative manner to achieve a satisfactory design plan along with its analytical merits. After management approval the documented design is released for implementation.

### **1.2.2 Implementation**

Implementation follows design and the manufacturing designer's focus is shifted towards determining the most economical way to carry out the installation. This involves; generation of changeover schedule, economic analysis and actual installation of equipment. As a consequence of the implementation exercise, the designer may review details of the design and adjust if necessary.

### **1.2.3 Operation**

During this phase, the performance of the layout is monitored. Two types of observations are applied; firstly short-term auditing of factory performance against the originally set (i.e. design) objectives, secondly, longer term observations of plant performance against changing requirements. These observations can detect ineffective use of facilities or technical failures and therefore can trigger a new design review. Thus the cycle of design, implementation and operation will be repeated in the light of new facility requirements.

Since the prime considerations at each phase are different, therefore, the CAFL software development can be divided into three stages :

1. Design
2. Implementation
3. Operation

This research concentrates on a CAD based layout design model, with implementation and operation studies being reserved for future research. The main objectives will be to develop a modular software system which would initially satisfy the needs of design and allow sufficient flexibility to enhance and extend it to accommodate the two remaining phases (implementation and operation).

### **1.3 THE DESIGN SOLUTION APPROACH**

Conceptually CAFL design is a specialised form of engineering design and therefore a solution approach identical to those applied in classic engineering design can be applied.

#### **1.3.1 Engineering Design**

An important consideration in creating a new design system is to identify the stages in the design process being investigated. An early definition of the design process was given by Shigley [50], who defined a six stage design process. With the introduction of computers and the development of early CAD software, Groover and Zimmers [25] mapped use of CAD packages within the design process. Later, Majchrzak, et al., [35] defined the role of the designer in CAD and design process (Chapter 2). The trio of designer, computer and CAD software has been referred to as true "CAD system" by Goetsch [23].



The relevance of CAD and the process of design will be expanded in Chapter 2 as the beginning of a new CAD-CAFL approach.

### **1.3.2 CAFL Design**

Four leading authors on facilities planning (Francis and White [22], Tompkins and Moore [53] and Tompkins and White [55]) have also adapted the general design process and defined the facilities layout design task as identical to engineering design. Tompkins and Moore [53] illustrate two steps of the layout design process which were automated in early CAFL software. A review of these three works has been included as a bridge between engineering design and CAFL.

### **1.3.3 Components of Facilities Planning**

The historical development of facilities planning shows an interrelation between "images" and "analyses". The images provide "visualisation" whereas analyses determine the merits of any particular arrangement of the images (proposal). The early designers made use of architectural plans, two dimensional templates and three dimensional iconic models to achieve "visualisation". This visualisation has always been considered an important part of the design process. The facilities designer will be required to discuss requirements and expectations with various functional groups (e.g. production, maintenance, safety, quality control) for each layout proposal. All of these functional groups need to visualise the proposed facilities plan from their own perspective. Without visualisation coordinated analysis would be very difficult. Consequently, graphics will continue to provide primary support to layout planning tasks.

However, "visualisation" on its own is usually not sufficient for total evaluation. There are additional needs for quantitative and qualitative analysis to enable robust design solutions to be developed. In traditional pre-computer facilities planning, the designers have combined "images", "flow" and "judgement" with a generalised view that "flow" would be the appropriate "quantitative" basis for location of facilities. These three basic elements (images, flow and judgement) of the early layout design process are identical to "computer graphics", "quantitative analysis" and "qualitative analysis" in Computer Aided Facilities Layout (CAFL). Therefore, three natural elements of CAFL facilities planning are established.

#### **1.3.4 Objectives of Facilities Layout**

Further evidence of these three natural elements (spatial, quantitative and qualitative) can be obtained from the objectives of facilities planning reported by Francis and White [22], Apple [5] and Tompkins and White [55], adopted in Table 1.1, which illustrates the influences of the three elements on objectives.

From the Table 1.1 it can be seen that objectives can be classified into the three categories; spatial, quantitative and qualitative. It may be argued that in a particular application one of these objectives might be predominant, nevertheless, the scope of the activities in most projects will fall within all these categories.

The combination of spatial, quantitative and qualitative objectives make facilities planning an ill structured problem. In the majority of case studies, these objectives will compete or conflict with each other.

### 1.3.5 Problem Complexity and Diversity

Further complexity of the facilities planning problem can be judged from the diversity of layout situations which may be sufficiently unique to qualify for specific synthesis and evaluation approach. This may be illustrated by an imaginary case study which may allow any combination of the factors listed in Table 1.2.

The analytical approach will vary and the work content will be different depending upon the particular case study situation being investigated. Observations reveal, the graphics element to be common in all of these diverse case studies, and only the degree and content of analysis to differ. Therefore the common nature of the use of graphical representation has been identified.

**Table 1.1 Multiple Criteria in Layout Planning.**

<b>Objectives*</b>	<b>Influences</b>	<b>Criteria</b>
Provide means to achieve organisational objectives	Qualitative Quantitative Spatial	System performance Life cycle costing Space utilisation
Minimise handling cost	Quantitative Spatial	Flow, Distance and cost minimisation
Provide maximum flexibility	Qualitative Spatial	Space ratios Sensitivity analysis
Minimise capital cost	Qualitative Quantitative Spatial	Productivity Utilisation ratios Space utilisation
Efficient utilisation of space, manpower and equipment	Qualitative Quantitative	Productivity Utilisation ratios
Provisions for employee safety, job satisfaction and comfort	Qualitative Spatial	Safety standards Employee performance Employee moral

\* Extracted from Francis and White [22], Tompkins and White [55] and Apple [5].

### 1.3.6 Graphics in CAFL

The evolution of CAFL software can be divided into three generations; the early CAFL software (first), purpose built bespoke software (second) and application of proprietary software (third).

#### First Generation CAFL Software

First evidence of CAFL software appeared in 1963, when CRAFT [6], the first improvement program, developed during the early 60's was published. Incidentally, during the same period, at the University of Liverpool, the first construction program, published in 1964, was being developed by Whitehead and Eldars [56]. Following these two programs, many other CAFL programs were developed (e.g. CORELAP [32], COFAD [54], PLANET [4] and ALDEP [49]).

Two interesting features, common in all first generation CAFL programs are; the design process is procedural (batch background)

**Table 1.2 Factors Illustrating Complexity and Diversity in Layouts Problems**

<b>Factor</b>	<b>Examples</b>
1. Application area	Factory, Warehouse, Office, Hospital
2. Problem in focus	Facilities, Materials Handling System, Services/Utilities
3. Problem size	Major change, minor adjustment
4. Stage of analysis	Design, Implementation, Operation
5. Level of detail	Location: Factory, Buildings, Departments Layout: Departments, Cells, Workstation
6. State of problem	New construction, relayout
7. Criteria	Spatial, quantitative, qualitative
8. Changeover form	At once, gradual

rather than creative (interactive) and programs do not have graphics. There is little communication or flexibility in programs and the software is in control of the design process. The quality of resultant layouts is generally criticised (e.g. [22] and [8]).

### **Second Generation CAFL Software**

Since the application of graphics has been identified as an essential requirement for good CAFL, later CAFL applications were enhanced by use of purpose written graphics routines (e.g. GINO) and the interactive layout design process was initiated. However, these CAFL programs did not interest industrial designers because of their specialist and unsupported nature. This lack of success in the field is expanded in Chapter 3.

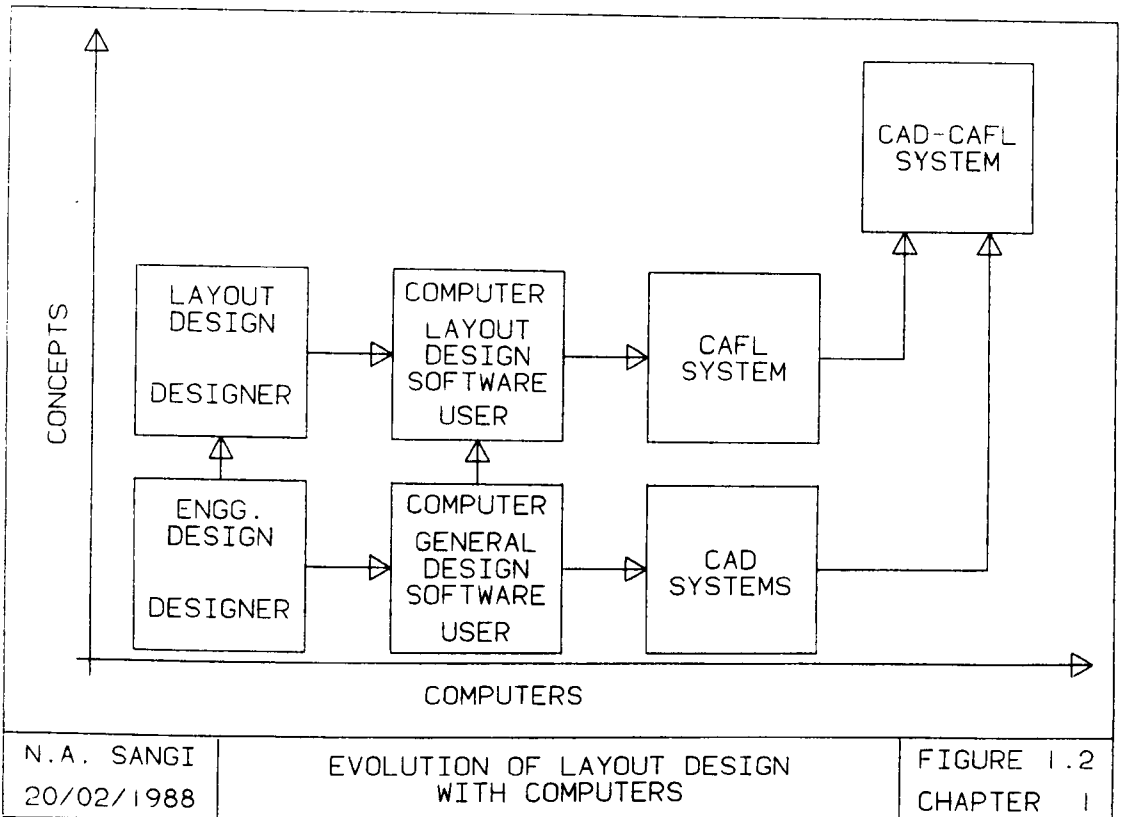
### **Third Generation CAFL Software**

Subsequent to the failure of first and second generation CAFL software, the CAFL designer interest shifted to commercial CAD software applications. This software offered reliability and support whilst being comparatively cheaper to buy than in-house applications development. The survey by Driscoll and Sangi [13] identified four types of commercial software, namely; Spreadsheet, DBMS, Simulation and CAD were being applied to CAFL.

From these four types of commercial packages, only CAD offers full graphics capability in a form most suitable to the CAFL design process. Since CAFL is the conceptual application of engineering design, and CAD has been provided to enhance engineering design, a new merger of both CAD and CAFL is proposed. This merged application of CAFL design concepts and Computer Aided Design (CAD) technology will enhance CAFL design and provide an opportunity to develop a new

generation of CAD-CAFL software. Figure 1.2 illustrates this point.

The details of the integrated CAD-CAFL philosophy will be developed in chapter 4. The remainder of this chapter will review CAD and its potential uses for CAFL and introduce basic components of a CAD-CAFL system.



## 1.4 CAD AND CAFL

### 1.4.1 Level of CAD Use

The use of Computer Aided Design (CAD) has grown to an estimated 100,000 plus CAD workstations in 1985. World market sales gauged at over US\$ 3.0 billion and further estimates suggest that, by the year 2010, CAD would provide a US\$ 10 billion world market with over 2 million workstations in operation [35]. A survey of CAD/CAM and CAE systems [21] reports that mechanical CAD/CAM systems account for 53%, electronic 22.5%, Architectural and Engineering Construction (A-E-C)

17.7%, mapping 5.2% and others 1.6%. The same survey reports that in 1982, approximately 12,000 processors (CPU) were installed worldwide by CAD vendors operating from the USA alone. The 40% growth in the total CAD market was estimated with 55% in mechanical and 58% in A-E-C CAD market.

CADAM, a proprietary system from CADAM, INC. and marketed by IBM was rated the most popular CAD package with over 13,000 active workstations worldwide.

The PC based CAD software is anticipated to grow fast and major vendors such as Computervision and IBM have entered the PC CAD market which was estimated to be worth US\$ 40 million in 1984. In PC CAD, AutoCAD leads with over 10,000 operational licences, and is expecting to overtake CADAM's base of 13,000 operational workstations<sup>1</sup>.

In the light of growing penetration of CAD in industry, particularly in mechanical and A-E-C applications, a CAD based approach to CAFL would make a suitable contribution.

#### **1.4.2 Visualisation in CAD**

Full drafting features in an interactive mode, can assist the designer to construct and visualise the problem, identify bottlenecks and avoid practical problems of space allocation.

Various modes of CAD use in CAFL visualisation were conceptualised in an early paper presented in 1986 [12]. This work examined the use of 2-D drafting, solid modelling and kinematics and commented that economical and/or technical constraints make use of

---

<sup>1</sup> AutoCAD sales was quoted "on average 1500 licences per month" which gives estimate 18000 licences per year. CADAM sales are not known. Since the information was quoted in 1984, therefore most likely AutoCAD has already become leader in CAD software.

kinematics and solid models infeasible at whole factory visualisation level.

Satisfactory visualisation of a layout can be achieved by using 2-D CAD which provides both a useful and cheaper method of "assembling" sets of facilities on the shop floor plan. This composite facilities plan view of the factory floor may be then manipulated using powerful CAD features to generate layout alternates. For third generation software this is being considered as the minimum representation required by a CAFL designer.

#### **1.4.3 Analyses in CAD**

Generally, CAFL programs use quantitative means to achieve solutions. The two most widely used models are; Total Material Handling Cost (TMHC) and Closeness Desirability (CD). Both models use location data with costs and/or relationships to evaluate layout feasibility. Therefore, location data, common to both approaches can be obtained from a CAD drawing and used in either of the models for layout analysis or evaluation.

Analyses in CAD can be performed at two levels; within CAD and outside CAD. In first method, area calculations and mass properties analysis can be performed within the majority of CAD systems. The second method is to allow a purpose written application program to access a CAD database, extracting data and performing analysis outside CAD. An example of interfacing to external software is the frequently produced Bill Of Material (BOM) processing. This second method of analysis (referred to as geometry interface), offers the main potential for development of a CAD based CAFL analysis package.

Use of specially written geometry interface programs for extracting the locations (coordinates) of set of facilities for use in analytical programs was identified in 1986 [12].



#### **1.4.4 CAD Database**

CAD systems store graphical data in a CAD database. This allows the user to organise and access data for different visualisations and interface mechanisms in a structured manner.

Efforts have been made, to represent manufacturing areas, by researchers (e.g. Kalviatis [31], Grech [24] Malde and Bafna [36] and Hanley [27]). However these efforts have been limited to representation only. Better attempts were made by academics e.g. Driscoll and Sangi [12], [48] and McGetrick and Hitchings [37]. These approaches, discussed later in the thesis, have progressed along the line of visualisation together with analysis. These approaches, however, have not yet fully examined the CAD potential for CAFL.

The exploitation of the full CAD potential to CAFL has already been identified as an area for future work. This work would involve developing procedures to solve CAFL problems within CAD, key tasks being definition and organisation of graphics data, defining mechanisms to carry out analysis, and exploration of the limitations and advantages of using a CAD-CAFL approach.

#### **1.5 DBMS AND CAFL**

The diverse nature of facility layout problems combined with the high levels of data needed to support quantitative and qualitative analysis lead naturally to a need for structured data management. This data will practically be extracted from large corporate database increasing the possibility of database involvement. The need to combine and utilise data from graphics and manufacturing sources is identified as part of CAD-CAFL model. Use of powerful data handling

facilities for both quantitative and qualitative data should therefore be employed in parallel to CAD software.

The collection and preparation of data in a suitable format is one of the reasons which significantly discouraged designers to use CAFL programs. An ideal situation would be to use CAD to provide graphics, DBMS to carry out data handling, CAFL analytical programs to perform analyses and a set of user interface programs to integrate the design process.

#### **1.6 THE CAD-CAFL SYSTEM**

There are four main functional components in a CAD based CAFL system; the computer (hardware plus operating system), CAD package, CAFL analysis software and the designer. Each one has a role to play in the evaluation of any CAFL case study. The designer uses a CAD package to prepare and submit the case study to the computer. Subsequently the designer utilises the CAD package and CAFL software to control computer operations specific to CAFL design and evaluation. The effectiveness of the CAD-CAFL system depends upon combined activities (and capabilities) of the two above functional components.

In theory, the best layout solution can be achieved if the combined activity of the designer, computer, CAD package and CAFL software can be put to the best performance. Expanding on this, the designer's knowledge of each case study and his ability to utilise the software set for modelling and evaluation; the ability of CAD and CAFL software to accurately model and evaluate the case study; the capability of computer to perform all the tasks requested by the designer, all have an influence on the layout solution. Thus CAFL

development effort should take into consideration, the advantages and limitations of the four functional components of the CAFL system.

### **The Computer**

Computer considerations, noted as important for CAD-CAFL software development are :

1. The graphics capability.
2. Processing power.
3. Operating system support to peripherals and packages.

Graphics capability involves; the peripherals to display, manipulate and store graphical images. Processing power concerns efficient utilisation of computer resources to perform necessary data (graphical and manufacturing) handling, design and evaluation tasks.

Operating systems play an integrated function to enable the designer to best utilise the hardware, CAD package and CAFL software. Peripherals are driven by the operating system therefore operating system capability to drive graphics peripherals becomes important.

### **The CAFL Software and CAD Package**

The uniqueness of different case studies in CAFL requires a well coordinated interactive working and graphics supported design process. Evaluation in CAFL consists of; quantitative, qualitative and spatial means of representing and analysing those case studies. A CAD package can be employed in parallel to CAFL analysis software to effectively support and enhance spatial representation and analysis within CAD-CAFL system.

CAD packages provide design, drafting, and data storage mechanisms primarily aimed at the general design process. Effort is required to identify CAD potential in CAFL and to define mechanisms and structures to organise and store graphical data in a form suitable to CAFL designers. The geometry interface part of CAD system was identified earlier as having basic potential for CAD-CAFL analysis software development.

### **The Designer**

When developing the CAD-CAFL system, consideration should be given to the knowledge level of the ultimate user (designer) in four areas; the use of computer, CAD package, CAFL software and the case study itself. High levels of knowledge within these areas will enable the designer to carry out his responsibilities effectively.

Computer (hardware and operating system) and CAD package are two areas generally developed and supported by manufacturers. The software developer therefore should concentrate on the two remaining main areas and utilise computer and CAD package resources effectively to support the design process. Three important tasks are :

1. To study in greater depth the processes and procedures involved in CAFL case studies.
2. To identify computer and CAD features useful in CAFL software development.
3. To identify designer activities for effective CAD-CAFL and designer interface.

This has an advantage that the software developer can maximise the functional capabilities of computer, CAD package and CAFL

software to the best benefit of the designer and precise modelling of the case studies.

### **1.7 THE RESEARCH PROPOSAL**

The proposal in this thesis consists of research work in two parts:

- a) New thorough international review of CAFL software to establish the extent of new approaches to CAFL.
- b) The start of a new CAD based CAFL software model.

The design stage of the facilities life cycle is selected as main area of research in CAD-CAFL model development. The research effort will concentrate on CAD-CAFL design model development embracing the following points:

1. An investigation of CAD for potential applications in CAFL.
2. Specifying the framework for CAD-CAFL package development.
3. Developing an initial CAD-CAFL model to meet the framework specifications.
4. Test and refine the model against acceptable test cases.
5. Specify the next generation of useful developments in CAD-CAFL modelling.

### **1.8 CHAPTER STYLE**

Within this thesis considerable work will be presented on an exclusive international review of CAFL software and application of a CAD-CAFL model. As a means of structuring the presentation of this

work each chapter will begin with the specific objectives of the chapter in question.

**CHAPTER 2**

**LITERATURE REVIEW**

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 CHAPTER OBJECTIVES

The computer application presented in this thesis is a combination of Computer Aided Design (CAD) and Computer Aided Facilities Layout (CAFL) in a new approach to facilities planning. In preparing the ground for development of the new CAD-CAFL model, this chapter will cover the relationship between general design and CAFL and will review leading texts relevant to CAFL. A major international survey of CAFL software is given in Chapter 3 as the exclusive review of the state of the art in CAFL. Consequently the objectives of this chapter are :

1. To introduce the components of the design process
2. To relate these components of design to Computer Aided Facilities Layout.
3. To identify previous academic reviews of CAFL procedures.
4. To update these reviews to cover current publications.
5. To prepare for the extensive international survey of CAFL software.

#### 2.2 DESIGN METHODOLOGIES

The works of four authors, with reputations in engineering design, have been selected as a means of identifying stages in the design process. The authors have been selected to cover the time span from pre CAD (Shigley, 1963-1977), through CAD drafting and CAD/CAM (Groover and Zimmers, 1984) and up to present (Majchrzak,



et al. 1987). The progressive stages of design identified by each author will be introduced and will be followed by a review of their importance in CAFL.

### **2.2.1 Shigley, J.E., 1977 [50]**

Six identifiable steps in engineering design were introduced by Shigley (Figure 2.1a).

#### **A. Recognition of Need**

Quoting from Shigley,

"..... design begins when an engineer recognizes a need and decides to do something about it." (p. 4)

This recognition of the design need can result from; identification of the existence of a problem, identification that requirements of the original design have changed or a perception of a new idea for an innovative design. The recognition of need leads to a statement of project "aims".

#### **B. Definition of Problem**

The second step is to define the scope of the design process, i.e bounds and constraints, desired characteristics of the final design and specifications of possible design inputs, solution methods and outputs.

The definition of the design task through a project specifications will lead to a clear statement of the objectives.

Satisfying these objectives partially or wholly, should fulfil the aims of the project.

### **C. Synthesis**

### **D. Analysis and Optimisation**

Synthesis refers to the actual design generation process. Three levels of design generation exist. In the first level all the sources of information are known and problem solving methods are explicitly defined. Under these circumstances, the designer decisions are simple and routine.

The second level of problem exists where sources of information can be identified in advance but where there is an open choice on the method of generating solutions. This often leads to reliable designs but not necessarily optimal designs.

The third level involves limited information sources and no concept in advance of the solution approach. This results in an almost pure research task.

The design of factory layout is in the second level, where many sources of information are known but solution strategies are not specific.

Progressive analysis and improvement is required in order to satisfy design objectives and optimise the design solution. Quoting again from Shigley,

".... synthesis cannot take place without both analysis and optimisation ...." (p. 6)

Therefore, an iterative "design, analyse and improve to optimise" loop is initiated until "optimum design" is achieved.

The analysis is performed in two stages. Firstly, to check whether the design meets the specifications, if not, either synthesis is performed again to generate a new proposal, or present design is improved and analysed again. The second stage of analysis is performed to optimise the design. For this reason, a study of design alternatives is performed to identify an optimum design.

#### **E. Evaluation**

An important step in the design process, as identified by Shigley,

"Evaluation is the final proof of a successful design, which usually involves the testing of a prototype in the laboratory."

(p. 7)

This is where a prototype is physically constructed and tested to confirm that the design; meets specifications, is an optimum design and can be economically constructed and used.

This comment by Shigley clearly identifies the pre-computer era. The prohibitive cost of prototype building has been replaced by computerised design analysis and simulation procedures of which CAFL is an excellent example.

#### **F. Presentation**

Four comments quoted from the author describe the role of presentation and its importance in the success of the design process.

" Communicating the design to others is the final, vital step in design process." (p. 7)

"Presentation is a selling job." (p. 7)

"Basically, there are only three means of communication available to us. These are the written, the oral and the graphical forms." (p. 7)

"The written or spoken word often requires study for comprehension, but pictures are readily understood and should be used freely." (p. 7)

The author emphasises the need for proper communication of the design and identifies graphical means as a powerful tool for explaining the design.

One of the considerable bonuses of CAD and hence CAFL is its value in presenting work in a graphical form.

This design process, does not end with design being developed. Manufacturing and marketing processes which follow the prototype design, could influence, the prototype and could reinitiate the design process. Therefore design, followed by implementation (manufacturing) and operation (product performance with customer) can be seen as three phases of product's life cycle.

### **2.2.2 Groover, M.P. and Zimmers, E.W. (Jr.), 1984 [25]**

Groover and Zimmers [25] is one of the most widely used and valued books on CAD/CAM. In their work, the authors have taken up work of Shigley previously described, and have identified the role that CAD can play in assisting the engineering designer (Figure 2.1b).

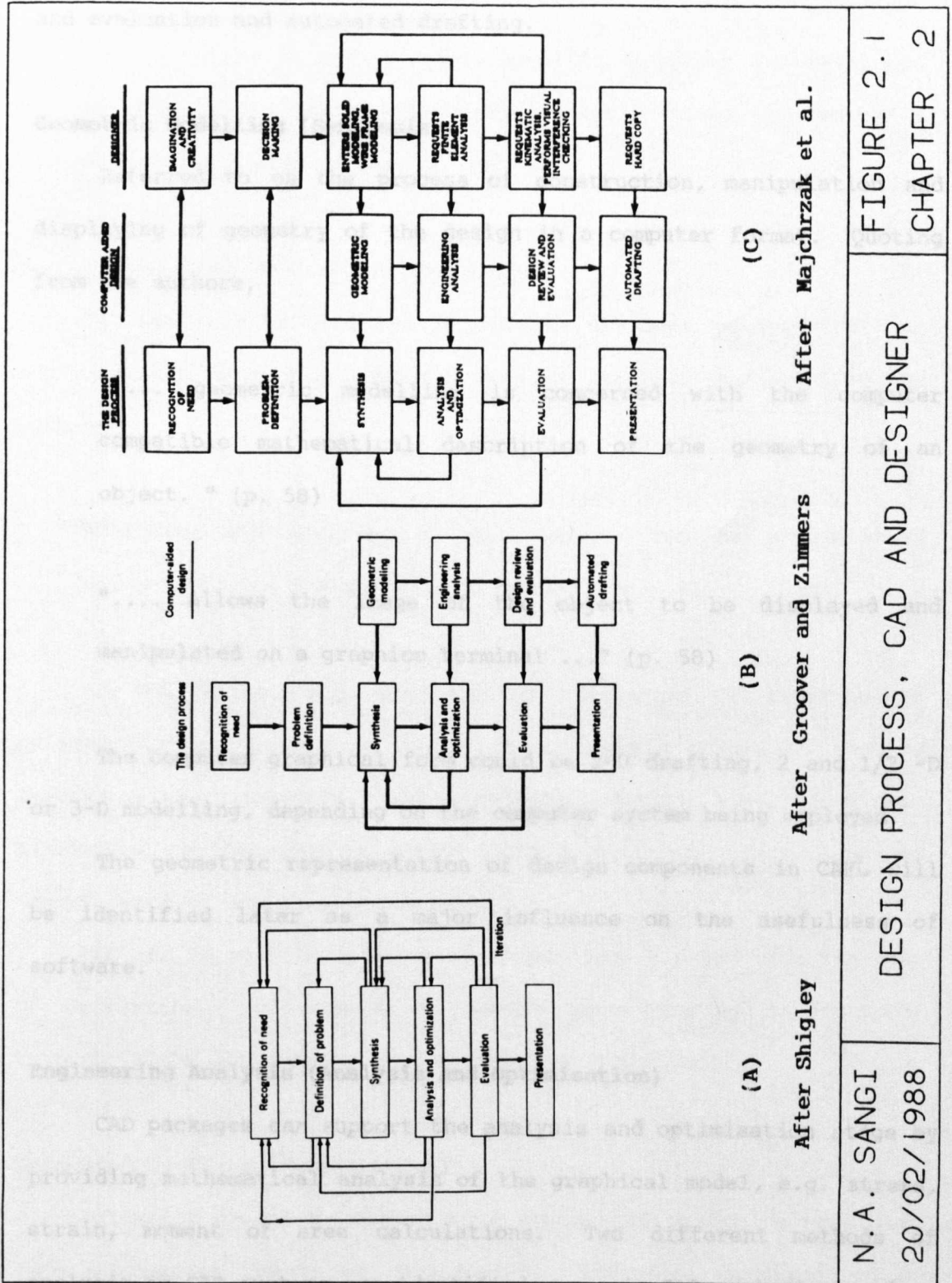


FIGURE 2.1  
CHAPTER 2

DESIGN PROCESS, CAD AND DESIGNER

N.A. SANGI  
20/02/1988

Four areas of CAD where computers can help the designer are identified; geometric modelling, engineering analysis, design review and evaluation and automated drafting.

### **Geometric Modelling (Synthesis)**

Referred to as the process of construction, manipulation and displaying of geometry of the design in a computer format. Quoting from the authors,

".... geometric modelling is concerned with the computer compatible mathematical description of the geometry of an object. " (p. 58)

".... allows the image of the object to be displayed and manipulated on a graphics terminal ..." (p. 58)

The computer graphical form could be 2-D drafting, 2 and 1/2 -D or 3-D modelling, depending on the computer system being employed.

The geometric representation of design components in CAFL will be identified later as a major influence on the usefulness of software.

### **Engineering Analysis (Analysis and Optimisation)**

CAD packages can support the analysis and optimisation stage by providing mathematical analysis of the graphical model, e.g. stress, strain, moment of area calculations. Two different methods of analysis in CAD systems are identified; generic CAD analysis routines and specialised analysis programs. Generic analysis is found in the standard analysis functions within the CAD package e.g. area

calculations and mass properties. These however are not sufficient. Quoting from the authors,

"It is often necessary that specific programs be developed internally by the engineering analysis group to solve a particular design problem". (p. 61)

#### **Design Review and Evaluation (Evaluation)**

CAD can also be employed to aid the designer in modifications and manipulation of the graphical form of design. Quoting from the authors,

"Checking the accuracy of the designs can be accomplished conveniently on the graphics terminal." (p. 63)

The CAD features e.g. dimensioning, tolerances and layering can be employed in conjunction to other analysis routines to confirm manufacturing, assembly and evaluate design specifications. Kinematics can be used to study dynamic behaviour of designs and interference of assembly mechanisms.

CAD can be seen as a means of speeding up and reducing the cost of evaluation. CAD can also provide manufacturing instructions through CAD/CAM for subsequent prototype construction.

#### **Automated Drafting (Presentation)**

Automated drafting relates to a process of producing hard copy from a computer models of the design. Therefore construction of

detailed drawing can add presentation value to the management and communication to the production personnel.

The extent to which computers play a role in design can be related to the three types of design problems described earlier.

Where known data and known solution procedures exist high automation, even total automation is possible. At the other extreme the CAD system becomes a medium for holding and manipulating information and the designer dominates the design process.

One of the most significant question in CAFL is the relative roles played by computer and designer. This point will be extensively examined in the review of the software.

As can be seen that, entire design process has not been computerised. The difficulty in computerisation of all stages, resulted from the nature of the design problems just described. In order to increase CAD coverage of the design processes, modern general purpose CAD systems are structured in several sets of small routines to perform "unit tasks" ( small steps common in many design procedures).

This "unit task" approach in CAD software, therefore allowed designer to combine creativity and procedure by way of making a choice of applying multiple unit tasks at various stages of design. Subsequent introduction of this approach, required that the CAD designer will need to develop expertise in two areas; design process and use of CAD. Many modern CAD systems are developed and extended to improve dialogue between computer and the designer and allow for designer freedom in design process.



### **2.2.3 Majchrzak, A., et al., 1987 [35]**

The role that a designer plays in using a modern CAD systems has been explained by the authors, who expanded on the works of Shigley, Groover and Zimmers with emphasis on the designer. While looking at human aspects of CAD use, the authors describe the specific actions designers perform in using a CAD system, as illustrated in Figure 2.1c.

With the first two stages of the design process (recognition and definition) being dependent on special designer attributes (e.g. imagination, sensitivity and experience) and case study attributes (e.g. scope of the problem) CAD is of limited use. Assistance is available to the designer in the remaining four stages, in the form of either interactive combined designer and computer activity or "batch type" fixed procedures initiated by designer selection.

One important aspect of CAD is the construction of the graphical representation which is then used to communicate between computer and designer at all computerised stages of the design process. Thus the integral value of graphical representation in computer aided design has been identified.

### **2.3 RELATING CAD TO CAFL DESIGN**

Having identified the six stages in the design process and their implementation in CAD, the work of four acknowledged authors in layout design is examined to identify the relevance of design procedures within layout design and the stages of layout design that have been computerised. The selected work consists of the original text of Francis and White [22], a more elaborate recent text of Tompkins and White [55] and a monograph publication of Tompkins and Moore [53]. The material from first two text books is used to

examine the relationship of design and layout design, whilst the third publication is used to identify the stages of layout design where computers had been applied.

**Francis, R.L. and White, J.A., 1974 [22]**

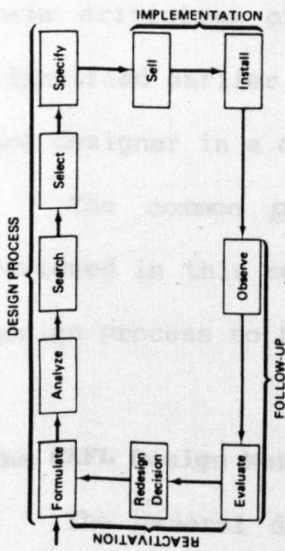
Francis and White [22], classified layout design as an special engineering design problem, with an aim to seek an optimum arrangement of facilities on factory floor. The synergy between the six stage design process and the CAFL approach recommended by Francis and White is illustrated in Figure 2.2a, drawn from the work of the two authors.

A comparison between Francis and White and Shigley reveals a high level of similarity in approach. For example, "formulate" is an equivalent of "definition", "analyze" and "search" are equivalent to steps, "analysis and improvement" and "evaluation", and finally "specify" and "sell" are equivalents to "presentation" in Shigley's design process.

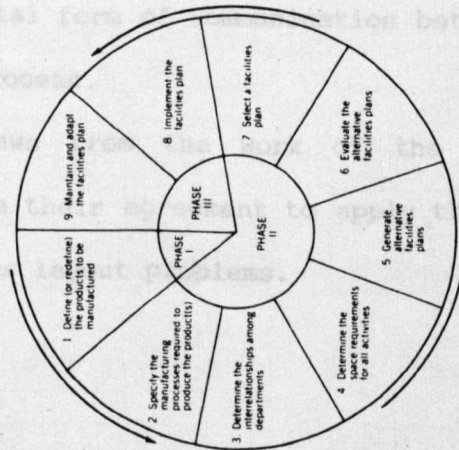
Francis and White then introduce a two part (implementation and operation) continuous appraisal of layout life cycles. The theme of life cycle appraisal of facility layouts is popular with many CAFL researchers (e.g. Hitchings [29], Driscoll [11], Abdul-Magid [1], Lilley [34], Rosenblatt [47] and Afentakis [2]).

**Tompkins, J.A. and White, J.A., 1985 [55]**

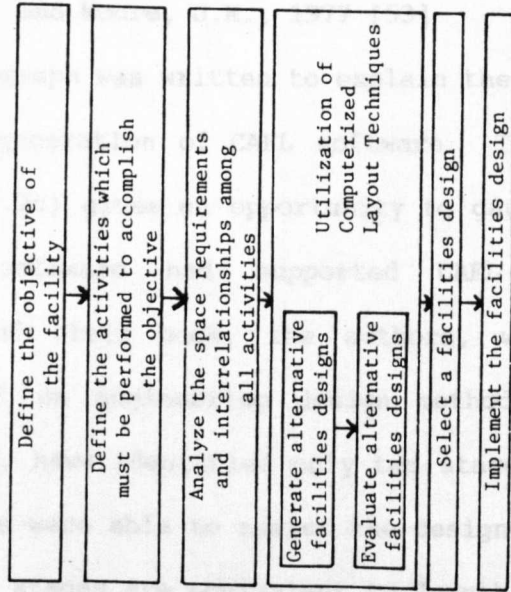
Tompkins and White have adopted the Francis and White's design and life cycle approach, with a first phase of problem definition, a second phase covering the remaining design activity and third phase covering the implementation and operation stages of the life cycle. Figure 2.2b illustrates the three phase life cycle of facilities



(A) After Francis and White



(B) After Tompkins and White



(C) After Tompkins and Moore

planning. Following to Francis and White, the authors have emphasised use of engineering design procedures on facility layout problem.

**Tompkins, J.A. and Moore, J.M., 1977 [53]**

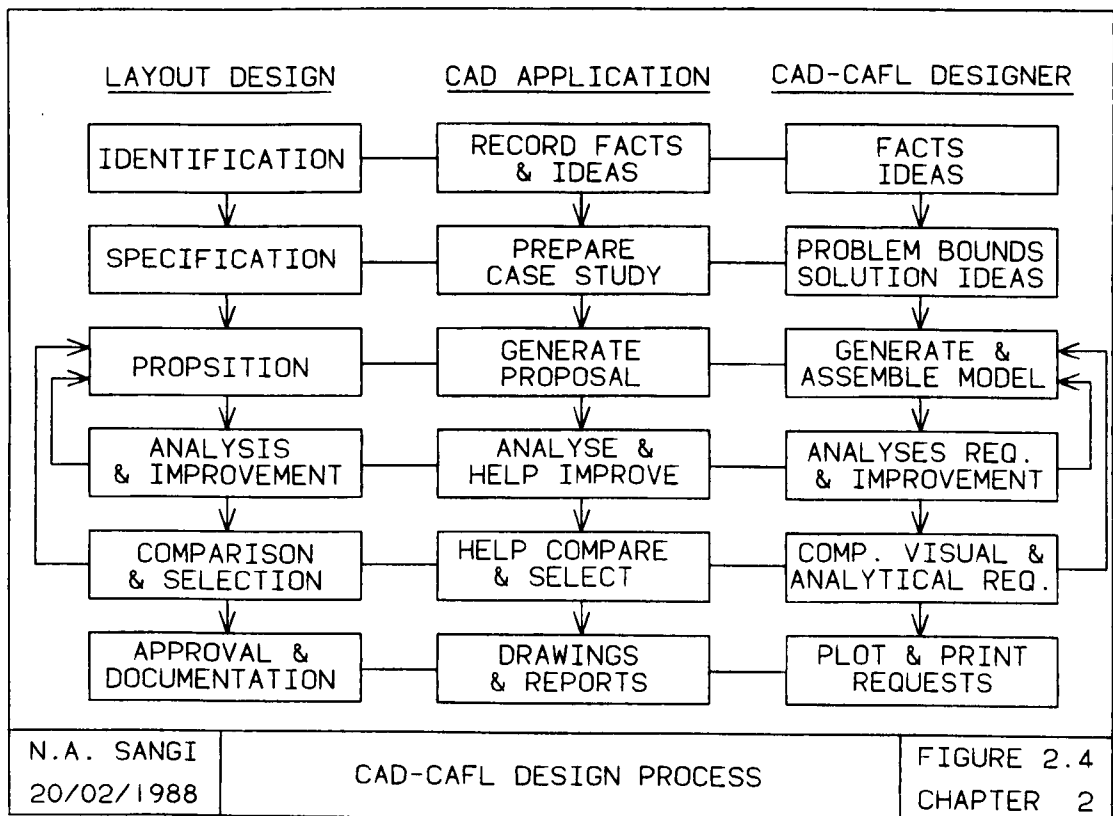
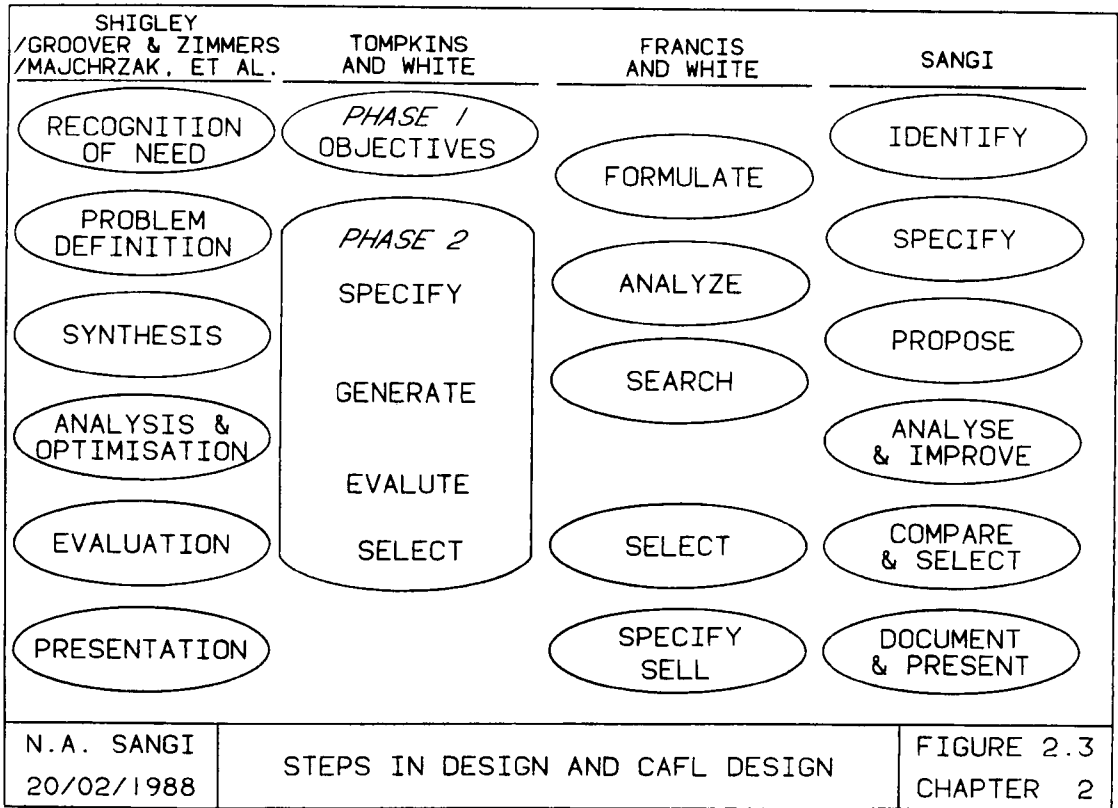
This monograph was written to explain the working of the "Famous Five" first generation of CAFL software. The examination of this work (Figure 2.2c) gives an opportunity to gauge the extent to which early CAFL software had supported CAFL designers. In the introduction of their book, the authors, while recommending the application of an engineering design methodology to the facility layout problem, have identified only two stages of layout design, in which computers were able to assist the designer.

These two stages are equivalent to "synthesis" and "analysis and optimisation", of the original design process of Shigley. Unlike, CAD, "synthesis" in CAFL did not have a graphical form. One of the main criticisms of early CAFL software is its lack of graphics, identified earlier as a vital form of communication between computer and designer in a design process.

The common point drawn from the work of the four authors reviewed in this section is their agreement to apply the engineering design process to facilities layout problems.

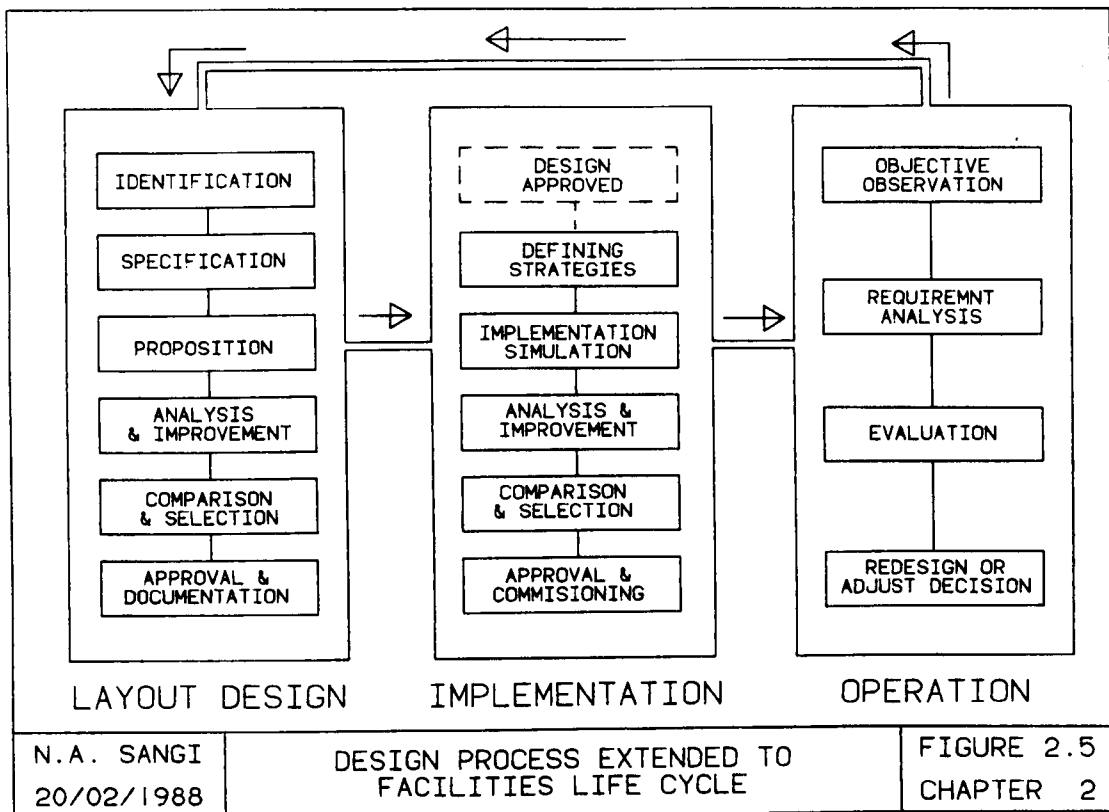
**The CAFL Design Methodology**

The general design process developed in this thesis is drawn from a synthesis of these approaches, most notably; Francis and White [22] and Majchrzak, et al. [35], in context of merged application of CAFL and CAD concepts. Figure 2.3 compares the main steps that will be developed in this work with the approaches discussed earlier in



this chapter. The extension from the approach of Majchrzak, et al. (Figure 2.1c) is shown in Figure 2.4, where the designer can use a CAD system to record the initial state of the problem for latter reference. The extension to Francis and White's approach to life cycle is illustrated in Figure 2.5. The implementation and operation stages can be seen as related to design but separate problem areas.

The details of the new conceptual CAD-CAFL philosophy are discussed in Chapter 4.



#### 2.4 PREDECESSORS TO THE PRESENT WORK

The research in this thesis will be shown to be a new contribution to a research programme started in 1972 and transferred to Liverpool University in 1975. To date the programme has involved

three doctoral submissions; the original work of Driscoll [11] and the extensions of Abdul-Magid [1] and Lilley [34].

#### 2.4.1 Driscoll, J., 1975 [11]

The original research work carried out by Driscoll in 1975 is a two part (design and implementation) philosophy. This work is centred on the job shop situation, where layout changes may be required with each new production programme. Costs of layout changes estimated are examined against material movement cost over a life span of the production programme.

In first part, a new cell layout is proposed based on pregrouped cells, with location priority defined by high materials movement cost and the number of fixed workcentres in each cell. A two part material movement cost model (fixed loading and unloading cost for each batch and a distance related variable cost) is used. The consideration of a defined traffic system was introduced in calculation of distances for a more realistic distance calculation. Additionally, a boundary area for each cell was introduced to allow material movement by operators. Thus cost of handling occurs only when materials are moved outside the boundary distance.

Layout of work centres, within each cell is left for designer in order to reduce calculation time and allow subjective decisions by designer.

In the second part, study of implementation policies is undertaken. Allowable time of changeover for each period and life span of the job shop are considered. The existing work centre relocation is considered over consecutive non productive time periods within the life span of project. A practical constraint of fixed facilities as well as the introduction of layout changes within

limited time intervals were two features of changeover model. Although net present value criteria is used, net return on capital has also been analysed considering limited amount of capital available at any time period for layout changes.

Following the philosophy, a three part interactive computer program was developed. The first program prepares and checks data, the second part of program proposes cell layouts and the third part allows the simulation of relayout process based on financial constraints, fixed positions, and material movement cost economy.

The original program output was restricted to printer (a limitation of first generation programs), which was later extended by Choi [9] to include batch graphics. The work is project oriented, with a design and implementation stages combined in a single relayout project for evaluation.

While, acknowledging the the earlier work of Hitchings [29] in dynamic layout study, these programs UA1-UA3 can be seen as the start of software development for implementation simulation.

#### **2.4.2 Abdul-Magid, E.E., 1980 [1]**

Abdul-Magid extended the simulation work and examined the effects of four different criteria in dynamic layout evaluation. Four computer programs were developed; three in batch mode and a fourth one interactive model. The first three programs minimise, production loss, changeover time and cell disruption respectively. The fourth program is an interactive combination of first three models. This work therefore can be seen as an early, multiple model relayout implementation research.

Abdul-Magid has provided an excellent review of early layout techniques and has evaluated the technical details of computerised



models up to 1980. Therefore Abdul-Magid's work is being identified in this thesis as an excellent reference on the review of layout techniques.

#### **2.4.3 Lilley, M.T., 1985 [34]**

Lilley chose to return to the original two part layout problem (design and implementation). Four programs; MS-S1 (data preparation and checking), MS-S2 (layout design), MS-S3 (batch mode simulation) and MS-S4 (interactive graphics based simulation) were developed.

The first program MS-S1 undertakes data preparation and checking. The design program MS-S2 takes pregrouped cells as input and starts layout design in three steps:

1. Determine MHC within cells.
2. Based on MHC, determine cell positions on layout.
3. Interactive placement of individual facilities by designer.

The design model is applied at cell level, individual work centres are placed interactively on the layout by the designer using facility templates.

The two simulation programs (MS-S3 and MS-S4) are similar in evaluation, MS-S3 operating in batch mode whilst MS-S4 is an interactive graphics based program, incorporating GINO routines. Having achieved interactive design with reasonable graphics work, Lilley concentrated on simulation, where multiple model, interactive graphics based simulation models were produced for assisting the designer. Five policies were available as part of the evaluation models in MS-S3 and MS-S4 software :

1. Instantaneous changeover policy
2. Minimisation of changeover time policy
3. Minimisation of production losses policy
4. Minimisation of cell disruption policy
5. Maximisation of materials movement cost gain policy.

Four major enhancements of Lilley's work can be identified compared to the work of Driscoll and Abdul-Magid. These are :

1. Bespoke GINO based graphics routine incorporated in software.
2. Application of graph theory at the design stage using materials movement cost between cells.
3. Multiple simulation models refined and extended.
4. Interactive mode of operation with interactive graphics

Therefore, Lilley's work can be referred to as a final phase of second generation software.

With the difficulties of maintaining lengthy bespoke GINO-F software through successive new versions of FORTRAN and GINO-F the concept for this thesis was developed. This concept involved the examination of the potential of CAD as a replacement and enhancement for graphical display, an area not previously examined.

## **2.5 IDENTIFIED SOURCES OF INFORMATION ON CAFL**

The extensive previous work on CAFL at Liverpool University, and the international survey of current state of the art (given in Chapter 3), has brought to light a collection of existing CAFL reviews. As a consequence a review of CAFL back to its origin will

not be conducted in this chapter. More appropriately these leading reviews will be identified and supported in the next section by recent publications relevant to the CAD-CAFL interface. Tables 2.1, 2.2 and 2.3 list the existing reviews.

**Table 2.1 Identified Published Paper Reviews**

References	Year	Subject Areas Covered
1. El-Rayah and Hollier [16]	1970	Traditional schematic, Graphical and systematic, mathematical and optimisation and computerised heuristics algorithms. Total 55 references, 1948-1968 (plus 22 references in bibliography).
2. Moore	[39] 1974	Survey of 33 computerised programs plus preview of CAFL progress. Total 46 references, 1950-1973.
3. Moore	[41] 1978	User survey of software use in the USA and the United Kingdom. Appendix B contains 45 references on CAFL (original collection of Dr. J.A. Tompkins) 1961-1977.
4. Heisterberg	[28] 1978	Review of modern CAFL software development, 37 software programs identified in the areas of CAFL design, material handling system, warehouse and factory simulation. Total 125 references, 1962-1977.
5. Levary and Kalchik	[33] 1985	Comparative review of 15 computer programs and two manual procedures. Total 33 references, 1955-1982.

**Table 2.2 Identified Theses Reviews**

<b>References</b>	<b>Year</b>	<b>Subject Areas Covered</b>
1. Driscoll	[11] 1975	Review of; qualitative and systematic, mathematical and schematic, computerised layout (11 programs) and dynamic plant layout. Good review of both non computerised and computerised layout techniques. Total 65 references covering period 1951-1975 (plus 115 references in bibliography).
2. Abdul-Magid	[1] 1980	An excellent review of non computerised and computerised layout design procedures and changeover models. Total 57 references identified, 1951-1980 (plus 101 references in bibliography).
3. Lilley	[34] 1985	Review of previous theses (Driscoll and Abdul-Magid), computerised procedures (seven additional to Abdul-Magid) and dynamic layout simulation. Total 70 references, 1955-1985 (plus 222 bibliographic references).

**Table 2.3 Identified Book Reviews**

<b>References</b>	<b>Year</b>	<b>Subject Areas Covered</b>
1. Apple	[5] 1977	Organised into 19 chapters, covering topics in facilities design, materials handling, conventional layout design techniques and O.R. models. Additionally, process design, services and area allocation topics are covered. Four early CAFL programs are reviewed.
2. Francis and White	[22] 1974	A valuable analytical reference on layout and location procedures. Organised in 10 chapters, mainly covers O.R. and mathematical models for location and layout. Five early CAFL programs are also reviewed.
3. Tompkins and White	[55] 1984	Four part, 19 chapter text book covers facilities planning life cycle topics with examples and exercises. Perhaps an elaborated, more versatile update of Francis and White covering additional topics of material handling, storage and warehouse design. Practical and theoretical examples are given. This text is considered as most recent and thorough reference on facilities planning subject.

## **2.6 RECENT CAD-CAFL PUBLICATIONS**

The works of 13 authors covering the period from 1981 to 1987 have been identified for discussion.

### **2.6.1 Industrial CAD-CAFL Applications**

**Kalvaitis, R., 1981 [31]**

This paper describes the development process for designing an early in-house CAD program at the Ford Motor Company, U.S.A. This is the earliest reference found on industrial layout drafting using a

CAD program. The geometrical data from manual drawings was extracted (in a numerical code form) and read into the CAD database via a card reader. A CRT display and CAD program were later used to check and modify this image data. This CAD program used a 65 Kbyte (16 bit word) mini computer, card reader for primary data input and a CRT screen plus light pen as modification and display devices.

This CAD program development was intended to replace architectural drawings of the factory, and was later extended to mechanical component drafting by increasing drafting accuracy from  $\pm 1.5$  inch (for layout drawing) to 0.001 inch (for mechanical component drafting). This accuracy was obtained with reduced speed of processing and small amount of graphics details in the drawing.

The paper reports in excess of 1.3 Mbytes of data used in the construction of layout drawings. This indicates the high costs of computing involved in layout drafting and identifies the need to reduce unnecessary storage demands in representation of layout.

Two methods of reducing the workload on computer processors are identified; reduced accuracy in layout drawings and splitting layout images. The paper reports that, with an accuracy of  $\pm 1.5$  inches 8000 sq. feet drawing can be accommodated in a single file, as opposed to 5 sq. feet drawing with 0.001 inch accuracy.

Two methods of layout drawing separation are identified from this paper. Initially whole plant drawing details are divided into (30) sections and secondly, use of (255) overlays is made to separate layout images.

The need for separation of images is a practical necessity for two main reasons; firstly to reduce the number of images being visualised at any time by the designer, allowing an unambiguous visual analysis. Secondly, by reducing image details per file, the

overall performance of the CAD package and hardware can be improved (less computer memory and response times are required with reduced graphic file sizes).

These two methods of separation of layout drawing identified in this paper can be referred to as "distributed" and "selective" visualisation methods respectively. The selective visualisation allows selected layers of images being displayed and plotted, whereas distributed visualisation allows more details of local area while staying within single file limitations. Combinations of the two methods, where appropriate has been used within this research.

**Grech, L.L., 1982 [24]**

This paper outlines the potential benefits of using CAD for facilities planning instead of traditional methods. The paper does not describe the actual use made of a CAD system, but summarises potential advantages of the CAD-CAFL approach, realised during successful appraisal study, carried out at General Motors, U.S.A. The author places emphasis on the proper planning of a CAD based facilities layout. Seven considerations recommended for implementing CAD-CAFL approach suggested by the author are quoted directly :

- "- Dividing site into computer files. Logical divisions are along building or department boundaries, no larger than 100,000 sq. ft. per file.
- Creating standard templates such as bins, hydraulic units, desks etc.
- Standardising levels. Information must be stored consistently on specified levels.

- Creating names for drawings and computer files. Avoid names which will confuse non computer users.
- Developing commands and programs tailored to accomplish your specific needs.
- Developing system procedures. Well documented rules assure consistent results.
- Preparing a training program."

Two most important points are drawn from this reference. Firstly there exists an exploitable potential of CAD systems in layout design and secondly, a planned, well defined approach is a prerequisite of utilising the potential benefits of CAD within CAFL.

**Hanley, T.E., 1986 [27]**

The paper describes the development of layout data management on a proprietary CAD package CADDs (Computer Aided Design and Drafting system) marketed by Computervision Corporation.

This CAD based layout system is developed for the specific needs of the Land Rover plant in Coventry. Use of layers has been made for organising the graphical layout data. The paper illustrates a similar strategy as identified in an earlier review (CAD usage at Ford Motor Company, Kalviatis [31]) i.e concentration on factory layout architectural detail.

Interface capabilities (e.g. "Bill of Material" and "Data extract") are identified by the author. However, present use or planned future extensions are restricted to storing and extracting services requirement data for facilities, and not for layout design. Thereby leaving the designer to use ordinary CAD features to compile layout alternates without using any formal layout design procedure.



**Malde, A.J., and Bafna, K.M., 1986 [36]**

This paper is one further example of using CAD drafting features only to generate layout drawings and alternates. This work was carried under university supervision for an industrial client. A procedure similar to template arrangement on layout drawings was used with the difference that a CAD system was used to organise, store and manipulate images. Layout design was carried out by a series of interviews with concerned employees. Layers were used as key means in compiling and communicating layout alternates during consultations.

The method of evaluation again shows lack of use of any scientific criteria among practitioners. Nevertheless, the approach shows a growing use of CAD based layout in the industry.

These four papers ( Kalviatis [31], Grech [24], Malde and Bafna [36], and Hanley [27] ) support the survey results of Nicol and Hollier [44] (see Chapter 3), who found a lack of any scientific method of layout design in the 33 UK companies. Interestingly, none of these 33 companies in the Nicol and Hollier survey achieved a satisfactory practical layout result, with minor and major problems equally distributed among these companies. Quoting from Nicol and Hollier :

"This practical approach resulted in some problems mentioned not being exposed until after implementation".

Nicol and Hollier believed that this led to more frequent adjustment in facilities layouts.

This lack of using any scientific layout design method in industrial practitioners can partly be blamed upon the lack of "industry standard" layout design packages. First and second generation CAFL software have failed to satisfy these industrial clients. Modern commercial CAD packages have attracted practitioners to use CAD for layout data management and organisation, a further step is required to interface CAFL analysis models with CAD software and to start a new era of "robust and reliable" CAD-CAFL merged applications. However, planned and well defined approach is the prerequisite to CAD-CAFL success.

The second point of importance found in these approaches is that an already purchased CAD system can be used for facilities planning, all that will be required will be the additional analysis software to go with the more direct design, drafting and calculation tasks. Thus an increased utilisation of CAD within any company can be achieved by using it in CAD-CAFL applications. Unlike bespoke GINO based CAFL graphics, this approach would not require specialised computer resources (hardware plus software), training and expertise in programming. CAD-CAFL applications would therefore be a cheaper and attractive options to industries already employing a CAD package for other applications.

### **2.6.2 Academic CAD-CAFL Approaches**

**McGetrick, M.H. and Hitchings, G.G., 1987 [37]**

This paper is an example of a similar approach described later in this thesis, published at the same time as the second paper on the facilities planning research programme. The micro CAD package DOGS (Design Office Graphics System) was used to combine graphics and analysis in layout evaluation. The DOGS features equivalent to "parametric symbols" was used to generate facility shapes and the

analysis program DECOL was used in design and improvement of the layout. This research utilises a CAD interface to generate facilities and CAFL procedures. Five facilities example problem illustrated in this paper uses rectangular facility shapes which are located on a layout grid. Layout architectural details are generated using graphics editor. The most difficult area of CAD-CAFL development, as would be expected, is defining the interfacing mechanism of CAFL program and CAD packages. Quoting from the authors,

"One of the major problems encountered in this study was the interfacing of the two packages."

The area and centroids of facilities are sent to analysis package through a FORTRAN interface program for use in DECOL program. DECOL is an extension of TSP (an earlier CRAFT oriented improvement procedure, with built in "greedy" heuristics to find better solutions in later iterations). Muther's AIEOUX type relationships are used for layout scoring.

Parametric symbols feature in CAD packages was originally provided for automatic construction of "similar but of different size" mechanical components. This feature can be used to generate defined shapes with different sizes. Nuts, bolts and washers are the excellent example of general use of parametric symbols. The use of this facility can be made to automatically draw pre defined facility (outline) shapes in the layout drawing.

This paper shows an alternative source of interest in joint CAD-CAFL package development. Micro based CAD-CAFL applications however are dependent upon computer power. High degree of processing and storage demands put by the industrial size layouts, (identified

in this review [31]), limit the potential of microcomputer based application to relatively small size problems. Nevertheless, general trends in microcomputer power enhancement and reduced costs certainly make it an attractive choice.

### **2.6.3 Other CAD and CAFL Related Papers**

This section was added to cover recent related papers in CAFL or CAD and not CAD-CAFL together. This section comprises of four papers reviewed. The comments as their importance to the nature of CAFL and the work in this thesis are drawn within this review.

#### **Collier, L.M., 1983 [10] and Footlik, R.B., 1983 [20]**

These two article contrast the views of the two authors, first in favour of CAD use (merits) and other discussing CAD limitations. The three important points drawn from these two paper are :

#### **Merits**

1. CAD offers quality communication (in graphical form).
2. CAD allows structuring capability to image data for visualisation and storage.

#### **Limitations**

3. Generating layouts automatically by CAD does not take account of interference (i.e. multiple pieces of equipment may be assigned the same location).

The first two points identify potential points for CAD that can be exploited in CAFL. The third point shows a difficulty common in all CAD packages. Defining the logic to identify obstructions and

avoid overlapping of facilities is a costly computation as evidenced by the GRASP software [7]. The analytical attributes of designer are being used as an economical way out. Thus supporting view point of a combined designer and computer activity in facilities layout.

An important fact missing in the discussion presented in these two papers is the ability of a CAD package to interface with user developed application programs, a key factor in the future use of the CAD-CAFL approach. This is the case with all but few papers ( e.g. [12], [48] and [37]) on the CAD-CAFL subject.

#### **Anonymous, 1983 [3]**

This article reports the summary of a debate titled "The use of the computer for graphics and analysis is essential for effective layout planning." The debate was originally held in the Annual I.E. conference in May 1982. Six quotations from this summary report support the points made earlier :

#### **Merits**

1. "...the possibilities of dynamic simulation and use of multicolored displays and 3D images has made models, templates and cutouts obsolescent."
2. "... the capability to store and recall images and the ease with which modifications can be made mean more alternatives can be tried..."
3. "....once implemented, layouts can be kept up to date and future modifications really tested before implementation."
4. "...while computer system costs are coming down, the costs of engineering time are going up. The critical thing to be obtained through use of computer is productivity..."

## Limitations

5. "There is more in layout than space arrangement.....things that are difficult to input into an algorithm for a computer - will be neglected."
6. "... the main problem with computerized layout planning is that no two layouts are the same, and therefore it is difficult to standerzize the information that has to be fed to the computer."

The analysis of these quotations leads to a conclusion that computers and graphics although bring advantages of power, speed, visualisation and progressively cheaper solutions; are yet not sufficient for the classic problem of facilities layout. Research effort is required to explore the extent to which CAD can assist in CAFL and develop a methodology of using CAD-CAFL approach if CAD can be made useful in CAFL. Examining this CAD-CAFL area on a mainframe system is the second part of this thesis.

### Inglis, A., et al., 1985 [30]

This paper describes the results of an experiment in which 68 engineers were required to communicate with a CAD package using three modes of CAD software operation. These three modes were; optimum, modular and linear design techniques. Optimum mode refers to a "automatic design" i.e. computer solution generated for a given set of input parameters. Modular mode refers to user initiated dialogue "with the various options called from a menu" and solving the problem by using a set of computer tasks (menu options). The linear technique refers to "operator presented with a series of questions, progressing through the program in a linear fashion."

The study concludes that the modular approach is thought to be best for providing user control over problems. However, it did not provide a better solution than the optimisation technique during this test. It was suggested that for small well defined problems, optimisation would provide a better solution.

The results in the paper show that the use of a modular approach was preferred by users (48.53% preferred 5.08% disliked) over optimisation (30.88% preferred and 25.42% disliked), since optimisation in many cases is "programmed optimisation" dictated by the programmer rather than the designer. Quoting from the authors :

"One conclusion from the results is that a linear technique, which satisfies none of these design attributes, should not be used. The decision as to when to use the modular technique and when to use the optimal technique depends upon relative importance of the design attributes. The most appropriate approach might comprise of a combination of the two used in early stages of the design, with an optimization option being employed when the design possibilities have been explored and the parameters, constraints and objectives are no longer likely to change. At that stage a model presents a good 'fit' to the problem and good solution can emerge."

The authors have further suggested a combination of modular and optimisation techniques, with optimisation "within the context of a modular approach overall".

Recalling the types of design problems mentioned earlier, where layout design is considered illstructured, the modular approach is best suited, supported by "unit task" optimisation in a form of menu

driven software. This will not only correctly tackle CAFL design problems, but will give CAFL users an insight into the decisions in an acceptable form.

## 2.7 SUMMARY

From the analysis of these 21 design, CAFL and CAD-CAFL authors reviewed in this chapter the following points are drawn in support of this research :

1. Facilities design problem can be solved by the use of an engineering design methodology.
2. Present CAD systems can not replace designer attributes and therefore a combined Designer - CAD approach is essential.
3. Modern CAD systems offer a range of flexible modelling and analysis "unit tasks" to the designer to retain designer creativity and expedite the design process.
4. CAD offers cheap and versatile solution for use by industrial sector facilities planners. A planned and well defined CAD-CAFL approach with extension to CAFL analysis is therefore highly feasible and useful research.
5. The potential of applying CAD software in parallel to CAFL software exists and should be pursued further.
6. Modular, menu driven CAD package structure is best suited to, and preferred by the engineers involved in the design process and therefore is suggested for CAD-CAFL software design.

The review and introduction have therefore substantiated combined CAD-CAFL as an area worthy of research.



## 2.8 THE NEED FOR INTERNATIONAL SURVEY

In the beginning of this chapter, it was identified that, the progress in the subject is best judged by a review of published literature and by direct questioning. In this chapter the subject of CAFL has been reviewed in relation to CAD and CAFL. A more exclusive and original review of the progress in CAFL is presented in Chapter 3, which reviews eight previous surveys to set up the scene for the new international survey of CAFL software and completes the picture on the state of the art in CAFL.

**CHAPTER 3**

**AN INTERNATIONAL SURVEY OF  
COMPUTER AIDED FACILITIES LAYOUT**

**AN INTERNATIONAL SURVEY OF COMPUTER AIDED FACILITIES LAYOUT**

**3.1 CHAPTER OBJECTIVES**

As stated in Chapter 1, the contribution to be made in this research falls into two areas; an updating of the general body of knowledge on CAFL and the specification and development of a new CAD based CAFL approach to quantitative layout planning. In this chapter, achieving the first objective, through a new detailed international survey, is described. The objectives of this chapter therefore are :

1. Reviewing previous surveys to establish CAFL perspective.
2. Discuss the new exclusive international survey to judge state of the art progress in CAFL software.

**3.2 PREVIOUS SURVEY PERSPECTIVE**

In all, eight previous surveys covering various aspects of facilities planning have been published as shown in Table 3.1. The most detailed and significant of these surveys are the three publications of Moore, which examined the majority of first generation software. First paper examined CAFL software from the authors viewpoint, in 1974 [39] and subsequently in the 1976 [40] and 1978 [41] two papers examined users perspective of CAFL in the USA and in the United Kingdom respectively.

**Moore, J.M., 1974 [39]**

The 1974 survey by Moore (conducted in 1972 and first presented in 1973) concentrates significantly on software details. Twenty nine questions were asked covering type of program, type of data used, representation of problems, computer language, problem size, solution procedure, output format, working mode (batch or interactive), software age and availability.

**Table 3.1 Previous Surveys Perspective**

	<b>Moore 1974</b>	<b>Moore 1976</b>	<b>Moore 1978</b>	<b>Hales 1979</b>	<b>Muther &amp; Phillips 1983</b>	<b>Nicol &amp; Hollier 1983</b>	<b>Filley 1983</b>	<b>Filley 1983</b>
Geographical area	Int.	USA	UK/ USA	USA	USA	UK	USA	USA
Sample Size	31	175	285	126	463	33	27	130
Survey Population								
Users	*	*	*	*	*			
Authors	*							
Suppliers							*	*
Companies						*		
Survey Subjects								
Layout								
Practice						*		
Computer Use				*				
Software								
Authors								
Development								
Content	*							
Marketing								
Users		*	*				*	*
Comments			*					

These questions were followed by six general questions designed to identify further software and solicit a general opinion on software usefulness. The survey attracted 31 responses in total and

identified 33 pieces of software. Until the present survey the first survey by Moore remained the only attempt to gather information of software packages. The 29 questions used by Moore gave only an outline of software contents. The survey however very creditably gave the first published account of 33 CAFL packages.

Detailed discussion of Moore's findings in this survey will be made later in this chapter as part of a comparison of past and present surveys. This comparison will be an important indicator of change over the intervening decade.

#### **Moore, J.M., 1976 [40] and 1978 [41]**

Moore extended his survey of CAFL by seeking the opinions of users in 1976. Two groups were surveyed, one in the USA and one in England. In the USA 175 out of 203 returned surveys, obtained with the help of Industrial Engineering Journal and Purdue University, contained comments on CAFL use. In the United Kingdom, 102 out of 110 surveys, obtained with the help of the Institute of Materials Handling and the Lucas Institute Birmingham University, were received from practicing layout engineers.

Nine questions were asked in the survey covering user experience, knowledge of Systematic Layout Planning (SLP), computerised layout and operational research approaches.

Moore's results, discussed further in the comparison of surveys later in this chapter, showed three interesting results. Firstly layout planners generally spend a long time on layout work, both sets of results showing more than 50% of respondents having more than five years experience. Secondly replies showed the oldest programs (CRAFT, CORELAP and ALDEP) to be the most used. Finally 60-70% of CAFL users found software to be only of marginal use.

**Hales, H.L., 1979 [26]**

A subsequent survey by Hales [26] examined only the question of who was using computers in facilities planning.

Covering 126 attendees at facilities planning seminars (a user group) the main comments in the paper concerned the low level of use of CAFL, with only 20% of planners using any form of software and only 2% of planners using CAFL software. As a result of this apparent low use of CAFL shown by Moore [40], [41] and Hales [26], the survey described in this chapter was expanded to examine in some detail users and authors opinion on software usefulness.

**Nicol, L.M., and Hollier, R.H., 1983 [44]**

The apparent low level of scientific computer based facilities planning shown by Hales [26] is further reflected in a paper published by Nicol and Hollier [44] which covered practical plant layout practices in 33 UK companies. This review mentioned earlier in this thesis, gives a good comparison of CAFL and applied layout practices.

The results found by the authors indicated a low level of scientific layout design. Comments in the paper indicated only four of the 33 company replies had even heard of SLP or other formal approaches to facilities planning. Examining the methods of working used by layout personnel in terms of influences, objectives, flexibility and problem size, further evidence of low scientific approach is forthcoming.

Amongst the influences on layout decisions are direction from parent companies, the prejudices of directors, building constraints and previous layouts and consensus amongst staff. This combination

does not support the existence of a widespread scientific approach to layout design.

Planning objectives used by survey replies indicate plant and materials handling as by far the most dominant consideration (30 replies with only one using handling cost). Manufacturing considerations were the priority in 19 cases and most surprisingly no reply indicated finance as an objective.

The size of layout problem (expressed in terms of departments) was found in the majority of cases to be 15 or fewer. This is a useful piece of evidence for the approach developed later in this research. With problem sizes perhaps lower than anticipated, both the development of a mainframe CAD based system (proposed later) and a microcomputer based CAFL package are possibilities within existing memory constraints.

Further evidence of the instructed approach of layout planners came with the points that companies were not aware of layout costs, did not have site developments and organisationally did not see layout (critical to good factory operation) as a senior management task.

Nicol and Hollier therefore give an opportunity to contrast the practice of facilities planning against the objectives of Computer Aided Facilities Layout (CAFL). The resultant summary conclusion is that the importance of facilities layout needs to be stressed in the industrial environment, and the availability of usable CAFL software will help put this message over.

The paper by Nicol and Hollier provides therefore further reinforcement for examining in detail CAFL software, which is developed primarily as the basis of scientific facilities planning.

**Filley, R.D., 1984 [17] and 1985 [18]**

The most recent survey(s) of software for facilities planning highlights one of the dilemmas of CAFL as indicated in the introduction, i.e. distinguishing between drafting of layout drawing and true CAFL. The survey(s) of Filley [17], [18] covered initially commercial CAD packages and then all commercial software that could be used in facilities planning. Whilst CAD packages, decision support software and management information database packages were mentioned, the surveys did not contain an extensive list of known CAFL software.

**Muther, R., and Phillips, E.J., 1983 [43]**

The work of Nicol and Hollier in the United Kingdom is complimented by a similar but more general survey by Muther and Phillips in the United States. Taking six years to complete, the study's most important finding was the lack of any "clear, definite objectives for facilities planners".

Problems were identified from the start of work in the lack of objectives and difficulties in interpreting management desires.

The survey, which also showed the highest group of layout personal had long experience in the job (2-10 years 38.7%, 10+ 17.5%), highlighted a lack of long term attention to planning. This is not surprising when from a sample of 463 only 16 percent of planners had managerial titles, similar to Nicol and Hollier findings on the low status of facilities planning.

Muther and Phillips differed in one important aspect from Nicol and Hollier, and that is with regard to the philosophy behind criteria. Muther and Phillips found the most important consideration to be the question of economics or financial cost. Perhaps this is



indicative of national differences. The rating of economic considerations as the priority indicates a greater interest in scientific or quantifiable layout planning, a point that will be reinforced later in the new survey.

### **3.3 SUMMARY JUSTIFICATION FOR THE SURVEY**

Summarising on previous surveys, therefore, the most detailed and authoritative investigation had been carried out over a decade ago by Moore and subsequent works had identified a poor approach to facilities planning.

This leaves a substantial gap in knowledge as to the progress that has been made over the period 1978 to 1988, a period in which very significant changes in computing hardware, software and working methods has occurred. In addition, reviews of journals and conference proceedings indicate an exponentially growing number of CAFL packages being published over this decade.

For these reasons the conducting of a new survey, particularly where the opportunity is taken to significantly increase the scope of interrogation beyond the level of Moore's international survey, is considered to be a significant contribution to the body of knowledge of CAFL.

One significant decision was made with regard to the structure of this survey. The areas covered by the survey were increased and the depth of interrogation was extended on the basis that those who would respond, would be prepared to respond in detail. This is particularly true as the targeted survey population was made up of persons known to be involved in CAFL work. A new area of survey included the history of software development, considered important in explaining why CAFL software was used in the way it is used. The

significance of depth of interrogation will become apparent in the remainder of this chapter.

### **3.4 SURVEY BACKGROUND**

#### **3.4.1 Objectives**

The objectives of the survey can be quoted directly from the final survey report as :

1. To identify the researchers and the historic research effort in CAFL.
2. To investigate the computer hardware employed in support of CAFL.
3. To examine in detail the components of CAFL packages, including methods of data entry, methods of problem representation, the procedures for layout design employed and the evaluation models used to evaluate results.
4. To gauge the extent to which CAFL software is being offered commercially.
5. To seek and examine opinions of CAFL users as to the merits and drawbacks of software they have used.

The logic of these objectives follows closely the justification and points identified in the previous survey perspective.

Objective one, related to historic effort in CAFL, serves two purposes, the provision of a record of effort, but more importantly, this historical review will allow comments to be drawn on the relationship between software development effort and the level of actual industrial use. Objective four is included to further support investigation of the relationship between CAFL development and use.

Objectives two and three provide the information needed to examine whether in reality changes in computer hardware, software and working method are affecting CAFL package structures. Objective three is the most detailed questioned objective within the survey.

The fifth objective allows to collation of the opinions of the leading international researchers in CAFL and in particular is aimed at gauging their experience based opinions of software applicability.

### **3.4.2 Timetable**

The concept of the survey was developed into several prototype questionnaires in the early part of 1985 as the first part of the research programme. By May 1985 the version of survey questionnaire to be issued had been completed. The first posting to a sample of potential respondents went into the mail by the end of May. Further questionnaires were dispatched progressively through to September 1985. This was then followed by a first series of reminders two months behind each initial survey posting. Where the reminder failed to solicit a reply, a second invitation and questionnaire was dispatched towards the end of 1985. Newly identified names from early responses were also polled at this point in time.

The analysis of the results started at the beginning of 1986 with the compilation of responses into databases and the initial assessment of data. A slow return rate delayed the detailed analysis of results until the late summer of 1986. The results [13], in the form of a set of 46 illustrations and 10 tables were prepared along with the final report at the end of 1986 and sent to each individual respondent. Two papers [14], [15] have been published on survey results in August 1987. The full set of illustrations and results

are given in Appendix E. Where illustrations are discussed in this chapter, they are reproduced for convenience of examination.

### **3.4.3 Structure**

The survey questionnaire, a complete copy of which is shown in Appendix E, has been divided into six sections to reflect the aims and justification of the subjects. The six sections are :

- A. Personal Information (four main questions)
- B. Development of CAFL software (eight main questions)
- C. Contents of CAFL software (seven main and 26 subheadings)
- D. Marketing of CAFL software (one main heading)
- E. The use of CAFL software (three main headings)
- F. General comment (two main headings)

Quoting from the report abstract, the survey document contains 69 major questions, which expand to 274 items when multiple choice answers are considered. Allowing for the number of repeat submissions from respondents, contributors have considered an estimated 14,000 individual questions.

### **3.4.4 Coverage and Response**

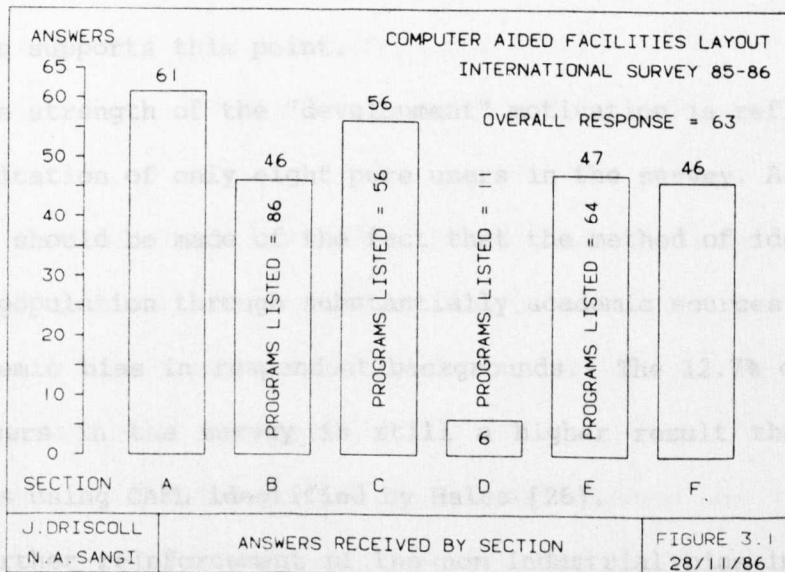
The survey polled active researchers in 24 countries, with 122 questionnaires being mailed to academics, industrial practitioners, consultants and vendors. The methods used to identify survey names include personal contact, literature search and recommendation by early survey respondents.

The size of the questionnaire, as predicted, did not deter a significant number of individuals responding. In all, 63 replies

were received from 15 countries representing all five continents. Twenty one percent (26 questionnaires) were returned by postal services as untraceable addresses, leaving 96 successful postings. The response rate was therefore 66% of questionnaires reaching their destination (51% of total dispatched).

One hundred and one programs were identified by the survey. Eighty six of these programs being listed in the historical review (section B) and 56 were submitted for detailed analysis in section C. Further clarification, subsequent to publication of the survey, identified the first survey package as being from 1965<sup>1</sup> giving a 20 year software review.

The answers by section are illustrated in Figure 3.1. The replies to the early sections of the survey consist of 61 answers to the area of CAFL interest, 46 responses to the history of CAFL work (86 programs), and 56 replies to the detailed analysis of software. The later sections produced six replies on marketing CAFL software (11 programs), 47 analyses of the use of CAFL (64 programs) and over 20 comments were included amongst the 46 Section F responses.



<sup>1</sup>One respondent required adjustment of dates between European and Japanese calendars, a difference of 25 years.

### 3.5 SURVEY SECTION A : PERSONAL INFORMATION

General Objective: To identify current active researchers in CAFL.

Survey Questions: A1 - A4 (Appendix [E1])

Illustrations: A1 - A4 (Appendix [E5])

The statistics on mailing and replies have been given in the section on survey coverage. At this point there is limited value in examining geographical distribution other than to acknowledge the very high level of interest and response from the United States (59%).

The results with regard to area of interest show a strong bias towards software development with the results, in order, being development (69%), use of software (39.7%), and marketing (9.5%). Eight replies were received showing no continuing interest in CAFL.

This bias towards the academic development and publication of new CAFL software detracts from the development of industrially useful packages, where sustained effort on individual software is required over long periods. The very low interest in marketing CAFL software supports this point.

The strength of the "development" motivation is reflected in the identification of only eight pure users in the survey. Acknowledgment however should be made of the fact that the method of identifying the survey population through substantially academic sources will lead to an academic bias in respondent backgrounds. The 12.7% of identified pure users in the survey is still a higher result than the 2% of planners using CAFL identified by Hales [26].

Further reinforcement of the non industrial bias in researchers can be judged by a simple analysis of mailing addresses. These

indicated that 73% of replies were from academics and only 22.2% were from the combined consultants/industrial area.

Only four computer companies/software houses were clearly identified as being active in CAFL. As CAFL is not a high volume sales, and as shown in the review of previous surveys, CAFL is not a priority in companies [44], there is unlikely to be a sustainable return on any extensive investment in software development.

Three conclusions are drawn from the background of respondents;

- Software development, is confirmed as the main motivation of the research sample.
- Independent users are relatively rare.
- No extensive interest in commercial CAFL activity was evident.

### **3.6 SURVEY SECTION B : DEVELOPMENT OF CAFL SOFTWARE**

General Objective : To document the profile of CAFL research teams and their level of activity.

Survey Questions : B1 - B8 (Appendix [E1])

Illustrations : B1 - B8 (Appendix [E5])

As identified in the survey background, a historical review of CAFL will provide, for the first time, a collated record of effect and equally importantly will allow examination of the influence of effort on software usefulness.

Within this review one significant change has been made to results published in the survey report. The survey report identifies the earliest software as ALPS, credited with a 1948 origin. Upon

further investigation it has been realised that the dates supplied by the author followed the Japanese Imperial calendar which is 25 years behind conventional dating. Results have been corrected therefore in this thesis with regard to ALPS (1973) and CRL-CAD (1981).

With this amendment the profile of interest in the subject and software development both show exponential growth in the 1960, 1970 and 1980 decades. The cumulative number of CAFL researchers grew from 8 to 26 to 44 over the three decades whilst the start of software package development expanded from 5 to 33 to 76 over the same period.

The most significant points on the historical analysis however, are the results with respect to the time spent on developing software packages and the size of teams involved. To discuss these further Figures 3.2 and 3.3 (survey Figures B3 and B4 respectively) have been reproduced in the text.

### **Development Time**

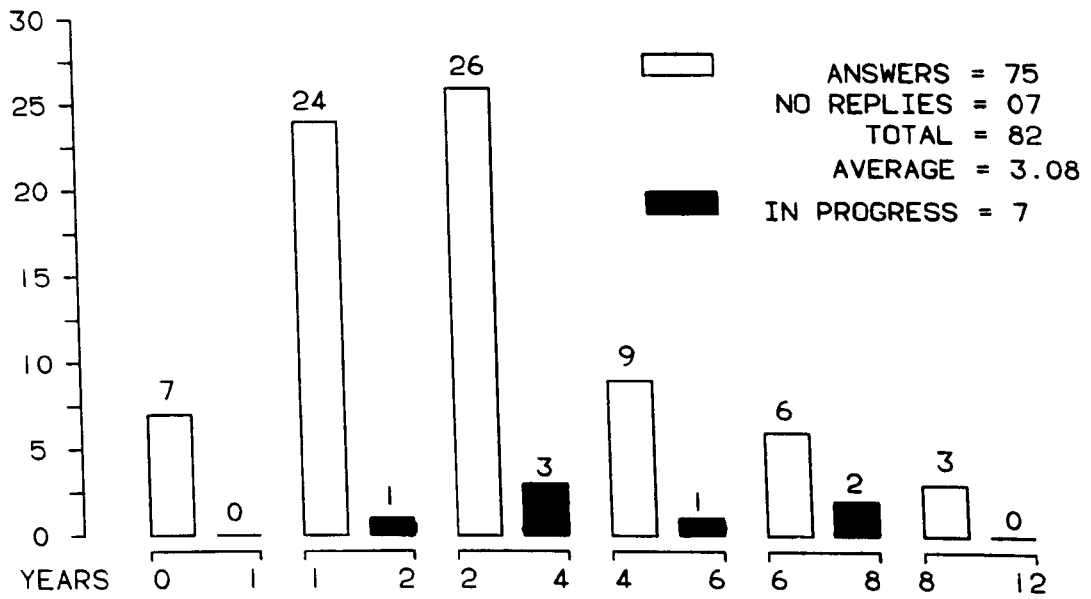
The average development time was recorded as 3.08 years. A similar average development time is also indicated from answers to the question on total man effort (B4), the grand total of 255 divided by the number of packages (82) results in 3.1 years time per software development.

Two significant points from this typical three year cycle are drawn. Firstly, this is not sufficient for the progressive development of a package up to commercial standard, and secondly it reinforces the stereotype of an academic environment with a three year research programme and constant turnover of software (82) packages.



SOFTWARE

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86



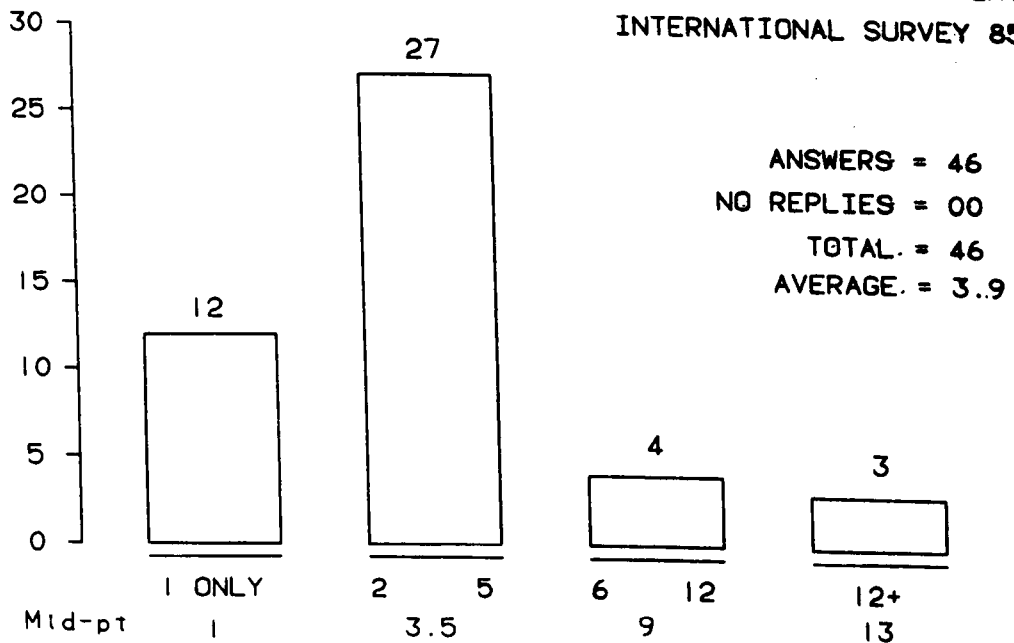
J.DRISCOLL  
N.A.SANGI

SOFTWARE DEVELOPMENT TIME (B2)

FIGURE 3.2  
28/11/86

ANSWERS

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86



J.DRISCOLL  
N.A.SANGI

RESEARCH TEAM SIZE (B3)

FIGURE 3.3  
28/11/86

## Research Team Size

About one quarter of the respondents claimed sole authorship of their models, with average team size indicated 3.9 participants per software package. An alternative estimate of average effort from total effort (255) man years divided by total replies (45) and average model development time of 3.08 years would give 1.83 people in each research team.

The picture however once again is of small groups working on the continuing generation of new packages.

A final reinforcement of the picture of CAFL development as being more academic than industrial can be seen in Table 3.2.

Commercial applicability and user friendly software requires the support of professional programmers. When asked if such support had been used only 26% of respondents indicated receiving some professional assistance. However, only two (CAFL and CUTFIT) of the 16 programs listed in Table 3.2 were offered for commercial third party use (extracted from Section D - commercial marketing).

From the list of conclusions drawn on the whole of Section B, two have been extracted as being of particular importance to this thesis :

- The picture is one of small teams 'turning over' new models as evidenced by the average 3 year - 2 person development effort.
- The emphasis of the majority of CAFL effort is again the creation of research software and not applications packages.

**Table 3.2. CAFL Software Receiving Professional Support**

<b>Program</b>	<b>Computer</b>	<b>Purpose</b>
ALVARI		Plan variation
ARCHADES	Apple IIe	Layout planning
CAFL	IBM 370	Factory layout
CUTFIT	VAX 11/750+AT	Warehouse layout
DECOL	VAX 11/750	Factory layout
INTALA	VAX 11/780	
INVOPLAN	Sun	Space planning
LAYCON	VAX 11/780	Factory layout
MACE	Burroughs	Research
MUGHAL	Burroughs	Research
PALLADIO TEST		
PLANTLAYOUT	Apple II	IIE use
RMA/Micro	Apple IIe	Facilities Planing
SPACE	IBM XT-AT	Space planning
SCORELAP	IBM 360	Interactive
TRANWARE	VAX	Warehouse layout

### **3.7 SURVEY SECTION C : CONTENTS OF CAFL SOFTWARE**

General Objective : To analyse in detail the structure and operating methods of known packages

With Section C of the survey, the emphasis of interest changes. Whilst Sections A, B, D, E and F relate to the environment of CAFL research and achievement, Section C relates to the technical structure and content of individual packages.

Previous theses have already reviewed packages from a basis of published texts and papers [11], [1] and [34]. Section C is designed to provide for this thesis the necessary and important equivalent technical review of software contents. With this aim in mind, Section C is organised into six subject areas:

1. Computational characteristics  
(Survey Questions C.1 - C.2.5 excluding C.2.2)
2. Working mode  
(Survey Questions C.3 - C.3.4)
3. Data verification  
(Survey Questions C.4.1 - C.4.2)
4. Problem representation and graphics  
(Survey Questions C.5.1 - C.5.5)
5. Layout design  
(Survey Questions C.6.1 - C.6.4)
6. Layout Evaluation  
(Survey Questions C.7.1 - C.7.5)

The sequence of subjects are designed to allow the comprehensive analysis of packages. In all, 56 packages were offered for scrutiny.

### **3.7.1 Computational Characteristics**

Survey Questions : C1 - C2.5 (Appendix [E1])

Illustrations : C1 - C5 (Appendix [E5])

Computer processors and peripherals are strong indicators of the working methods, transferability and eventual use of software. Indeed, the analysis of the structure of software is not set in complete context unless information is known on the associated hardware and subsequent hardware limitations.

### **Computers**

The survey indicated 72% of software operated on multi-user (mainframe/mini) computers, with VAX/DEC known for its engineering

applications, the leading computer. The greater use of mainframe is the result of two facts; firstly mainframe computers have been available since the 1950 period and secondly mainframe computers are extensively used by academics (the dominant group in the survey sample). The use of microcomputers has a good track record of growth, achieving over a quarter of all CAFL applications. Faster processors, larger memory and graphics capabilities will make microcomputer CAFL as strong an approach as mainframe solutions.

This section of the survey highlights one of the fundamental choices facing CAFL development, the choice between mainframe and microcomputer based activity. The choice process, between two equally valid development routes, is discussed later in Chapter 4.

Evidence of the considerable commercial investment in providing microcomputer environments can be seen in the emergence of OS2, DOS 4.0 operating systems and the commercial CAD and database packages such as AutoCAD, PC CADAM and DBASE III plus etc.

### **Input and Output Devices**

The survey indicated only about a quarter of the packages use old methods of input and output (i.e. 21.5% use card or tape as input and 25.5% use printer only as output). The use of graphics related devices, considered more advanced, accounted for about 26% (input devices) and 61% (output devices).

Comparing VDU use with Moore's survey (Table 3.10), an increase from 10% to 44% over a decade is shown. In all, about 69% of software used graphics devices, whilst indicating the importance of changing to CAFL, printer based output has decreased in the

intervening years from 69% to 35% of output devices indicating the importance of visualisation to CAFL.

Interestingly, 36% of software did not have printer output which indicates a limitation on analysis of layouts. This result conforms with another result obtained later (Q3.2) and suggests that about one third of the software did not undertake any form of analysis and therefore would not be considered comprehensive CAFL software.

### **Computer Languages**

The survey shows FORTRAN and BASIC to be the most widely used languages in CAFL programs. Comparing with the previous survey shows that use of FORTRAN has reduced from 75% in Moore's survey (Table 3.9) to 49% in the present survey, whereas use of BASIC has grown from 4% to 18%. This result is evidence of a growing development pattern in microcomputer based CAFL software.

About 17% of programs made use of multiple languages. Of these, nine programs used graphics devices as well - a suggestion of a dual graphics and analytical software approach. Use of PROLOG and LISP was also identified which indicates AI related approaches. The use of DBMS and Simulation languages suggests involvement of commercial DBMS and Simulation package.

In all, 12 different languages are in use in CAFL development. This is important evidence of a very healthy trend towards examining the usefulness of modern computing ideas in CAFL, for example Artificial Intelligence (AI) approaches. The drawback is that these applications will remain largely experimental and will not disseminate quickly into the industrial environment.

In addition to software language experimentation, the survey produces evidence of commercial software application in CAFL (Figure

3.4). About one quarter of the respondents indicated commercial supporting software. Three main groups of software identified here are; CAD packages (seven), general purpose graphics routines, (four) and simulation languages (five).

Increased use of commercial support software shows movement away from development of a basic CAFL software to quicker, high quality development using application software. The drawback of taking this path is that the commercial and technical restrictions of such packages will then apply, a point extensively discussed in the experimental chapters later in this thesis.

### 3.7.2 Working Mode

Survey Questions : C3.1 - C3.4 (Appendix [E1])

Illustrations : C6 - C9 (Appendix [E5])

The first division within working mode is the ratio between traditional, often criticised (e.g. [39], [1] and [11]) batch operation and design orientated interactive working.

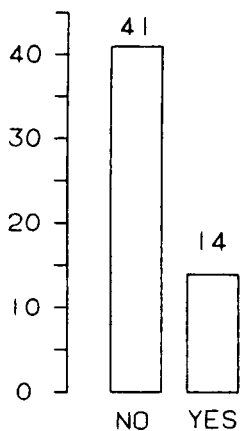
The survey shows a clear 2:1 ratio in favour of interactive models, with early batch programs being identified in the survey as undergoing the transition to interactive operation (e.g. CULLINAIN<sup>2</sup> RELAY1-2B, HABMS, DECOL, SIMSHOP and SCORELAP). Interactive operation is considered essential in a design process involving spatial, numeric and qualitative judgement, as in the case of CAFL.

---

<sup>2</sup> Name of the respondent.

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

ANSWERS  
NO REPLIES = 1



COMMERCIAL SUPPORT SOFTWARE LISTED

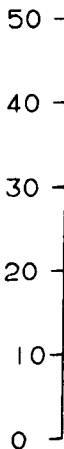
AUTOCAD	GINO-F (3)
CADAM/CATIA/ MEDUSA/GPGS	PROLOG/DBMS
CADDS4/NEWVAR	SLAM/GASP IV (2)
CAPS/ECSL	TRANSSHIPMENT (LP) PACKAGE
GASP II	
GINO-F/DOGS	VISICALC/LOTUS

J. DRISCOLL  
N. A. SANGI

COMMERCIAL SUPPORT SOFTWARE (C2.5)

FIGURE 3.4  
28/11/86

ANSWERS



COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

NO REPLIES = 0

DATA CHECK  
DRAFTING  
GENERATION  
IMPROVEMENT  
ANALYSIS  
ANIMATION  
LIFE-CYCLE  
KINMATICS  
3-D MODELING  
OTHERS

J. DRISCOLL  
N. A. SANGI

TASKS UNDERTAKEN (C3.2)

FIGURE 3.5  
28/11/86



## **Tasks Undertaken**

A preliminary view of software tasks undertaken (Figure 3.5) shows that 45 packages performed the traditional tasks of layout generation or improvement. Thirty seven examples of analysis and 20 examples of graphical drafting supported this design process, showing that the interest in the graphics aspects of layout is substantially increased.

The definition of CAFL as a quantitative, qualitative and spatial combination of problem has been stressed throughout this thesis. The figure of only 66% programs undertaking any form of analysis is indicative that remaining one third pure drafting programs are being employed as CAFL models. Allowing this confusion to continue will not be of value to CAFL development in the long term.

Again, healthy experimentation with new techniques (animation, kinematics, 3-D imaging and life cycle analysis) is identified in the list of tasks undertaken. Further evidence of this experimentation appears in the perceived areas of technology application, with Artificial Intelligence, Expert Systems and FMS design being quoted. Among such programs, CRL-CAD (1981) was the earliest response to AI based approach, while a more publicised [19] and [45] package FADES has been reported in 1984.

## **Problem Size**

Handling industrial size problems does not seem to be a problem with many packages. While average capacity was estimated 60 facilities about 30% packages were found capable of handling over 100 facilities. The earlier review of Nicol and Hollier [44] identified that majority of the companies surveyed had layout problems with 15 or fewer departments, thus problem size is not going to be a

difficulty. However, the ambiguity of the term "facility" which has been defined in literature in different contexts e.g. factory, department in a factory, process plant or workcentre has to be considered, since the factory may contain few departments but many workcentres.

### **3.7.3 Data Verification**

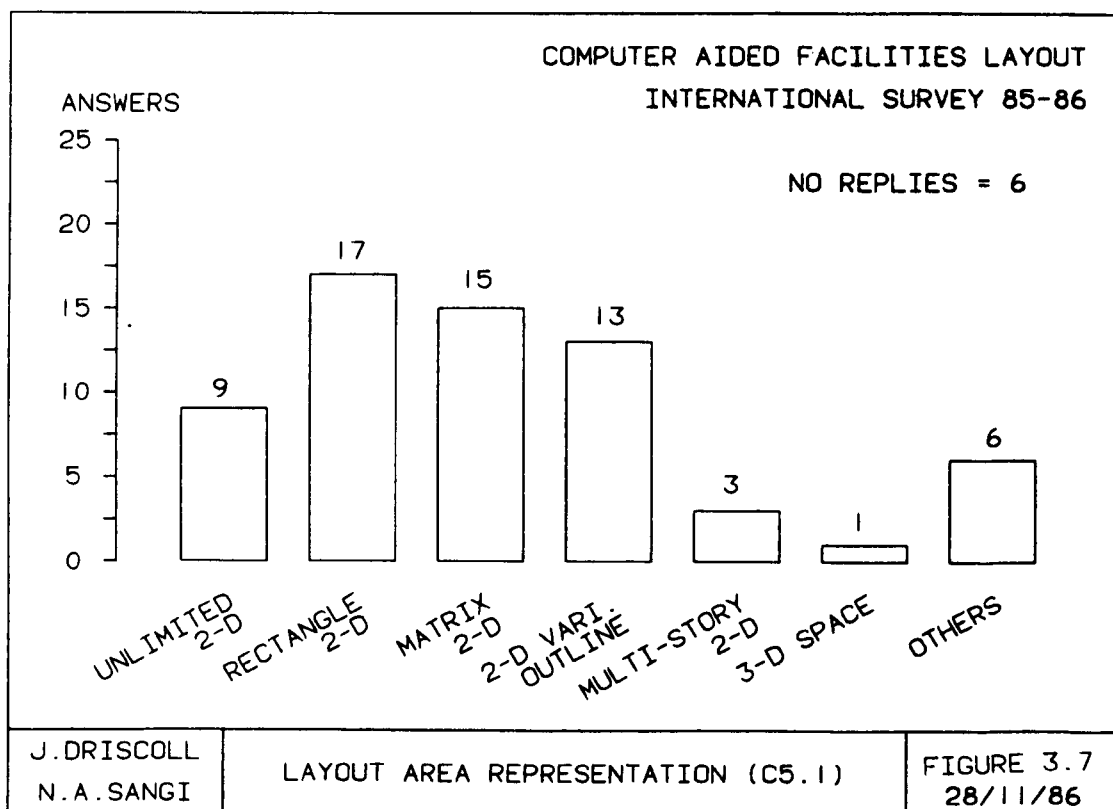
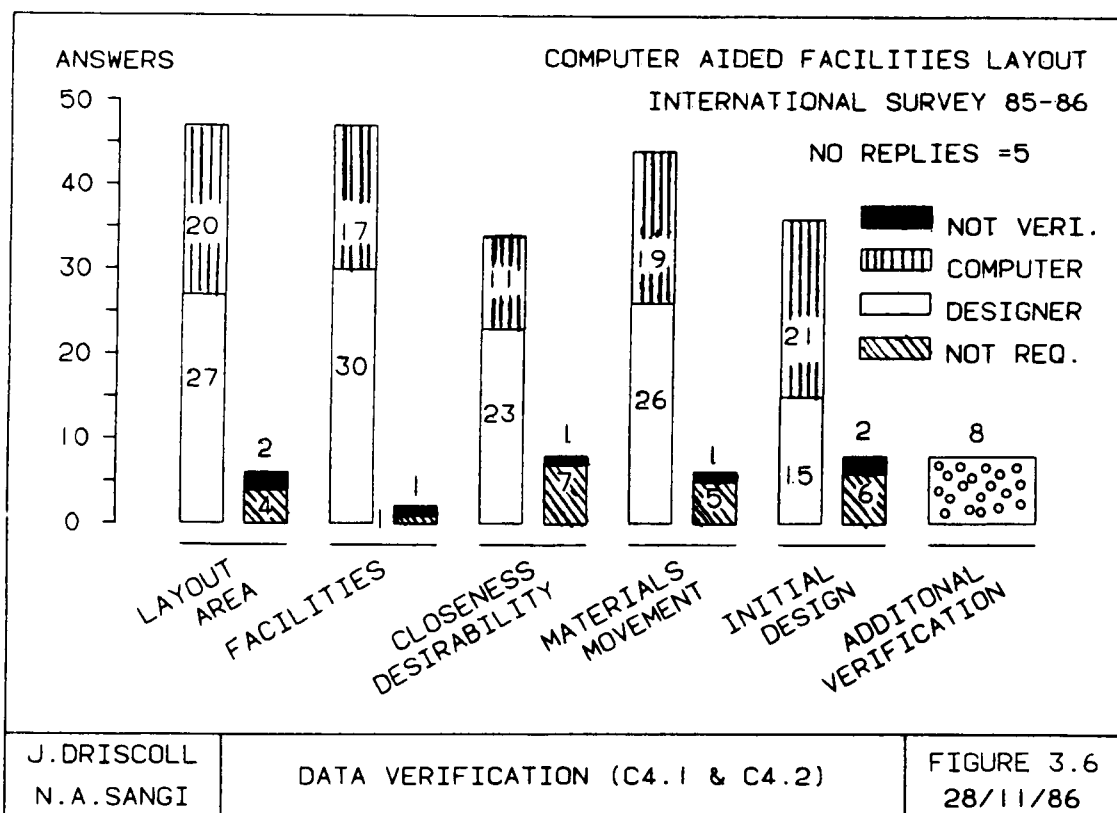
Survey Questions : C4.1 - C4.2 (Appendix [E1])

Illustrations : C10 (Appendix [E5])

Figure 3.6 shows the distribution of data verification across six categories of data. Initially the expectation would have been a high proportion of manual checking on image related subjects (e.g. layout area) and high proportion of computer checking on numeric data (e.g. materials movement). The actual results show an even distribution across all categories.

A hypothesis can be formed as to why this has occurred? Replies were given not on whether all aspects of say, layout area, were checked but on the basis that some kind of verification occurred. This of course could be restricted to a simple numeric parts of complex data fields.

This relationship between designer and computer is a relationship discussed from several views (interpretation, analysis, working methods etc.) in this thesis. From a data verification viewpoint where the designer is anticipated to be an "effective" means of analysis, he can be supported by designing or "structuring" carefully the the images presented during design process.



### **3.7.4 Problem Representation and Graphics**

Survey Questions : C5.1 - C5.5 (Appendix [E1])

Illustrations : C11 - C14 (Appendix [E5])

The quality of spatial representation (i.e. graphics) is a key factor in the eventual usefulness of CAFL software. Two main components that require graphical representation are layout area and facilities. Figure 3.7 and 3.8 show the survey response to layout area and facilities representation respectively.

#### **Layout Area**

The first significant group of programs, using matrix 2-D can be identified as aging first generation program. The more modern and those applications which are substantially CAD applications are represented in the 2-D variable outline and unlimited 2-D categories. Four experimental approaches (three multi story and one 3-D representation were identified.

The 'other' methods of representation relate to non dimensional approaches such as networks and directed graphs. SLPCALC did not require graphical representation as it is essentially spread sheet based supporting software.

#### **Facilities**

The first two methods (point and unit 2-D) covering (40% of answers) do not provide adequate practical representation and indicate first generation software. Although proportional matrix, in principle is an improvement and may represent the shapes and sizes of facilities, but it is still inconvenient to the designer and is again an indication of early line printer based software. This

"inconvenience" is caused by the need to write routines to control facility shapes and the restriction to thinking in terms of "coordinate axes" oriented building block shapes. In light of modern graphics available, these representations can no longer be considered satisfactory. Beyond 2-D representation, limited 3-D work has been identified.

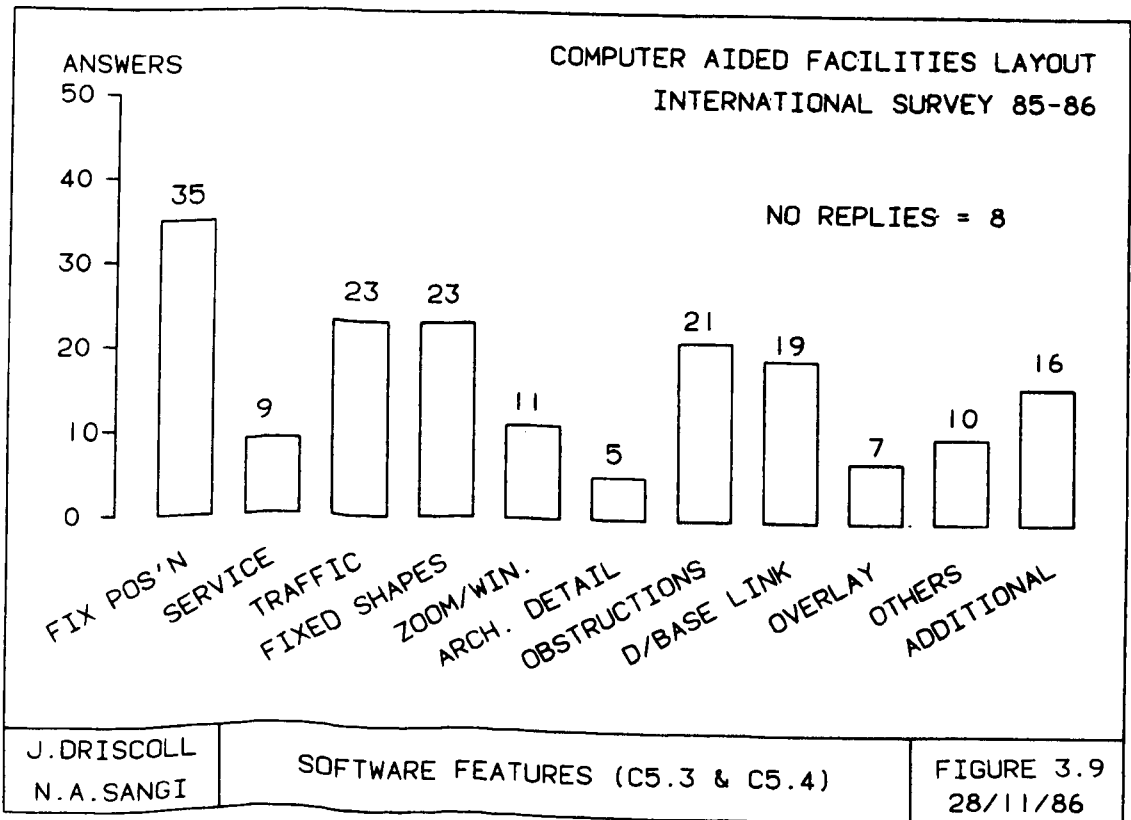
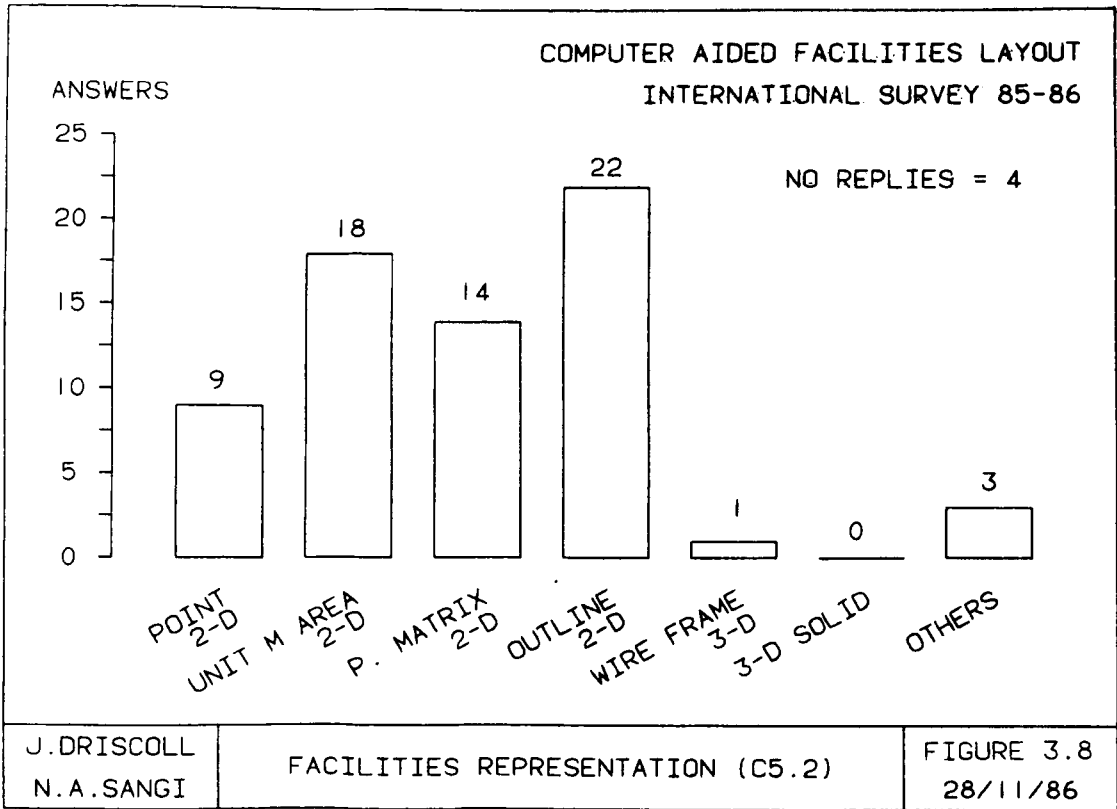
The median picture is therefore, of a 2-D variable outline for layout area and 2-D outline for facilities representation. The attractions of this combination are:

- 1) Affinity to drafting packages
- 2) Good visualisation
- 3) Economy of storage and processing.

Below this level of representation the problem is not adequately represented, above this level (e.g. 3-D) the cost in hardware, software and processing power is too high.

### **Software Features**

In order to enhance software packages, additional features may be included by individual software developers. Two types of additional features are identified; model representation related and software operation related. The survey response to software features is illustrated in Figure 3.9. Features like fixed position, traffic routes, fixed shape and obstructions can be seen as examples of increased problem representation and features like window/zoom, overlay and database link can be identified as software operation related features. On average, each program had two to three of these features. "Other" general features included specification of selection priorities, specialised warehouse layout, flow analysis and systems performance analysis.



The presence of CAD packages is identified from CAD related features, for example, window, zoom and/or overlay features which were found in 21% of packages listed. Further evidence of application of CAD was found in additional graphics features which included crosshatching, space evaluation, dimensioning, CAD interface and facility rotation.

The development of relationship between CAFL software (or CAD based CAFL package) and database is a theme exploited in some detail in the software development in this thesis.

The software feature analysis therefore reveals that proportionately more effort is put into adding problem related features than into enhancing general computing features.

### **Layout Activity**

The examination of layout activity i.e. the criteria used to represent action within software highlights two well used objectives; "inter facility movement" and "closeness desirability ". The survey shows that both methods were equally popular among software developers. Although answers to later survey questions indicate number of "dual" activity representation, where for example closeness desirability tables are used in inter facility movement models. The key point from the question of activity representation is the confirmation of high use of two well established criteria mentioned earlier. The 'activity list' (e.g. manufacturing program) related responses reflect to more realistic quantitative criteria based programs where actual manufacturing information is used to calculate quantities, cost and/or relationships.

### 3.7.5 Layout Design

Survey Questions : C6.1 - C6.4 (Appendix [E1])

Illustrations : C15 - C17 (Appendix [E5])

Earlier in Figure 3.5, improvement and construction procedures were identified, their popularity is recorded again in Figure 3.10. About one third of programs adapted a dual construction and improvement approach in which initially a layout is generated and then improved further in a second phase. The remainder of the programs specialised in either improvement or construction.

The survey identified two programs, INSITE-CAD and Versa CAD as drafting only approaches. The 20 programs which used special models include six operational research programs (e.g. linear programming, assignment problem etc.) and five simulation models.

Three programs marked as miscellaneous used additional features such as tree and spine shaped layouts based on a range of designer selected modes and group technology based approach. The review of design methods will concentrate on the highest used procedures; improvement and construction.

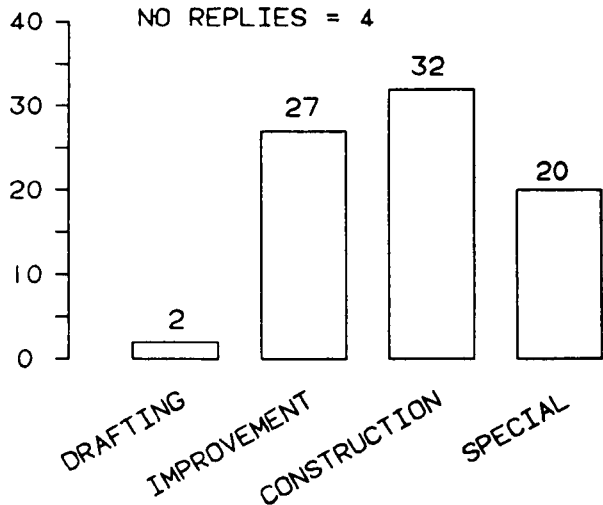
#### **Improvement Procedures**

The improvement procedures start with a given initial layout as data and improve this initial layout by an exchange and evaluation process. The improvement procedure may continue through many iterations, therefore a mechanism to direct improvement and to terminate solution generation is required. Features that influence this design process are; ability to fix facilities, the basis on which facilities are exchanged and whether facilities change shape during exchange. As improvement procedures start from an initial



COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

ANSWERS



SPECIAL	
CAPACITY PLANNING	1
CALCULATION AID	1
EXPERT SYSTEM	2
GRAPH THEORY	2
O.R MODELS	6
SIMULATION	5
MISCELLANEOUS	3

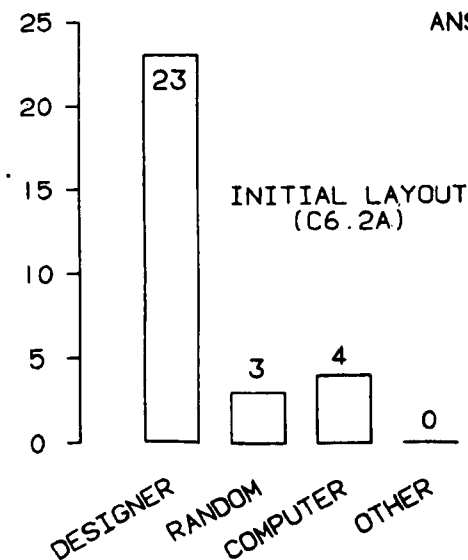
J.DRISCOLL  
N.A.SANGI

LAYOUT DESIGN PROCEDURES (C6.1 & C6.4)

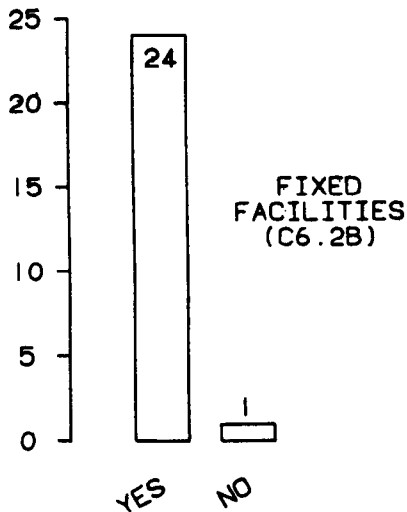
FIGURE 3.10  
28/11/86

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

ANSWERS



ANSWERS 25



J.DRISCOLL  
N.A.SANGI

IMPROVEMENT PROGRAMS (C6.2) CONT...

FIGURE 3.11A  
28/11/86

layout and improve the starting design progressively. This therefore results in a local optimum solution [1]. Some techniques consequently generate several starting solutions in an effort to hit the optimum solution. Improvement programs can be considered therefore in two parts i.e. the method of initial layout generation and the method of exchange for improvement. Figures 3.11a, 3.11b and 3.11c summarise the survey findings related to improvement programs.

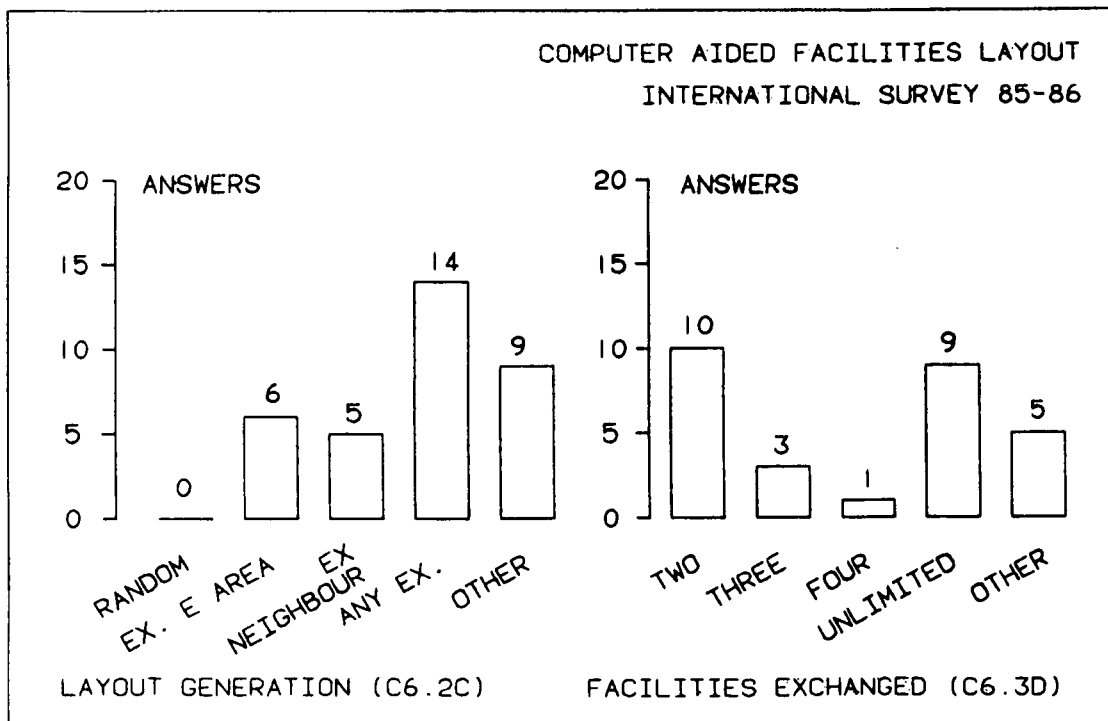
#### **a) Initial Layout Generation**

Initial layout generation is undertaken via designer input in 85% of improvement procedures. Three programs allow multiple choice layout generation. Fixed facilities on the initial layout is available in almost all improvement procedures. Note the availability of three random generation procedures (targeting optimal solutions) as mentioned earlier.

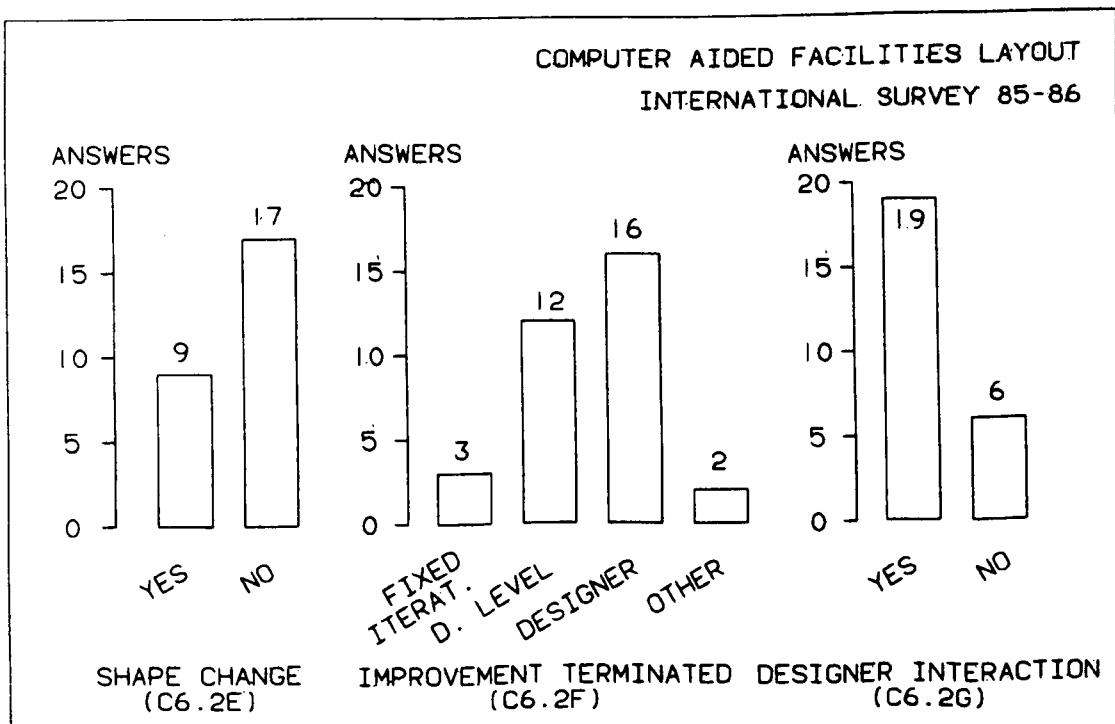
#### **b) Improvement**

The process of generating each new layout arrangement suggests about 11 packages allow equal area and/or neighbour exchange - a concept adapted from the original CRAFT program. About 14 packages are more liberal, allowing any exchange. The 'other' nine packages used different, non CRAFT like, approaches which included; designer selection (2), undefined graph theory algorithm (2), gravity movement (1) and refined exchange procedures (4).

Generally reducing the number of exchanges will reduce the computation time per iteration, and will increase the number of iterations required. The solutions produced by different levels of exchange may be quite different from each other. Restriction on number of exchanges is found in 10 packages. Three packages could



J.DRISCOLL N.A.SANGI	IMPROVEMENT PROGRAMS (C6.2) CONT...	FIGURE 3.11B 28/11/86
-------------------------	-------------------------------------	--------------------------



J.DRISCOLL N.A.SANGI	IMPROVEMENT PROGRAMS (C6.2)	FIGURE 3.11C 28/11/86
-------------------------	-----------------------------	--------------------------

allow two or three exchanges, whereas one package allows up to four exchanges each time. Nine procedures allow any number of exchanges. The 'other' five procedures allow designer to select the number of exchanges undertaken at one time.

The change of facility shape was required in older CRAFT type programs to maintain matrix boundaries. In order to prevent side effect of departments splitting, complex procedures would be required. In the case of many graphics based CAFL procedures, fixed shape templates are used, therefore higher number of 'no' answers is predictable.

A high proportion (16 out of 25) of designer termination of the iterative process is identified, as would be expected with previously identified 2:1 majority of interactive programs. Two programs terminated after achieving a satisfactory set goal (batch orientation). Question C6.2G assessing the level of designer interaction at any program stages, further supports increased designer involvement, where 76% designer control in improvement procedures is allowed.

### **Construction Procedures**

Construction procedures select and place facilities on an initially blank layout area in a "crystal growing" fashion, the layout process being completed when all facilities are placed. There were 32 programs which used construction procedures to design layouts. The results are given in Figures 3.12a and 3.12b.

Construction procedures generally require decisions at two stages; the selection of a facility for placement and the placement of that facility in the layout. The method of selection and for

placement has a strong influence on the efficiency of construction programs.

#### **a) Selection**

As shown in Figure 3.12a the majority programs equally offer designer choice and ranked selection. Half (eight) of the programs using a ranking method, do so on the basis of closeness desirability. Six programs use rank order of materials movement. Other ranking methods recorded were data entry order, level of constraint, and designer specified multiple criteria ranking.

Random selection, used in two programs, provides a method of searching for solutions where there is no indication that any particular criteria or method of selection is appropriate.

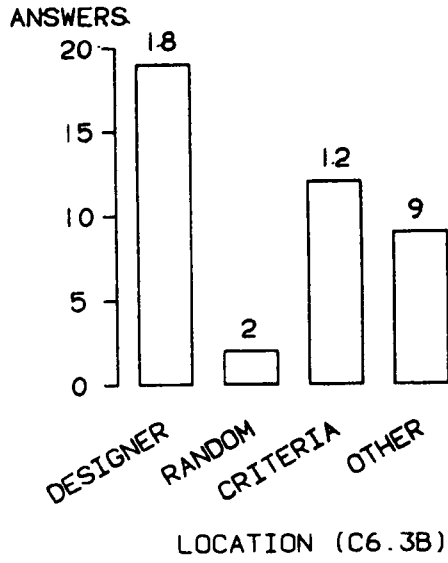
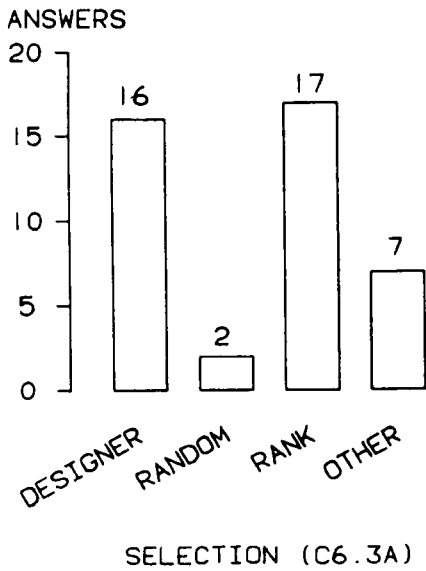
'Other' selection methods identified include; knowledge based interrogation, an adjacency structure, a tree search algorithm, a generalised algorithm and three undefined heuristics.

Combined designer choice and rule guided selection is considered the method of working appropriate to good layout construction software. To expand on this, it would be expected that the designer could best contribute by overseeing and changing, where applicable in individual case studies, the working of computer selection heuristics.

#### **b) Placement**

The second key decision in construction procedures is placement of each facility in the layout. Designer placement has been identified in the majority of programs, pointing; firstly to a healthy sign of designer directed CAFL software and secondly to the difficulty of writing software capable of placement.

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

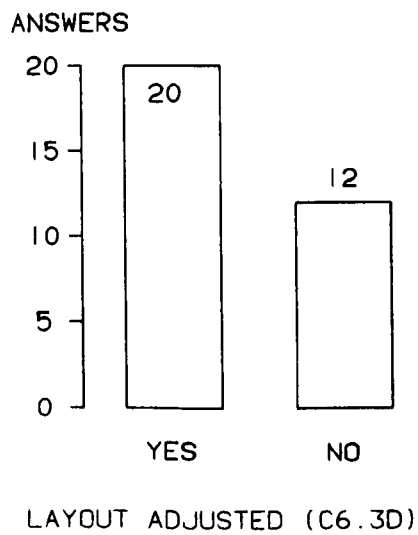
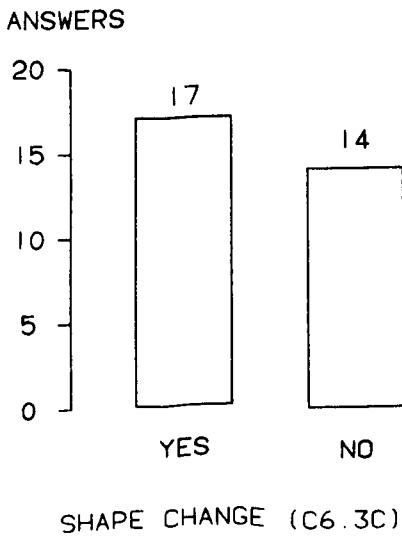


J.DRISCOLL  
N.A.SANGI

CONSTRUCTION PROGRAMS (C6.3) CON...

FIGURE 3.12A  
28/11/86

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86



J.DRISCOLL  
N.A.SANGI

CONSTRUCTION PROGRAMS (C6.3)

FIGURE 3.12B  
28/11/86

The placement process has again identified a high designer involvement. This is particularly understandable when placing facilities in a layout for two reasons:

1. The location, whilst satisfying the computer based criteria, may be failing other spatial, quantitative, qualitative or case study related criteria.
2. The shape of the the facility as constructed by the computer needs to be supervised to ensure realism.

Five of the better survey programs emphasised this designer - computer collaborative approach at the placement stage. Two construction programs (CADFLO and OFFICE) used a collaborative basis in both selection and placement .

The criteria based programs employ closeness desirability (4), materials movement and/or cost (3), multi model (2), graph theory (1) and undefined approaches (2).

The 'other' procedures included knowledge base, predefined pattern placement, a variety of assignment and graph theory models and two undefined methods.

In order to assess the practical value of construction programs, the question was asked whether layouts are adjusted manually after being completed by CAFL program. A high percentage (63%) of the construction programs require manual adjustment. This adjustment is required for two reasons. Firstly the old (matrix type) programs use special routines for maintaining shape of the departments. The departmental shapes, as stated earlier, are often not very practical for the process involved. Secondly, construction programs grow like a "crystal" and usually result in an irregular final building outline.

It was found that a quarter (eight) of construction programs do not allow any interference from the designer during the entire design and evaluation process. The practical usefulness of these programs is questioned by the reasons put forward in this analysis.

### **3.7.6 Layout Evaluation**

Survey Questions : C7.1 - C7.5 (Appendix [E1])

Illustrations : C18 - C21 (Appendix [E5])

Following the generation of layouts, it is necessary to evaluate the arrangement with respect to the initial objectives and to compare the solution with any competing alternatives. This evaluation can be undertaken from four viewpoints, namely; spatial, qualitative, quantitative and financial. Space related problems, require relative spacing and positioning of layout objects which in turn require graphical representation and visual examination of spatial positions.

Qualitative evaluation represents the unquantified merits of the layout which need to be considered (e.g. employee comfort, safety etc.). Programs which consider qualitative aspects usually develop closeness desirability tables. These models, (referred to as closeness desirability models), prepare one or more closeness desirability tables based on subjective rating of factors to be considered. The tables can then be merged, scaled and converted into numerical values, which are eventually used to evaluate layout score reflecting overall spatial proximity index.

Quantitative models make use of quantities and/or costs of flows between facilities. The from-to matrices of flow quantities and cost data are merged and evaluated to find the overall quantitative value/cost of any particular spatial arrangement. Usually total flow



(or flow cost) as a function of distance, is calculated to provide quantitative evaluation.

Financial evaluation considers all costs associated with commissioning of the layout projects and expected returns during operational life. This is particularly required for the majority of engineering layouts and projects.

The survey response to layout evaluation is shown in Figure 3.13. This shows that the quantitative criteria materials movement are present in 36 packages (70% of software). Forty percent of models use both qualitative and quantitative criteria, which is a move towards realistic evaluation of layouts. In all 27 (51%) of programs used closeness desirability, of which 11% used closeness desirability exclusively. A modest proportion of packages incorporated financial criteria (eight programs) accounting for 15% of software. An interesting fact was observed in, that none of the 'pure closeness desirability' models (11%), used financial criteria - a strong indicator of a limitation on the use of subjective criteria as they show an inability to relate to financial evaluation.

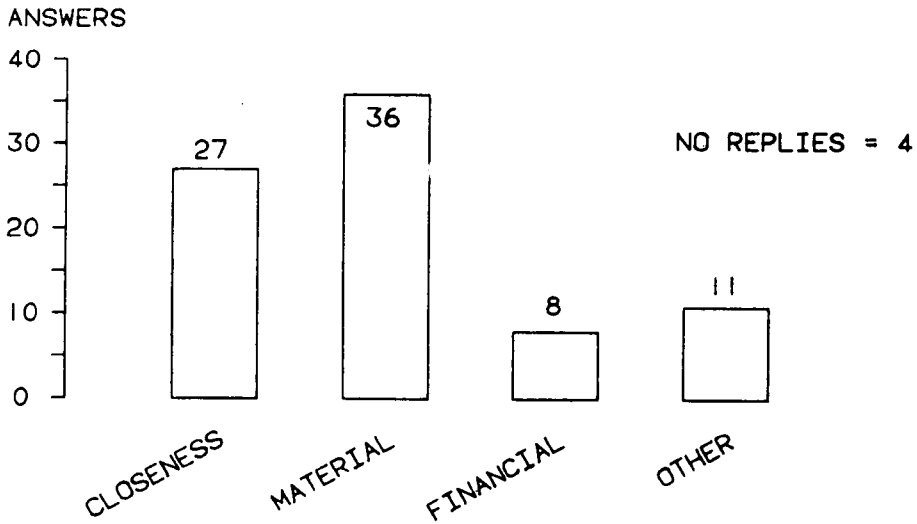
### **Closeness Desirability Models**

Twenty five programs (of 27 programs marked in Figure 3.13) were described in detail and the results are summarised in Figures 3.14a and 3.14b. Four major aspects of using closeness desirability are examined in the questions; nature of subjective scale, enumeration method, multiple factor subjective matrices and the scoring method.

#### **a) Subjective scale**

The subjective classification used by Muther [42] dominates the programs described in the survey, appearing in some form of software

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

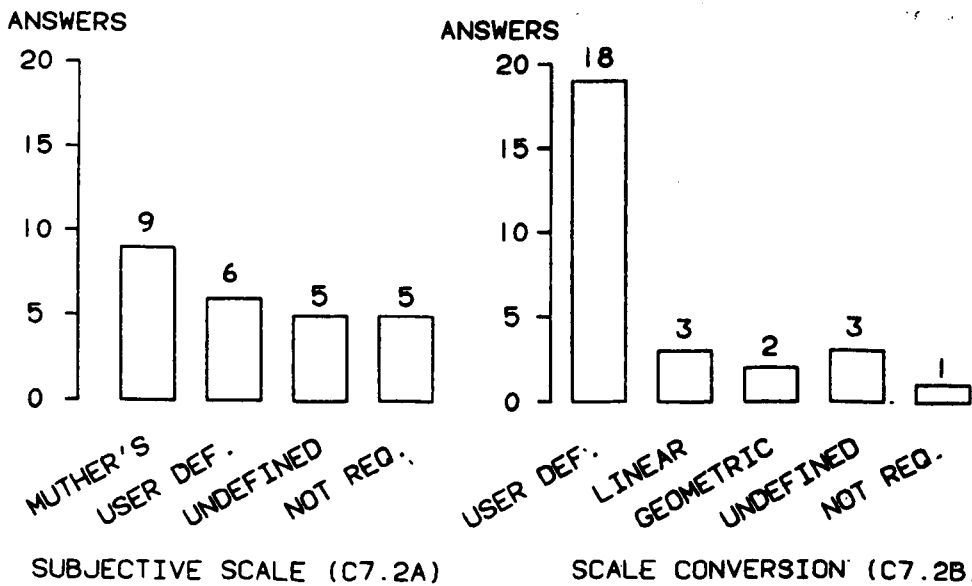


J.DRISCOLL  
N.A.SANGI

LAYOUT EVALUATION (C7.1 & C7.5)

FIGURE 3.13  
28/11/86

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86



J.DRISCOLL  
N.A.SANGI

CLOSENESS DESIRABILITY MODELS (C7.2)  
CONT...

FIGURE 3.14A  
28/11/86

programs. User defined classification was available in six programs and five responses were indefinite about the approach used. One major difficulty with the Muther's approach is resolving the conversion of subjective classifications into numerate value as Muthers' scales have no indication of linearity.

#### **b) Enumeration method**

Conversion to a numerate scale is dominantly defined by the users (i.e. user gives values to classifications). A few programs start with preset values which can be amended by users. With such a high appearance of user definition of scale conversion the ability to compare and evaluate scores become doubtful. Five programs bypassed subjective classifications and entered direct numerate values.

#### **c) Multiple matrices**

In evaluating qualitative relationships, two concepts can be built into procedures; the single composite entry and the individual detailed review. Single composite means the designer takes all factors in account and balances them, entering as a consequence a single closeness desirability value. Thus avoids the question of merging the matrices.

The individual factor approach has a separate matrix for each variable of importance or for each expert opinion. The question then arises as to how to relatively judge these matrices. Ten program used multiple matrices of which two programs used more than one method of combining.

#### **d) Layout scoring**

The layout scoring methods employed are shown in Figure 3.14b. This shows boundary detection is used in the majority of replies.

This method can be criticised for three reasons; designer manipulation of boundaries, non matrix layout prove difficult in defining neighbours and no indication of the effect of distance on the relationship values.

Summarising closeness desirability models, the procedures in which so much of individual test cases is left to designer judgement makes these procedures overall suspect.

### **Materials Movement Models**

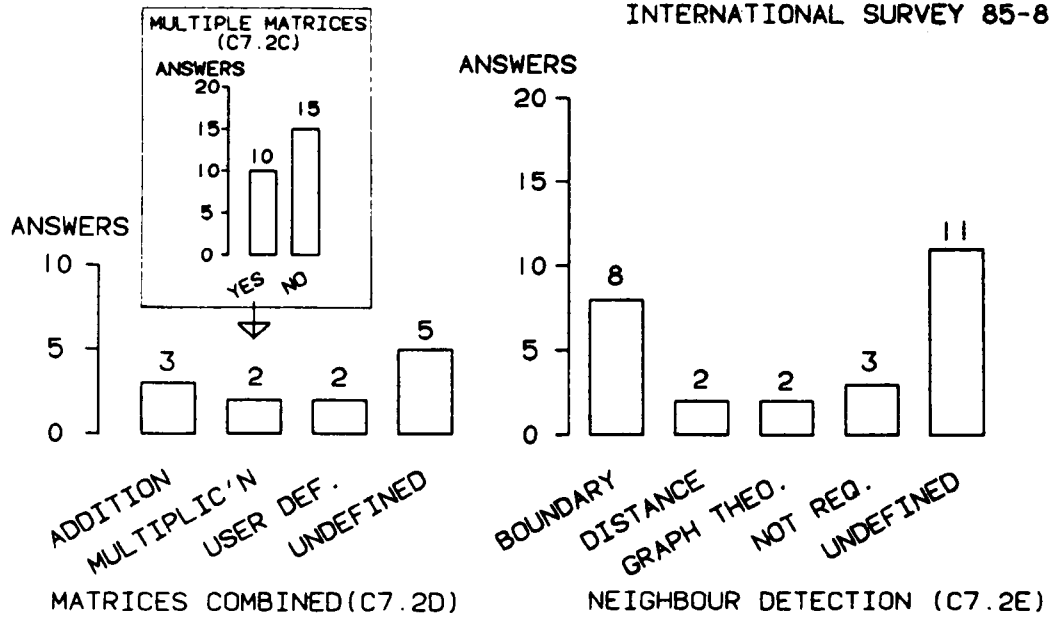
The two important factors of material movement models are; distance calculation and conversion of distance into flow and/or material handling cost for layout evaluation.

#### **a) Distance calculation**

The method of distance calculation (e.g. rectangular, straight line, traffic system) and the start and end of each journey (e.g. centre to centre, load and unload points) influence the quality of answer produced. The survey results, as illustrated in Figure 3.15a, show that 18 programs use straight line distances and 22 programs allow rectangular distances. Thirteen programs, representing over one third, allow both choices. Only 12 programs allow for any form of traffic system. Interestingly, six programs allow for full choice (i.e. straight line, rectangular and traffic system) which is considered a very good, realistic approach. The 'other' replies include move times (two), flow structure (one) and not required (one).

Twenty one of the programs have no alternative to straight line or rectangular coordinate distance measurement. In modern manufacturing these approaches are going to be inaccurate due to

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

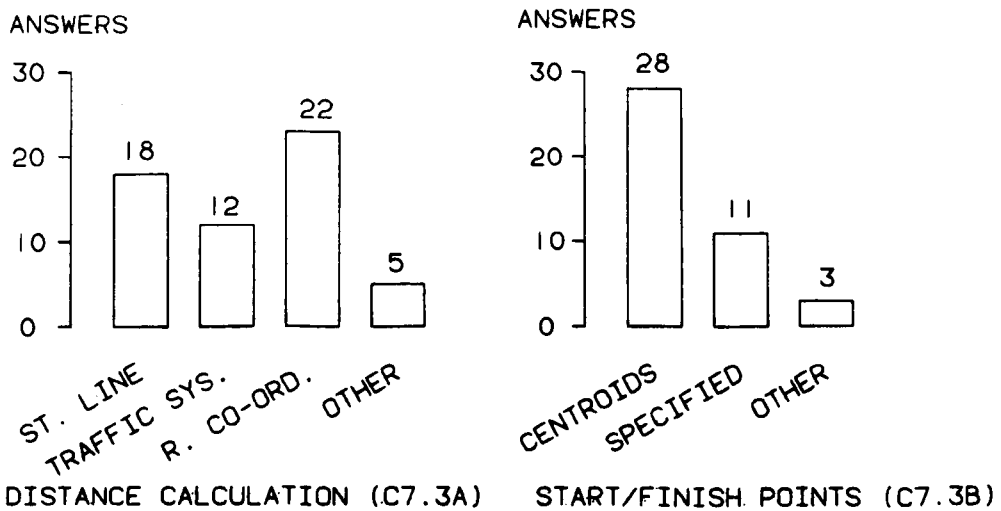


J.DRISCOLL  
N.A.SANGI

CLOSENESS DESIRABILITY MODELS (C7.2)

FIGURE 3.14B  
28/11/86

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86



J.DRISCOLL  
N.A.SANGI

MATERIAL MOVEMENT MODELS (C7.3) CONT...

FIGURE 3.15A  
28/11/86

complex Automated Guided Vehicle (AGV) movement patterns etc. and therefore raise question over the long term value of the packages concerned.

#### **b) Distance conversion**

The survey results, shown in Figure 3.15b, indicate that majority of programs use either distance (13 occasions) or proportional cost with distances (14 occasions). The more sophisticated approach of distance proportional cost plus fixed element costing of move has been used in six programs.

Previous researchers (e.g. [11] and [1]) have identified the limitations of a movement only model and the latter six programs are supported as showing a move in the direction of more accurate costing calculation.

Understanding how individual programs evaluate materials movement is an essential part of evaluating each program's usefulness. Considerable errors can occur with the more simplistic methods and two part journey calculation is seen as more appropriate.

#### **Financial Evaluation**

Two important tasks in financial evaluation are the appraisal of layout costs and time related project costs/benefits. Only eight respondents were positive about the inclusion of financial evaluation in programs, of which, seven considered combined installation costs and material handling savings. Four programs considered production loss costs, whilst, only three programs worked out production benefits. One program MS-S1-4 listed under category, 'other', claimed that six different cost calculations were available in five

combinations. The most popular technique used for financial evaluation was found to be discounted cash flow.

The importance of financial evaluation can not be overstated. Phillips and Muther [43], in the survey of practitioners, indicated that economic objectives were ranked the largest philosophy group behind layout projects. Financial objectives can be considered the universal comparator when assessing projects i.e. financial comparisons or evaluations can readily be understood and are therefore considered in this work as a long term objective of any CAFL software.

### **Special Approaches**

The 11 procedures marked as "other" in Figure 3.13 consist of six simulation orientated system performance models, one multi criteria model, two architectural related programs, two hybrid models (combination of placement cost and materials movement cost) and one undefined evaluation model.

Section C as can be seen from the original survey document, is the most substantial section within the survey. Seven points of particular relation to the direction of work within this thesis are drawn at this point.

- The only really acceptable form of working is interactive design procedure. The problem with its complex relationships, requires a designer involvement and present computers simply can not match with graphical scanning ability of the designer.
- Strong graphics is now available to support interactive working. The implementation of high quality graphics (mainly through CAD packages is already in evidence, in the survey) as having started. Every effort should be made to replace first

generation, lineprinter oriented graphics which is still very much in evidence.

- Improvement and construction models are well established and have been accepted by the CAFL community. They therefore provide a basis, for design procedures, that would support a new graphics enhanced model.
- Material movement and closeness desirability are also well established as two widely accepted evaluation approaches. One or both of these, therefore can be used in new graphics enhanced CAFL approach.
- Use of micro computer is beginning to dominate CAFL research. Two polarisation cases are possible:

- a) A low cost micro computer - low cost CAD package based solution approach widely disseminated.
- b) A mainframe computer - advanced graphics based solution tailored towards customer base of specific CAD packages.

### **3.8 SURVEY SECTION D : MARKETING OF CAFL SOFTWARE**

General objective: To identify CAFL packages available for commercial third party use.

Survey Questions      D1    (Appendix [E1])  
illustrations          D1    (Appendix [E5])

At the onset of the survey one area of identified interest was the desire to collate and analyse information on an expected large population of commercially available CAFL packages. This expectation



was not fulfilled and in the event only a small group of 11 packages were identified in replies.

Two reasons are identified as cause of a low commercial activity returns. Firstly the CAFL development source is mainly academics where general objectives are education, training and excellence in research and development. Such development is generally difficult to adapt for a wider audience of practitioners. Secondly there was very little evidence of involvement of major software companies in true CAFL. Corporate activities were limited to either supplying older, unsupported, first generation software or the use of drafting package in CAFL. Two consecutive surveys by Filley [17], [18] further reinforced the corporate software house view that CAD is a fully suitable tool for layout planning.

It must be emphasised that CAFL is computer modelling and analysis of all three forms, namely; spatial, quantitative and qualitative, and not only one or two of these forms as in drafting based CAD.

The survey response identified eleven packages offered by six respondents. Four new packages were identified in this section making the running total 90 packages identified so far. The programs identified in this section are listed in Table 3.3.

Three points are drawn from the limited response to this section of the survey :

- The indication is that microcomputers are seen to have greater commercial potential than main frames.
- At least four of the 11 packages are known to be pure CAD or derivatives of drafting packages, reinforcing the point that software suppliers consider CAD drafting as CAFL solution.

- At least six programs are of academic origin and subject to all the limitations of nonprofessional software.

**Table 3.3 Programs Identified in Section D**

<b>Program</b>	<b>Computer Type</b>	<b>Principle Function</b>
1. CADAPPLE	Micro	CAD
2. CAFL	Mainframe	CAFL
3. CUTFIT	Mini	Branch and Bound - space problem
4. INSITE	-	CAFL space administration
7. INSITE-CAD	Micro	CAD based space administration
8. INTERLAY	-	Branch and Bound
5. SLPCALC	Micro	CAFL project costing
6. SPACEPLAN 3000	Micro	CAD
9. TYMCALC	Micro	General I.E. use
10. VersaCAD	Micro	CAD
11. WAD	Micro	Warehouse Design

### **3.9 SURVEY SECTION E : USERS OF CAFL SOFTWARE**

General objective: To assess the usability of a range of CAFL packages.

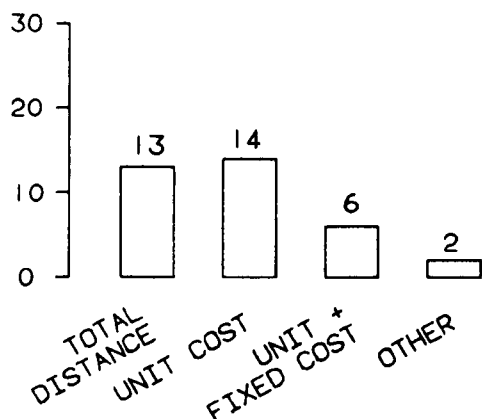
Survey Questions E1 - E3 (Appendix [E1])

Illustrations E1 - E4 (Appendix [E5])

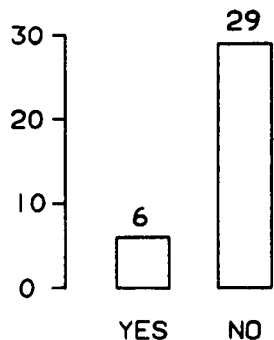
In order to compliment CAFL authors contribution in section C of the survey, user responses were requested of CAFL software being used. Twenty five respondents replied, identifying 64 package evaluations related to 26 unique packages. Eleven of the programs had not been previously identified and therefore increasing the total of known CAFL programs to 101 packages.

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

ANSWERS



ANSWERS



DISTANCE CONVERSION (C7.3C)

M H SYSTEM SELECTION (C7.3D)

J.DRISCOLL  
N.A.SANGI

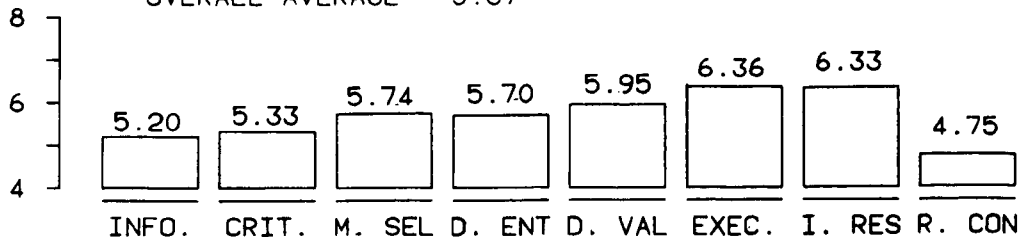
MATERIAL MOVEMENT MODELS (C7.3)

FIGURE 3.15B  
28/11/86

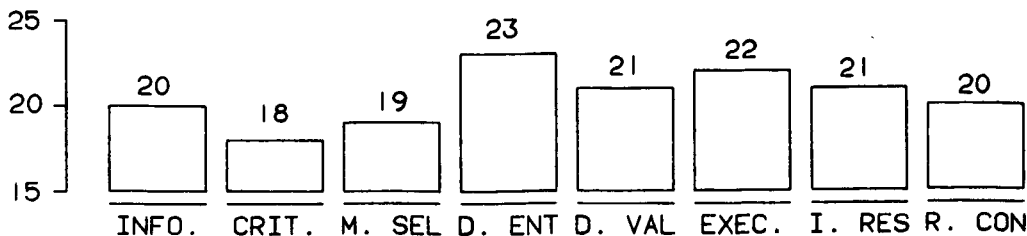
COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

AVERAGE

OVERALL AVERAGE = 5.67



ANSWERS



J.DRISCOLL  
N.A.SANGI

SOFTWARE USEABILITY RATINGS (E2)

FIGURE 3.16  
28/11/86

The contribution of this important survey section is to examine from a user viewpoint, the strengths and weaknesses of applied CAFL packages.

### **3.9.1 Application Experience**

The respondents who assisted in this section of the survey can be considered as an experienced peer group, with an average of 4.85 years using CAFL software and with only 25% showing less than one year experience.

In terms of packages, three quarters of respondents had experience of two or more CAFL packages. The breadth of application experience was also wide. Forty two percent of applications were in the industrial sector and nonproduction related (offices, buildings and warehouse layout) experience covers another 40%.

The high quality of the respondents to this section make the results of section E of particular value in reviewing the state of CAFL.

### **3.9.2 Software Usability**

The use of CAFL software involves three main stages; pre-execution, execution and post-execution. At the pre-execution stage identification of the problem, data collection and computer program selection is carried out. At the next stage, data is entered, validated and the program is executed. In the final stage, output of the program is received and has to be validated for its practicality.

The rating of ease of use at each of these stages is illustrated in Figure 3.16, where an interesting pattern emerges from the average score results. The initial formulation of problems into a computer suitable format proved the most difficult phase of using CAFL software. Difficulty progressively reduced once the CAFL program was applied.

However, significantly, the conversion of program results into practical layouts found to be most difficult task identified by majority of users. One major cause of this considerable readjustment is the absence of CAD based realistic representation of the layout problem.

### 3.9.3 User Opinion of Software Features

The responses to this series of questions (Question E3 A-D) gives a unique opportunity to assess expert opinion on both the detail of packages and overall performance at the same time.

Analysis of package content is divided into three parts; input and execution features (Figure 3.17a), design and evaluation features (Figure 3.17b) and output and graphics features (Figure 3.17c). For each question the number of occurrences is obtained on a ranked opinion of its value (on a scale 0= non existent to 9= excellent).

The opportunity has been taken to reassess the data collected and analysed in the survey report. This reassessment has basically excluded any "zero" (i.e. non existent) ratings as an identification of the feature not being available. This allows a stronger examination of the frequency of occurrence and the usefulness of the feature, as shown in Table 3.4.

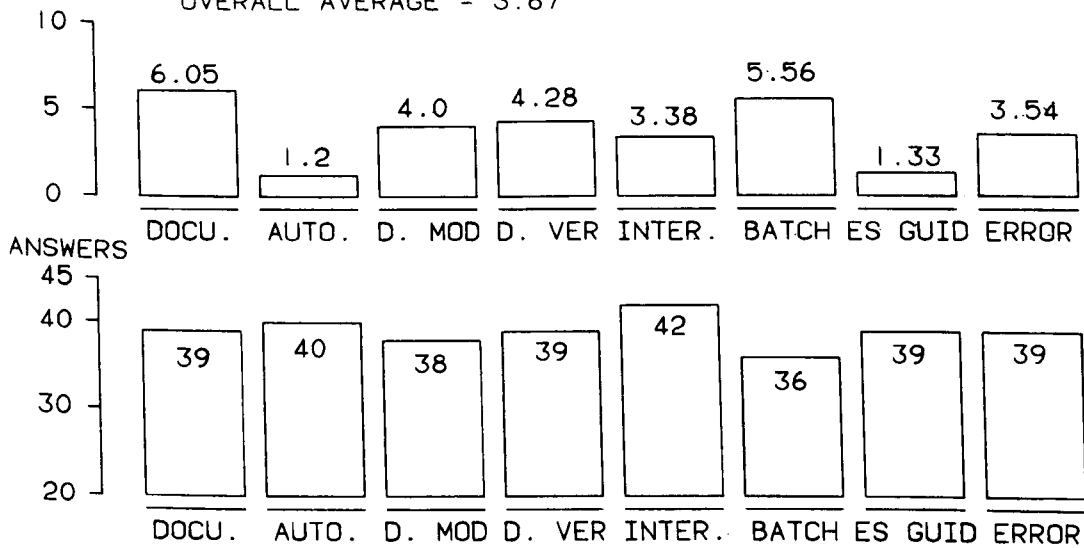
The first comment that can be drawn from Table 3.4, is the existence of an overall good rating of 6.43. This rating impression is reinforced later in the overall user opinion.

Taking input and execution features, the average rating was 6.28, with the highest rated feature being interactive working at 7.47. Automated data entry, although rated satisfactory, only occurs in eight programs, with manual data modification and verification still prevalent in an average 24 programs. This supports the current use of a "designer - computer" interactive working relationship.

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

AVERAGE

OVERALL AVERAGE = 3.67



J.DRISCOLL  
N.A.SANGI

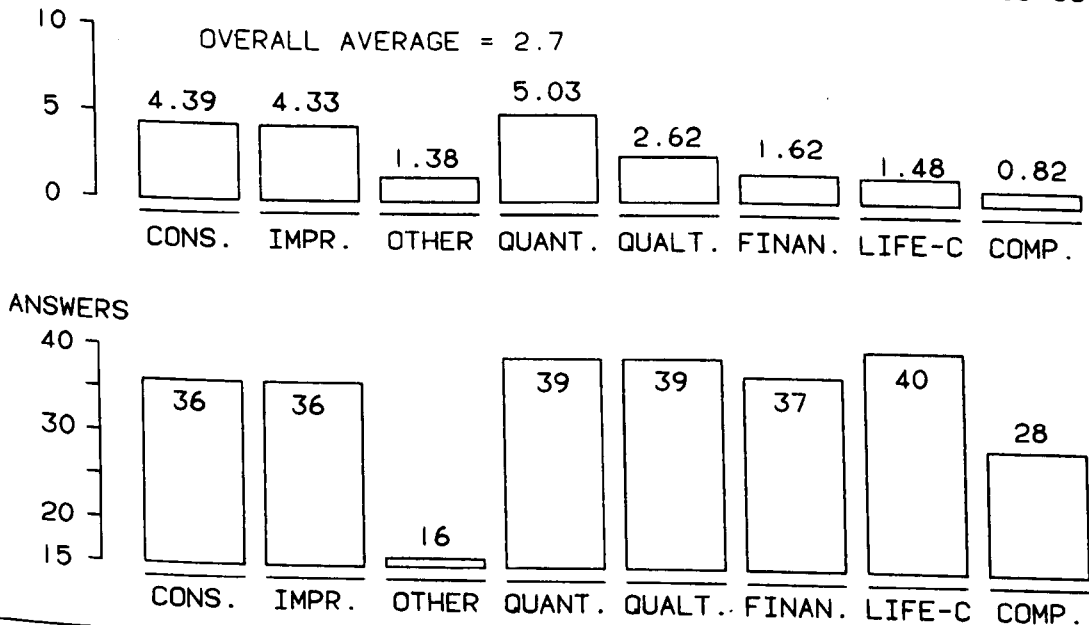
INPUT AND EXECUTION FEATURES (E3A)

FIGURE 3.17A  
28/11/86

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

AVERAGE

OVERALL AVERAGE = 2.7



J.DRISCOLL  
N.A.SANGI

DESIGN AND EVALUATION FEATURES (E3A)

FIGURE 3.17B  
28/11/86

**Table 3.4 Reassessment of CAFL Software Effectiveness**

<b>Software Feature</b>	<b>Total Replies</b>	<b>Zero Entries</b>	<b>Net Avail.</b>	<b>Total Ranking</b>	<b>Average Ranking</b>
<b>Input and execution features</b>					
Good documentation	39	2	37	236	6.38
Automated data collection	40	32	8	48	6.00
Data modification	38	15	23	152	6.60
Data verification	39	14	25	167	6.68
Interactive working	42	23	19	142	7.47
Batch background operation	36	5	31	200	6.45
Expert system guidance	39	30	9	52	5.78
Error diagnostics	39	11	28	138	4.93
				(group average 6.28)	
<b>Design and evaluation features</b>					
Construction layouts	36	13	23	158	6.87
Improvement layouts	36	13	23	156	6.78
Other (please specify)...	16	12	4	22	5.50
Quantitative evaluation	39	7	32	196	6.13
Qualitative evaluation	39	20	19	102	5.37
Financial criteria	37	27	10	60	6.00
Life-cycle costing	40	30	10	59	5.90
Complex (please specify) ...	28	24	4	23	5.75
				(group average 6.04)	
<b>Output and graphics features</b>					
On-line graphics	35	24	11	71	6.45
2-D	40	12	28	202	7.21
3-D	38	36	2	17	8.50
Solid modelling	38	36	2	13	6.50
Colour	37	30	7	42	6.00
Line printer	35	4	31	178	5.74
Graphical drawings	34	14	20	130	6.50
Other (please specify) ...	20	19	1	9	9.00
				(group average 6.99)	
				(overall average 6.43)	

The ability of a designer to carry out verification work on layout problems more efficiently than computer is supported by the low opinion of computerised error diagnostics at the lowest recorded value 4.93.

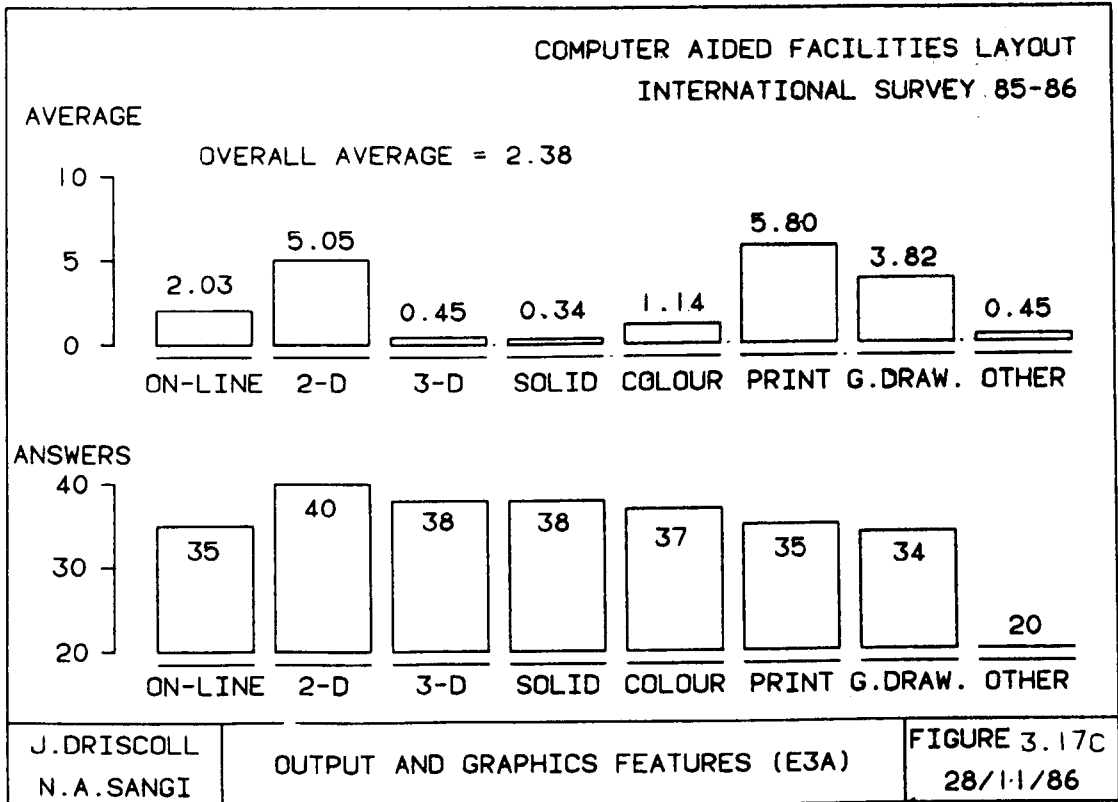
Design and evaluation features rated a satisfactory 6.04. The two common procedures, construction and improvement rated highly at 6.87 and 6.78 respectively. The subsequent evaluation procedures showed a preference for quantitative analysis with 32 responses, average 6.13 on the 1-9 scale. Qualitative evaluation models were used less (19 occasions) and rated less favourably at 5.37.

The most highly praised section of software was the output and graphics section at average of 7.0. However this includes low frequency highly praised occurrences of 3-D, solid modelling and other (miscellaneous) output procedures, there being five entries between the three subjects. Excluding these, the average is 6.38, still quite creditable.

An important point can be drawn from the existence of 28 responses on 2-D representation, which were very frequent and highly praised with rating reaching 7.21. The conclusion that can be drawn from this is that 2-D is conceived as an excellent and essential part of facilities layout planning.

The ability of CAD packages to provide this graphics imaging is identified by 15 occurrences (11 on-line graphics, two 3-D and two solid modellers).





### Overall Usability

The overall users opinion of software shows a healthy rating, with 51% of software rated good and an additional 33% being usable. As stated earlier, the high overall rating of software correlates to the ratings on individual package components under the revised analysis of user opinion.

### Shortcomings and Additional Features

Users of CAFL software however have not become complacent about the standard of software. Eighty eight percent of respondents have identified shortcomings in software used and 80% have requested additional features in future software.

The frequent criticisms concern batch working mode and unsatisfactory evaluation procedures. Batch working mode has been

**Table 3.5 User Listed Shortcomings and Additional Features.**

<b>Shortcomings</b>	<b>Frequency</b>	<b>Additional features</b>	<b>Frequency</b>
<b>Operational Features</b>			
Batch mode	12	Interactive mode	18
Difficult to use	3	Decision support systems	3
No graphics	6	Better graphics or CAD	18
No solid modelling	3	PC version	2
Poor processing	2		
<b>Model Features</b>			
Evaluation not good enough	14	Financial evaluation	9
Impractical layout	5	Practical layouts	5
Insufficient flexibility	2	Multiple model	5
Model philosophy weak	6	Real optimisation	5
No layout design stage	3	MH Systems design	1

continuously criticised in this thesis as unnecessary with present computing resources and as not a good feature of any design system. Critics of poor evaluation is indicative of the simplistic models still in use. The next significant criticism are lack of graphics, impractical layouts and weak model philosophy.

Lack of graphics and production of impractical layouts are strong supporting cases for the model approach developed later in this thesis, where advanced CAD is introduced to an interactive CAFL design procedure. Further support for the approach taken later, comes from the identification of better graphics and interactive working as the most desired additional features.

The users analysis provides us three indicators as to the direction of further work in CAFL :

- The quality of graphical representation has to be improved as evidenced by the necessity shown to adjust computer generated layouts into practical layouts. Further support of better

graphics comes from the high appearance of requests for better graphics in user justification.

- The use of a single criteria has been criticised as weak in CAFL design. This is further evidence as to multiple criteria, interactive procedures. Designer oriented approach would be desirable.

### **3.10 SURVEY SECTION F : USER COMMENTS**

At the end of the survey respondents were given the opportunity to add any comments that would extend the value of the survey. In all 23 comments were received, out of which 12 contained specific information on the subject of CAFL. All 12 are reproduced at this point along with a brief interpretation of the significance of the comment.

#### **Comments on the Role of CAFL**

- 1 "Computer Aided Facilities Layout is not used to any great extent by anyone. Some users will make a first pass at macro level layout. A detailed layout analysis cannot be done with the level of software available today. Some users fake the use of routines but in the long run they really develop the final layout manually."
- 2 "If you want to get more from academics the questions need to be reformed - most of their software work is likely to be like mine experimental, where ease of use and speed etc are secondary considerations; all we need to do is solve a particular problem in the absence of suitable commercial software."

- 3 "..... is a consulting firm with specialisation in facilities planning and material handling. We have seen a number of people with desires to use CAFL but with no understanding of the limitations or appropriate applications. More education in this area is necessary for user understanding."

The second and third comment support the view that current approaches to the CAFL are concerned largely with academic experimental software not particularly attuned to the needs of potential industrial users. The consequences of this are indicated in comment one, where compromises are being made in the use of CAFL software and results are frequently in need of CAFL practical adjustment.

#### **Comments on the Direction of CAFL Research**

- 4 "..... the [survey] orientation is toward single algorithm and single criterion softwares. We believe that this kind of software is moving toward obsolescence since we should move away from model competition and toward collaboration, based on the premise that some model or approach behaves better in some cases than others and that by combining the output of different models we can achieve better designs."
- 5 "The most time consuming and tedious part of a project is data development and conversion to a reusable form, modular software is required. Integrable layout, material handling, storage, mapping, piping, alternative layout developed and manual(s) [are] necessary".

- 6 "Well. I feel that the computerised facilities planning is not taking a new direction. Currently I am working on 'Layout problem in FMS', where you just can't apply the same idea and one might need more sophistication, in the area of mathematical modelling, graph theory and queueing theory before, developing software to solve these problems."
- 7 "Commonly available CAD systems in layout design e.g. \*\*\*\*\* Inc. are normally without the basic improvement facilities. They are difficult to use and lack flexibility. Although interactive computing is available there are usually severe limitations in this area."
- 8 "Our firm is interested in integrating a graphical simulation package software such as 'SEE WHY' with a facilities database in the VAX computer to study dynamically the throughput of parts based on different layout alternatives. For management review a picture is worth a thousand words as they say."

Comment seven is further confirmation of the need for CAFL software based on more than the core CAD package. Interestingly the author gives an indication that developing interactive CAD-analysis likes, which would give CAFL, is not going to be an easy process.

Comment four and six indicate a dissatisfaction with single criteria models. Both comments support a multi criteria approach as being appropriate to the class of problems referred to as CAFL.

Comment five and eight open up the question of how to deal with layout problems that are detailed, complex multi criteria and case study dependant. The indicated solution approach, strongly supported

in the work of this thesis, is the development of structured CAD database capable of multi level working and capable of being linked to external software.

### **Comments on Specific Approaches**

9 "In the past we have utilised CRAFT and CORELAP but currently see little practicality for their use. Our experience with the programs has been for starting point layouts only. We do use computer assistance with simulation, including graphics simulation, and for computer-aided drafting. Because of many variables ignored in CAFL, as well as the inherent bias resulting from the user input, I question the application for CAFL for more than starting point layouts. Programs such as CRAFT assume linear cost penalties associated with distance. This, of course, is rarely the case, particularly where automated material handling systems are in place.

Activity relationship programs suffer from the same limitation, an unrealistic cost penalty (or score) associated with good or bad proximity relationships. Additionally, user bias will frequently result in a solution very close to what may have been generated without any computer assistance.

Because the cost equations associated with layout relationships will differ from company to company, depending on the material handling system, the methods and the manufacturing philosophy, the use of a 'generic' CAFL program may be limited. Where distance costs are close to linear (i.e. warehousing) the programs such as CRAFT may be meaningful."

This is an excellent overview of the present CAFL position from an experienced U.S. consultant. Many key points associated with defining the present state of the art are in three comments including; limited usefulness of first generation, application specific software, doubts over single criterion, oversimplified models and the resorting to pure simulation and CAD drafting packages in the absence of good CAFL software.

### **Miscellaneous Comments**

- 10 "A professional CAFL INTERNATIONAL ASSOCIATION may be formed and time to time problems of interest may be circulated amongst members".
- 11 "Importantly many CAFL programs are proprietary and not available except at tremendous cost. It will be interesting to use what features users feel such programs should have and/or what CAFL programs should be able to do for them."
- 12 "The concept is to produce an interactive program controlled directly by the project/production manager responsible for the operation allowing judgmental over-ride at appropriate places"

The comment 12 gives a view supported with this research and commented upon previously.

### **3.11 COMPARISON OF SURVEYS**

Opportunity was taken in the original survey report [13] to compare selected results of the current survey and the other four surveys (Moore [39], Moore [41], Hales [26] and Muther and Phillips [43]) described earlier in this chapter. The comparative analysis is

reproduced in this section from the original survey report with corrected reference numbers corresponding to the reference list of this thesis.

The survey of Computer Aided Facilities Layout described in this report can be considered, hopefully with his blessing, as the descendant of James Moore's international survey of software published in 1974 [39]. Between the two surveys there have been a collection of general software reviews and three notable national surveys of CAFL users, two within the United States of America from Hales in 1979 [26] and Muther and Phillips in 1983 [43] and one covering the United States and the United Kingdom by Moore in 1978 [41].

The comprehensive nature of the present survey, covering both software and users, gives an opportunity to compare results in selected fields. This is undertaken in the understanding that none of the surveys used the same questions, polled the same sample or had the same objectives in undertaking the work. The comparisons therefore, based in some cases on the interpretations of the report authors, should be considered as a guide to changes in direction that have taken place over the last decade.

The comparisons to be made fall into three subject areas; characteristics of the people involved in CAFL, selected points of CAFL software program structures and opinions of the usefulness of CAFL.

### **3.11.1 Practitioners of CAFL**

The experience of CAFL users, identified on the basis of maximum years of software package use, can be compared with the length of experience of general facilities planning practitioners, as



identified in the surveys carried out in the last decade, those of Muther and Phillips [43], Moore [39] and Hales [26]. The comparison statistics are reproduced in Tables 3.6 and 3.7.

**TABLE 3.6 Comparison of Current, Moore and Hales Surveys.**

	DRISCOLL-SANGI *-----*	MOORE *-----*			HALES *---*
Year	1986		1978		1978
Place	International	USA	UK	Total	USA
Participants	21*	175	110	285	126
Length of user experience	%	%	%	%	%
Less than a year	5	17	8	14	30
Between 1-5 years	62 (1.0-5.0)	31	28	30	40
Over 5 years	33 (100)	52 (100)	64 (100)	56 (100)	30 (100)

\* 21 Respondents answered question E1A.

Fewer users of computerised facilities planning are in the 'novice' less than one year category than with the wider Moore, Hales and Muther surveys. This is balanced by fewer CAFL users having long term experience.

**TABLE 3.7 Comparison of Current and Muther and Phillips Surveys.**

	DRISCOLL-SANGI *-----*	MUTHER AND PHILLIPS *-----*
Year	1986	1976-82
Place	International	USA
Participants	21*	463
Length of user experience	%	%
Less than a year	5	25.0
Between 1-2 years	28 (1.00- 2.0)	18.8
Between 2-10 years	57 (2.01-10.0)	38.7
Over 10 years	10 (100)	17.5 (100.0)

\* 21 Respondents answered question E1A.

### 3.11.2 Procedures within CAFL Programs

#### Types of programs

Both the Moore international software survey and the present survey have reviewed the types of CAFL program developed by contributors and the comparative figures are shown in Table 3.8.

Comparing the two sets of statistics two changes are observable over the intervening decade; the balance between construction and improvement models and the application of new approaches. The newer survey indicates a closer pairing between construction and improvement models at 34% and 41% respectively. At the same time the emergence of simulation and the introduction of expert systems are evidence of the new software tools emerging from the field of computing.

**TABLE 3.8 Comparison of Program Types.**

	DRISCOLL-SANGI *-----*	MOORE *-----*
Year	1986	1974
Place	International	International
Total Programs	56	26
Program type	%	%
Construction	32 (41)	22 (63)
Improvement	27 (34)	10 (28)
Graph theory	2 ( 2)	1 ( 3)
Drafting	2 ( 2)	
OR Models	6 ( 7)	
Expert Systems	2 ( 2)	
Simulation	5 ( 6)	
Others	5 ( 6)	2 ( 6)
	(100)	(100)

Examine next the question of computer language employed as shown in Table 3.9. FORTRAN, the long serving engineer's mainframe language tops both surveys. Note however the considerable growth in the use

of BASIC with a 14% increase in share of languages applied, strongly indicative of the role now being played by micro computers. The second change of interest is the growing proliferation of languages

**TABLE 3.9 Comparison of Program Languages.**

	DRISCOLL-SANGI *-----*	MOORE *-----*
Year	1986	1974
Place	International	International
Language	%	%
Fortran	31 (49)	21 (75)
Algol	1 ( 1)	4 (14)
Basic	12 (18)	1 ( 4)
Assembler	1 ( 1)	
Pascal	6 ( 9)	
C	3 ( 5)	
Prolog	3 ( 5)	
Others	8 (12)	2 ( 7)
	(100)	(100)

in use, the present survey identifying 12 in total. This is going to produce a few problems if authors become interested in exchanging software.

Types of output has been examined in both the present and previous Moore survey, the comparative results being listed in Table 3.10.

The most significant change, readily identified and strongly indicative of the shift to higher levels of problem visualisation, is the move away from lineprinter output to screen based graphics. The 10% VDU use identified by Moore has now grown to a 44% level and includes colour graphics.

TABLE 3.10 Comparison of Output Devices.

		DRISCOLL-SANGI *-----*		MOORE *-----*	
Year		1986		1974	
Place		International		International	
Device		%		%	
Printer	Matrix			22	(46)
	List			11	(23)
	All	36	(35)	33	(69)
Plotter		21	(20)	8	(17)
Tube VDU	Alphanumeric	10	(10)		
	Mono graphics	19	(18)		
	Colour graphics	16	(16)		
	All	45	(44)	5	(10)
Others		1	( 1)	2	( 4)
			(100)		(100)

### 3.11.3 The Use of CAFL

Moore's 1978 survey and the present survey contain information on difficulties encountered by users of CAFL software. In the case of the Moore survey the difficulties were identified by direct questioning. For the present survey the responses to questions E2 and E3A were analysed by selecting any rating of 3 or less given in an answer, indicative of difficulty or an even worse response. Documentation is the first entry of question E3A, input data the first entry of E2, data entry and validation the fourth and fifth entries of E2, running the software the sixth entry of E2 and error diagnostics the seventh entry of E3A. The results obtained are listed in Table 3.11.

The difficulty of obtaining input data has eased, perhaps through the availability of far better micro computer and mainframe data bases. With increased expectations derived perhaps from the

**TABLE 3.11 Selection of Problems Encountered by CAFL Users**

Year Place	DRISCOLL-SANGI	MOORE		
	*-----*	*-----*		
	1986 International	1978 USA - UK		
Difficulty		USA	UK	Total
	%	%	%	%
Documentation	9 (20)	2 ( 8)	3 (30)	5 (14)
Obtaining input data	6 (13)	14 (54)	3 (30)	17 (47)
Data entry and validation	9 (20)	5 (19)	2 (20)	7 (19)
Running the software	3 ( 7)	3 (11)	2 (20)	5 (14)
Error diagnostics	18 (40) (100)	2 ( 8) (100)	0 ( 0) (100)	2 ( 6) (100)

higher quality micro packages the rating of documentation and error diagnostics now shows more perceived difficulty. Overall the comparison shows no consistency of problems.

The development of CAFL owes a historic debt to those early CAFL packages which helped establish the subject in the early 1960's. Characterised by matrix representation of facilities and layout areas

**TABLE 3.12 Popularity of First Generation CAFL Programs**

Year Place	DRISCOLL-SANGI	MOORE			
	*-----*	*-----*			
	1986 International	1978 USA - UK			
Package		USA	UK	Total	
CRAFT	13	25	3	28	41
CORELAP	10	17	2	19	29
ALDEP	10	11	2	13	23
PLANET	5	5	0	5	10
Totals	38	58	7	65	103

and the use of simple criteria for layout assessment, CRAFT is perhaps the best known example. Worthy of the title advanced in their day, these programs have proved durable with the passage of time. The extent of this durability appears in both the Moore 1978 survey and in the present survey as can be seen from Table 3.12 which lists popular packages used by survey respondents.

CRAFT, as can be seen, is still in use and has spread widely throughout the CAFL community, no doubt assisted by its availability through the IBM Shares Library. A commendation must go to Michael Deisenroth whose PLANET, straight out of university research, is popular amongst the construction programs.

There is however another view of the appearance of these first generation programs amongst the list of software being applied in the field. The public and professional perception of computing has moved on. The sophisticated CAD images of 3-D displays, kinematics and colour detail are expected of software dealing with problems of space and relative positioning. Continued use of these early programs therefore will result in a deteriorating industrial and commercial valuation of the subject of CAFL.

**TABLE 3.13 Comparison of Usefulness of Software.**

Year Sample Place	DRISCOLL-SANGI *-----*			MOORE *-----*			MOORE *-----*		
	1986 Authors-Users International			1978 User UK USA Total			1974 Authors International		
Usefulness	%			%			%		
Very good	5								
Good	17	22	(51)	Very	3 (27)	18 (36)	21 (35)	Extremely	10 (50)
Usable	14								
Weak	6	20	(47)	Marginal	8 (73)	29 (62)	37 (63)	Marginally	8 (40)
Very poor	1	1	( 2)	Time Waste	0 ( 0)	1 ( 2)	1 ( 2)	Useless	2 (10)
			(100)		(100)	(100)	(100)		(100)

Finally, consider this question of the value placed on CAFL programs as perceived over the past decade and reproduced from three surveys in Table 13.

The comparative figures between the two international surveys, both predominantly based on software author's comments, have changed little over the past decade. Around 50% of responses in both surveys indicate a high opinion of software and both indicate very little complete dissatisfaction. Users of CAFL software, as polled in the 1978 survey, are harder in their assessment, for although few felt software was a waste of time the majority (63%) found CAFL packages of only marginal use.

### **3.12 COLLECTED SUMMARY COMMENTS AND CONCLUSIONS**

The collected comments and conclusions presented at this point are drawn directly from the published report of this work. Minor changes have been made following the reassessment of section E: user opinions (see article 3.9), and these changes are indicated (marked with \*) where they occur.

#### **3.12.1 The Research and Development Effort in CAFL**

CAFL activity is of international interest, with the largest effort being maintained in the United States of America.

- 24 countries identified
- 59% of responses from the USA.

The publishers of CAFL software are mainly academics.

- 66% of responses estimated as academics.

CAFL development effort is growing exponentially and contains a nucleus of permanently committed researchers.

- 18 new research programmes started in the 1980's
- \* - 44 new packages or models started in the 1980's  
(more than the cumulative total to 1980)
- 52% questionnaire response from previous researchers
- 82% of respondents continuing CAFL work
- 48% of respondents involved in the development of more than one package.

CAFL effort is concentrated on model development and not on applications.

- 70% response to software development as the area of interest
- low 27% professional support for software development groups
- low 6 replies and 11 packages described in commercial applications.

CAFL research is undertaken by multi-disciplinary teams developing multiple software packages.

- 64% of teams are multi-disciplinary
- 75% dominance of teams by Industrial (Production) Engineers, OR-Systems and Computer Science disciplines
- Average team size is 3.9 people
- Average team commitment to date is 5.7 man years
- The average software development effort is 3.08 man years
- Consequently the average number of packages developed is 1.8
- only 26% of research effort by sole authors.



The further exchange of experience, software and development ideas on an international level would benefit the subject.

- Authors conclusion
- Section F respondent comment 10.

### **3.12.2 Computer Hardware and Languages**

The majority of software is still mainframe or minicomputer orientated.

- 72% of software on multi-user systems
- 57% FORTRAN use indicative of mainframe models.

Micro computer based applications are a significant growth area.

- 28% of software based on recently available micro computers
- 22% use of BASIC indicative of micro applications.

Over the next five years activity on mainframes will concentrate on making use of advanced graphics and data base facilities.

- Authors conclusion
- Comments on CAFL graphics shortcomings and desirable features.

Micro computers will undertake higher levels of CAFL work as they become more integrated with mainframe and as internal processing and memory requirements improve. Micros are particularly suited to the requirements of small and medium companies and will consequently open a wider CAFL market.

- Authors conclusion.

### 3.12.3 CAFL Software

#### Operational Characteristics and Applications

Interactive working is now the dominant working mode.

- 76% of programs capable of interactive working
- 59% of improvement programs are designer terminated, indicative of interactive working
- 70% of improvement programs include designer interaction
- 50% of construction programs involve designer selection of facilities for placement
- 56% of construction programs use designer placement of facilities
- 12 criticisms of batch working are recorded in Section E shortcomings
- 18 requests for interactive working are recorded in Section E desirable features.

The nature of CAFL, with spatial, quantitative and qualitative criteria to be considered at all design stages makes interactive working a necessity.

- Authors conclusion
- See Section F respondent comment 12.

Improvement and construction programs are still in the majority.

- 81% of software analysed is capable of improvement or construction approaches.

First generation matrix representation CAFL software is still available and being used.

- 40% of facility representations are impractical point and unit area
- 64% of responses to Section E, 'The use of CAFL software', related to CRAFT like first generation programs.

First generation programs are now dated in the light of modern computer capability.

- Authors conclusion
- 6 criticisms of model philosophy recorded in Section E shortcomings
- Further criticisms in the graphics section
- Criticism in Section F respondent comment 9.

New procedures and software are being applied to CAFL problems.

- The use of AI languages PROLOG and LISP
- 23% of Section C CAFL models perceived as AI-ES procedures
- The appearance of simulation languages SLAM, GASP and ECSL
- The application of spreadsheet packages LOTUS and VISICALC
- See Section F respondent comment 8.

Problem size is not a restriction on applications.

- The average capacity of software packages is 60 facilities
- 30% of software capable of dealing with over 100 facilities.

Preparing test case to be applied in software and the conversion of software results to realistic layouts suggest limitations on current software.

- Data entry and the conversion of results to practical layouts considered the most difficult CAFL tasks by Section E replies

- The opinion of software used was reduced to an overall average response of 2.9 on a scale of 0 (nonexistence) to 9 (excellence) by the lack of desirable features, a Section E response.
- \* (Overall rating reached 6.43 after zero entries were excluded)
- See Section F respondent comment 5.

Too low a standard is being set for overall software performance.

- Authors conclusion
- Section E overall ratings of usable 33% and good 40% contradict critical detailed analysis figures.
- \* (New overall rating of features (6.43) conforms with overall usability rating)

## **Graphics**

First generation lineprinter related representation fails to meet facility layout requirements.

- Authors conclusion
- 9 user criticisms on the lack of graphics are recorded in Section E shortcomings
- 18 requests for more graphics are recorded in Section E desirable features.

There is an improvement in the level of graphical problem representation.

- 26% of computer input devices are graphics related
- 61% of software supported by graphics screens
- 9 CAD and 4 Gino-F applications identified
- 37% of software includes drafting features.

### **Construction Models**

Construction models have a high designer-computer interaction level.

- 50% of construction models allow designer selection for placement
- 56% designer placement of facilities
- 63% manual adjustment of final solutions.

### **Improvement Models**

The starting layouts for improvement procedures can generally be manipulated to fit actual test case.

- 77% designer input of initial layouts
- Almost universal availability of fixed facilities.

The exchange procedures for providing the next layout pattern are generally restricted in their choice.

- 32% of responses indicate a restriction on the possible candidates for exchange
- 67% of responses indicate a restriction on the number of facilities exchanged each iteration.

There is a possibility of shape change problems during the iterative improvement process.

- 35% of software allows shape change
- Exotic rules are required to control new shape generation.

There is now high designer interaction in improvement procedures.

- 48% designer termination of improvement process
- 76% defined designer interaction

Improvement programs produce local optimums at best.

- Authors comment.

### **Evaluation**

Simple single criterion evaluation procedures fail to adequately analyse the complexities of facility layout tasks.

- Authors conclusion
- 14 criticisms of existing evaluation models recorded in Section E shortcomings
- 5 requests for multi-criteria evaluation recorded in Section E desirable features
- The low rating for evaluation procedures, the absence of financial models being the cause

\* (Only low frequency of evaluation models except quantitative models)

- Criticism in Section F respondent comment 4
- Criticism in Section F respondent comment 9.

Analysis of industrial CAFL problems involves a technical evaluation and a financial evaluation. Evaluation procedures should be capable of both.

- Authors conclusion
- 9 requests for financial evaluation recorded under Section E desirable features.

Closeness desirability and materials movement are the two most widely used criteria.

- 25 closeness desirability models and 35 materials movement models described in detail.

Closeness desirability models are suspect in interpretation of results.

- Original Muther like qualitative judgements based on loose definitions
- 67% of conversion to numeric values subject to designer control
- 60% use of a single relationship matrix suggestive of over simplification
- Methods of 'scoring' layouts open to abuse.

Materials movement models are suspect of not reflecting true materials movement.

- 67% use of centroid to centroid distances
- 70% use of straight line or rectangular coordinate distances.

Financial models are emerging to meet analysis requirements

- 4 packages involve life-cycle analysis
- 8 applications of financial evaluation procedures.

An area of CAFL development will be the production of modular interchangeable evaluation models

- Authors conclusion
- See Section F respondent comment 4
- See Section F respondent comment 5.

#### **3.12.4 The Marketing of CAFL Software**

The level of commercial use of CAFL software is low.

- Only 6 responses to survey Section D
- Only 11 packages listed which included 4 pure CAD packages
- Criticism in Section F respondent comment 1.

Commercial CAFL software is frequently restricted to CAD only packages.

- Authors experience
- 4 out of 11 packages in the marketing replies are CAD only
- See Section F respondent comment 7.

### 3.12.5 CAD and CAFL

CAD systems are related to and employed in CAFL.

- 7 commercial packages identified in software employed
- 2 additional packages identified in layout design analysis
- 4 kinematics and 1 3-D CAD applications identified
- 59% of authors perceive CAFL as an area of CAD
- 33% of software utilises 2-D variable outline facilities
- Zoom, window and overlay functions available on 21% of analysed software
- 4 out of 11 commercial CAFL responses relate to pure CAD packages.

CAD imaging, without CAFL analysis, is being employed.

- 36% of software has no lineprinter output
- 34% of software does not undertake analysis.

The use of CAD only does not meet the analytical requirements of facility layout and is therefore not adequate.

- Author conclusion
- Criticism in Section F respondent comment 7.



A measurable advance in CAFL is achieved when a high quality multi-level CAD system can be linked to modular analytical software.

- Authors conclusion
- See reference [12]
- See Section F respondent comment 5.

### **3.13 THE DIRECTION OF FUTURE WORK**

The analysis and survey of CAFL up to this point has identified a number of directions in which a new contribution to the subject can be made. Within this work the following scenario for CAFL research is proposed:

#### **The CAFL Model**

1. To implement a CAD based approach as a mechanism for providing the high quality graphics requirement.
2. To define within a selected, widely available CAD format, a structured graphics data base suitable for long term CAFL development.
3. To experiment with the development of software for the exchange of information between the graphics data base and associated analysis or external software.
4. To undertake this work within an applied industrial framework.

## **CHAPTER 4**

### **INTEGRATING CAD AND CAFL**

## CHAPTER 4

### INTEGRATING CAD AND CAFL

#### 4.1 CHAPTER OBJECTIVES

From the previous reviews, one strong contender for advancing the state of the art of Computer Aided Facilities Layout would be to extend further the role played by CAD. Two options are suggested; the use of a mainframe based CAD approach and the use of a microcomputer based CAD approach. The microcomputer option has some strong attractions, most notably the potential use by a wider audience of users. The choice however, has been made in this research to examine the role that an advanced mainframe CAD system could play in aiding the design of facilities for a more selective user base. This choice, has been influenced by installation of new powerful computing resources at Liverpool University and the subsequent challenge to pioneer the use of this equipment. It is acknowledged however, that both micro and mainframe options were considered as equally attractive approaches. Two objectives are set in this Chapter :

1. Specify the attributes of an ideal CAFL package.
2. Develop a conceptual framework of a practical CAD-CAFL package within the specifications of an ideal CAFL package.

#### 4.2 ATTRIBUTES OF AN IDEAL CAFL PACKAGE

Within the international survey, section C (software content) and section E (user analysis) identified many of the desirable

attributes in an ideal CAFL package. Three main attributes of a CAFL package have been previously defined by Driscoll and Sangi [12], and are reproduced in this section (Figure 4.1) for further expansion with respect to the graphical, quantitative and qualitative aspects of layout design.

- A. To represent accurately the components of the modelling process being employed.
- B. To possess qualities that ensure an effective interface between model(s) and the designer.

The variety of problem situations, models and evaluation criteria that can be employed in layout planning projects places a third requirement on more sophisticated software:

- C. The ability to adjust software with relative ease (versatility).

#### **4.2.1 Modelling**

In the original work [12] three attributes were listed with respect to the processes of modelling (Figure 4.1). A more detailed expansion of these, produces 16 problem modelling attributes.

#### **Graphical Modelling**

##### **a) Component images**

For individual components of the layout problem (facilities or layout areas) :

1. Quality graphics
2. Dimensionally accurate representation

3. Clear explanation of images being projected
4. A well established procedure for image generation

#### **b) Composite images**

When images of components are to be merged into composite layout drawing :

5. Versatility in combined images
6. Low level of confusion and ambiguity in the composites being produced
7. Efficiency of computer use

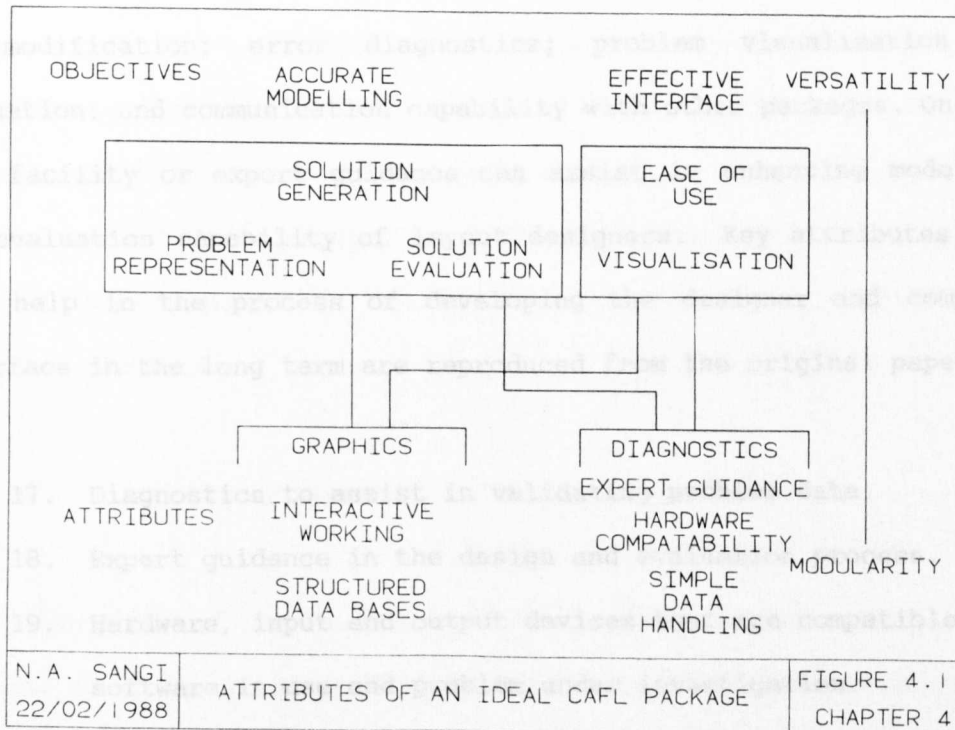
The key to success with each of these desirable attributes lies with two originally quoted features i.e. the existence and use of structured databases and quality graphics for realistic visualisation.

#### **Quantitative Modelling**

The qualitative aspects of CAFL can be examined from a point of view of how analysis takes place and what analysis takes place. The principal attributes describing an ideal CAFL package are :

8. On-line "quick" analysis for designers
9. The ability to transfer location data for subsequent background analysis.
10. The allowance of modular selection of multiple combination evaluation models
11. The existence of models that are credible in the manufacturing systems environment.
12. The existence of appropriate screen and hard copy report formats

These desirable attributes relate once again to the key existence of structured databases (this time on the manufacturing database side) and interactive working.



### Qualitative Modelling

No detailed manufacturing system layout can be produced without consideration of non quantifiable criteria. Therefore attributes associated with qualitative modelling include :

13. Provide the ability to allow designer changes
14. Provide support information (basic decision support system)
15. Potentially provide expert guidance (to assist designer to act "objectively" as opposed to "subjectively")
16. Record designer decisions

#### 4.2.2 Interfacing

The CAFL software performs the communication task between computer and the designer, in a manner dictated by the modelling approach. Typically the designers can be "non-computer expert" engineers who will require guidance in; data preparation, loading and its modification; error diagnostics; problem visualisation and evaluation; and communication capability with other packages. On-line help facility or expert guidance can assist in enhancing modelling and evaluation capability of layout designers. Key attributes that will help in the process of developing the designer and computer interface in the long term are reproduced from the original paper :

17. Diagnostics to assist in validating problem data.
18. Expert guidance in the design and evaluation process.
19. Hardware, input and output devices that are compatible with software in use and problem under investigation.
20. Software routines that permit simple data handling.

The first two attributes are seen as long term requirement whilst the second two interfacing attributes are required now to take advantage of modern computing resources.

Interfacing should be visualised both as an internal task (graphics - designer - data structures) and an external task (CAD - CAFL - Specialised Analytical package) with the long term additional attribute of :

21. Communications ability with pre and post layout design software.

### 4.2.3 Versatility

Generally CAFL software has shown to be problem and model specific. Modelling should be extended to incorporate multiple criteria in multiple combinations to suit a wide range of users. Choice in selection of criteria and application area, suitability to problem type, level of detail and type of information needed by the designer are important aids to flexible design procedures. Flexible and open ended software architecture will allow continued extension and development to cope with more diverse situations where desired. The attribute capable of meeting this versatility requirement is stated in the paper :

22. A modular approach to CAFL software development.

Twenty two of the most significant attributes of an ideal CAFL package have been identified. Four principle philosophies are identified from these attributes as fundamental to effective CAFL software applications :

1. The use of a structured approach in the recording and use of all forms of data.
2. High quality graphics based realistic problem representation.
3. A modular software approach capable of versatility, expansion and interfacing.
4. A high quality designer oriented design environment.

The four philosophies are considered through the specification of a CAFL model, described in the rest of this chapter and in the later experimental work.



### 4.3 THE CAD-CAFL PHILOSOPHY

The overall philosophy proposed in the second part of this thesis can be stated as :

**"The development of a structured and detailed graphics database for facilities planning can be seen as an essential part of the next generation of CAFL software packages. The subsequent combination of this (graphics) database with manufacturing (alpha numeric) database and analytical software will form the next generation of CAFL software packages."**

It can be seen therefore that, in this work the primary task involves the defining and generation of graphics database. The secondary objective is then the starting of work on linking, via geometry software, the graphical and non graphical information with analytical programs. In this context it is therefore felt important that an industrial layout problem be set to be used within the research program and as will be shown later, it was possible with help of Lucas Industries to achieve this objective.

The reminder of this chapter therefore concentrates on developing a theoretical CAFL model and following chapters will discuss the programs associated with development and testing graphics database and interface software.

The second research contribution within this thesis is therefore concerned with specifying a model and a philosophy for long term CAD based design and subsequently implementing initial software and database development.

The programme of work undertaken follows closely the order of presentation in this thesis and can be summarised as following :

- A. The development of a graphics data structure and theoretical model.
- B. Experimentation on the compilation of a solid model library of facilities.
- C. Experimentation on the transfer of 3-D to 2-D facility models.
- D. Development of 2-D factory imaging.
- E. Preliminary work on the development of geometry interface software for eventual linking to CAFL analysis tools.

#### **4.4 CONCEPTUAL CAD-CAFL MODEL REQUIREMENTS**

The functional mechanism of a conceptual framework for a CAD oriented CAFL model is shown in Figure 4.2. The activity within the conceptual framework, necessary for the identified spatial, quantitative and qualitative work is supported by the use of three databases :

1. Graphics database
2. Factory database
3. CAFL (problem) database

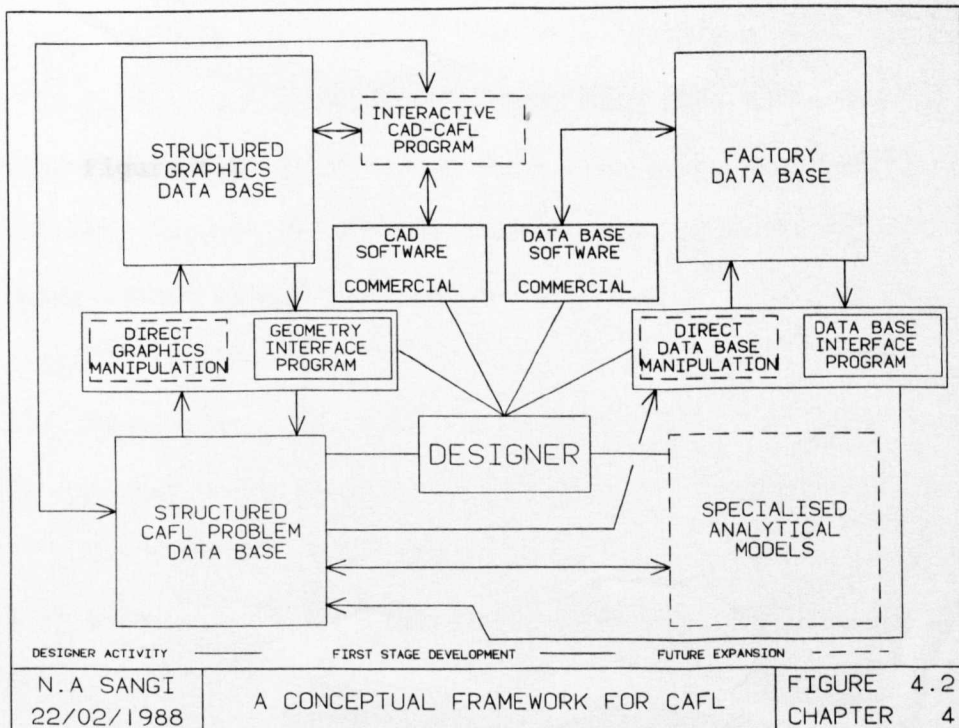
In order to drive the CAFL conceptual model four groups of software will be required :

1. CAD graphics software
2. DBMS software
3. Geometry and database interface software
4. Specialised CAFL analytical models

With this conceptual model the designer controls the design process through each design stage by application of each of the four software groups. Two forms of software are proprietary in origin; the CAD system and the Data Base Management System (DBMS). Geometry interface software and specialised analytical software would normally be specialist software developed from high level languages.

The conceptual framework consequently allows the placing of great importance on the role of designer or design team. One additional activity sequence is shown with respect to the dedicated analytical software. In the long-term, special packages may generate layout solutions, which could lead to automatic updating of drawing through the geometry interface module. Note however, that supervision of this activity would still be maintained by the designer.

for visualization and analysis purposes



#### 4.4.1 Structured Databases

##### Graphics Database

Establishment of this database is intended to reduce time and effort by the designer in generating and representing manufacturing layouts. Standard machine tools, material handling equipment (MHE), layout area, and service facilities would be properly represented in terms of accuracy and detail in any practical layout generation using this database.

With immediate availability of images from the CAD database, the design process of assembling and analysing potential factory layouts would itself be less time consuming. Further long term advantages would be the ability to maintain layout drawings and to give immediate access to problem images on a high frequency of occasions for visualisation and analysis purposes.

The CAD graphics database is intended to store the images which constitute the visualisation of the objects in any particular case study. If these images are not available they have to be developed by the designer. These images can be separated into four primary groups that subsequently can be used in combinations required by individual case study. These groups are:

1. Facilities
2. Layout area
3. Services and utilities
4. Materials Handling Equipment (MHE)

The basis of selecting four distinct groupings is found in two points. Firstly information is usually kept under the four headings

listed, each of which is quite distinct and therefore merits an identifiable part of the graphics database. Equally importantly as a new layout design is developed, the process uses combinations of four forms of image data and not generally all four continuously. An example of this is the placement of facilities not necessarily having to involve materials handling graphic information.

In practice, facilities and material handling equipment will be stored using similar structures and the layout area and services images will be coordinated.

The detailed structure and organisation of each of the four image groups will be highly dependant on the particular CAD package employed. Defining the detailed structure of image data records, and developing these records into a graphics database is a significant work load within the development of a CAD based CAFL design tool. How this is achieved for a selected CAD system is described in Chapter 5.

### **Factory Database**

The factory database serves as the source of production and control information, primarily intended for use in the planning of manufacture. This database is not seen as being developed, compiled and maintained by the layout designer. The role is more one of the designer extracting relevant information for the layout design process when required and compiling from this information significant parts of a specialist CAFL problem database. In the absence of an existing factory database the CAFL problem database would be constructed directly. Example of selective factory database information useful in CAFL would be :

**a) Product related data**

- Order details (quantities, batch sizes, transfer loads)
- Manufacturing routes
- Manufacturing times
- Cost data

**b) Facilities related data**

- Manufacturing capabilities
- Facilities groups
- Cost and productivity data
- Facilities relationships data

**c) Finance related data**

- Company rates of return and depreciation
- Overheads and investment information

**d) Factory organisational data**

- Project related information

Advantages of extracting information directly from a factory database include; speed of data acquisition, utilisation of current and accurate data and ability to selectively permute data from the wide source available, for different modelling and evaluation programs. This would allow data support in a flexible manner - a feature of modular CAFL packages intended for wide applications.

A powerful generation of software tools are now commercially available to build and maintain these databases. Known as DBMS packages, the philosophy of the conceptual CAFL models states that these packages should be employed for many of the same reasons that a

CAD package would be employed for graphics control i.e. efficiency of data control, manipulation and reporting.

In terms of the research program in this thesis the factory database presents a number of difficulties. Firstly these databases are company specific in the content and structure. Secondly they frequently lack a comprehensive collection of data in the right form. In addition accessing this data, even for a one-way exchange of information, is often a politically sensitive subject for data security or organisational policy reasons.

The approach therefore that has been adapted is to use background experience from an industrial test case to construct a theoretical factory database and to subsequently concentrate on using only those reports relevant to creating the CAFL database.

#### **CAFL Database**

Facility planning is a discrete, project oriented activity as opposed to the continuous management of factory production. When layout design projects are consequently undertaken, specialised CAFL (problem) databases which also enable study of layout problem in isolation from normal production, can be generated by acquiring information, from the CAD database and factory databases. The CAD database can supply data on workcentre (e.g. facility locations and orientation) and factory database will supply manufacturing data (e.g. product routes) as described earlier. The merging of this layout and manufacturing data, in a form suitable to analytical software and the design model employed, is the objective in creating this database.

The generation and maintenance of this database involve the significant development of geometry interface (for CAD system) and

database interface (for DBMS) application software. The development of the geometry interface and database interface application software will be seen later to have been a significant part of the work of this research programme. The constructed CAFL database then becomes available for two types of activity:

- a. The interactive designer-led design process.
- b. Background analytical software application.

Two examples of the use of a specialised combined manufacturing and geometric CAFL database can be given in support of creating the database.

In first example quantitative models, based on materials movement are considered. In these models, materials movement within layouts is frequently used as the quantitative justification for the positioning of facilities. The evaluation of materials movement requires the extraction of facility location and orientation data held within the geometric information base. This is then combined with movement cost, product quantity and product route data held in the manufacturing information database and placed within the third CAFL database. The combined information is then processed by analytical models operating through the CAFL database.

In a second example, the qualitative model, closeness desirability is considered, where the working relationships between neighbouring facilities is used for design evaluation. Information on the desirability of having particular neighbour combinations is held within the manufacturing database. This has to be combined with facility location and building structure information held within the geometric database. Using this combined information the overall desirability of particular layout plans can be evaluated.



The contents of this third (CAFL problem) database are intended to support data requirements of all the models added to the analytical software group. Therefore the manner in which the required data is acquired, organised and stored is important in defining how versatile use of information will be made. A key decision is required about employing the analytical models i.e. either to use previously developed models, each of which have individually defined data formats or to develop new CAFL software based on common data structure. Generally, previously developed models would require specially formatted data files suitable to the input and output statements of individual program. This would therefore, require maintenance of several sets of specially formatted data files, one set for each individual analytical program. Alternatively, a flexible data structure, allowing additional data fields when required, can be developed, which has the ability to support multiple analytical models, specifically developed to utilise the structure and content of the database. Taking the more versatile and comprehensive data structure will still allow the possibility of modifying the input and output statements of the previously developed programs to make use of new data structure. Two points have been made; firstly defining the data structure is an important consideration in software development and eventual use of data and secondly, an open-ended structure offers more flexibility, less ambiguity and therefore enhances modularity required by the future generation of CAFL systems.

Therefore use of a systematic, well defined and adaptable, data structure to assist in the development of software and activities of the designer is considered. Later in the thesis, it is explained how this objective was achieved.

#### 4.4.2 Software Components

##### Proprietary CAD Software

The general benefits of employing a proprietary CAD system have been discussed in the introductory chapter. These benefits are the results of the ability to generate and manipulate images quickly and effortlessly and the subsequent ability to store and retrieve images efficiently.

The use of proprietary CAD system with respect to CAFL is intended in five areas as described below :

1. Use of standard CAD features to develop, organise and manipulate individual facility images within a structured CAD graphics database.
2. Use of standard CAD features to compile and visualise composite factory layouts.
3. Provide an effective interface between images and designer through; drafting, viewing, plotting and storage of facilities.
4. Provide elementary on-line analysis aids e.g. area calculation.
5. Provide a means by which CAFL activities can be incorporated in the CAD environment (e.g. through geometry interface window).

The last of the five points needs expansion and stressing. CAD systems are primarily developed for general design and drafting purposes, and not for CAFL. Therefore effort is required to identify those CAD features which can be best used in CAFL design process and, in addition to following the design, add extra features or routines specific to CAFL. For example, CAD features centre of gravity and inertia calculations are of no use in CAFL. Whilst area calculations and the ability to assign attributes are very useful.

More advanced routines with CAD packages can also be examined from a "useful to CAFL" viewpoint. For example, normal use of "Bill of material" feature allows the listing of components in an assembly drawing. This feature can be used to list facilities in a composite layout drawing. In some cases, multiple options might be available to implement required CAFL features on an individual CAD package, a selection therefore can be made of "more useful" features.

The extent to which CAD can be used in CAFL is dependent on the computing limitations of a particular configuration of hardware and software. Testing out the capability of individual systems with respect to CAFL is a major task, examples of which are shown throughout Chapters 5 and 6.

The discussion on the conceptual role of CAD in a CAFL model has progressed from use of simple internal routines (e.g. drawing a line) to the potential use of complex internal routines (e.g. Bill of materials). One further important application exists; the development of relationships with external software. This is achieved with many proprietary CAD packages through the use of geometry interface facility.

### **Proprietary DBMS Software**

The use of DBMS in CAFL was earlier described in Chapter 1. The ability of commercial DBMS for efficient storage and retrieval of massive data can be used for improving the analytical ability of future CAFL systems. The conceptual model described in this thesis stresses on the need to utilise graphical and factory data to support multiple design and evaluation procedures. The use of a proprietary DBMS package can be made to effectively achieve the long term

objectives of highly efficient modular CAFL package, able to utilise multiple data fields for a variety of design and evaluation models.

This software is seen as already functioning within the organisation for handling factory data. Use of DBMS in CAFL is defined as the source and mechanism to generate information for CAFL problem database. In a long-term, this software could take the responsibility to maintain the CAFL related data alongside its primary use of handling factory data.

A database management package additionally supports multiple reporting and information processing at summary and detailed levels.

### **CAD Geometry Interface**

The potential of interface software can be identified from two differing needs of CAFL packages. Firstly, the information needs to be extracted from layout designs on the location, orientation and label name of facilities. This data can then be used in specialised analytical models. This type of activity, the extraction of quantitative data, will be necessary in many CAFL tasks.

The second example involves "feeding back" the outcome of analysis to automatically exchange layouts. This "automated design" approach is currently used in the computer preparation of detail drawing. The use of this feature however has to be considered carefully in CAFL, whereas the philosophy in this thesis stresses the role of the designer and is not directly supportive of a return to the "black box" batch generation of solutions typified in first generation CAFL. In terms of this research, emphasis is therefore placed on the first part of the interface i.e. direct graphic data acquisition. The second part can be seen as long term research

whereby direct modification of layout drawing, under appropriate supervision, can be performed.

The geometry interface program can be executed either interactively during a CAD session or in a batch background mode which does not require a specialised CAD terminal. Since the data extraction and its loading in to the CAFL problem database does not necessitate the fine supervision of the designer, this operation can be performed efficiently in a single automatic operation. Whereas the manipulation of facility images during layout design does necessitate the designer's attention and therefore should be performed in interactive mode. As background mode can be independent of the design, it is shown as separate item in Figure 4.2.

#### **DBMS Interface**

This interface software generally can be developed using application enhancement utilities within the DBMS. The effort in developing this data interface will largely depend on the individual DBMS and the data formats defined in the CAFL problem database for eventual use in CAFL analysis. In principle the DBMS could support the CAFL problem database and assume the responsibility of maintaining up-to-date information within the CAFL problem database during the design iterations.

Additionally the DBMS interface will take the task of multiple reporting of both data and results in standardised report formats.

Interactive use of DBMS can be extended once routines and report procedures are established. This execution is in the form of programmed instruction sequences (in high level languages) which will automate the extraction of information from the factory database.

This has all the advantages of speedy, simplified error free transfers.

In addition, programmed instructions in the long term can be extended to allow two way exchanges of data, with CAFL final results being feed back to the factory database e.g. location and assigned production groups of facilities.

### **Specialised Analytical Modules**

The most specialised purpose written programs will undertake the task of assisting designers in the generation and assessment of new manufacturing layouts. The international survey indicated that approximately one third of software for CAFL did not possess analysis capability, analysis being a requirement considered as essential within any CAFL conceptual framework. There may be two approaches taken in development of this module :

1. Presently available CAFL analysis models can be collected and converted for use as options within a suite of analysis programs. Analysis would be performed by selecting appropriate models. The survey has identified 101 pieces of software and literature review has identified another 48 program/models. From this wide range of models, selection can be made to implement more creditable programs for multiple analysis requirements placed, on analytical module. The work of Montreuil [38] has indicated that adaption of different programs to a common set of data is possible, since he has used CRAFT, CORELAP and PLANET to use data from the common data set and generate layouts. This approach has some long term merit as a "follow up" activity once the basics of graphics based CAFL design have been established.

2. A second approach would be to develop structured software suite which provides flexible analysis of CAD images. This software suite can be developed in a modular fashion and for the specific environment in which CAD-CAFL philosophy works. The example of this type of modular software development can be given as follows:

In total material handling cost models, the calculation of the distances is a common task. These distances can be calculated in several ways. For example; the centre to centre distances (straight line distances), rectangular distances, traffic route distances and materials dispatch location of one workcentre to delivery location of the next workcentre. In practical situations combinations of these type of distances occur frequently. Therefore software should allow to calculate distances in these combinations. As described earlier in this chapter, these distances can be used in many CAFL evaluation (e.g. material movement or closeness desirability) models. In a similar fashion, intermediate data files can be generated and used in multiple combinations to achieve modularity.

For both approaches the pattern of development would be to first explore and develop the graphics aspects of a CAD based system and then to follow up with the development of specialist analytical models.

In this chapter the desirable features of an ideal CAFL package have been outlined and the components of a conceptual framework have been discussed. This framework formed the basis of the CAD oriented facility layout package described and tested in the following chapters.

## CHAPTER 5

### THE DEVELOPMENT OF MEHRAN MODEL



## CHAPTER 5

### THE DEVELOPMENT OF MEHRAN MODEL

#### 5.1 CHAPTER OBJECTIVES

The previous chapters have identified that the specific objectives of the second part of the work in this thesis are the development of a CAD based CAFL procedure, with emphasis on the generation of a graphics database and development of geometry interface software to extract information from the graphical drawings. This chapter describes how this was achieved using modular software developed under the title "MEHRAN" on the University of Liverpool CAD system. The specific objectives of this chapter therefore are :

1. To introduce the computer resources employed.
2. To describe the MEHRAN model developed.
3. To illustrate initial developments in geometry interface software, identified as part of MEHRAN.
4. To illustrate process of development of MEHRAN model using a prototype test case.

The acronym MEHRAN stands for Modular graphics Enhanced Heuristics for Rational Allocation of Next facilities. The "MEHRAN" software is intended as a long term development project which modularly extends and enhances CAFL applications, by employing advanced graphics, data bases and multiple specialised analytical procedures. MEHRAN also means "bring kindness" and is a original

name of the historically famous, river "Indus", which brings kindness, by providing water, to the Indus valley - one of the well admired early civilisations. The name given to the software is due to authors' special feelings to the MEHRAN valley and this research work. MEHRAN, in CAFL environment, is intended to "bring kindness" to the users of future generation of CAFL systems employing advanced CAD for graphics and DBMS for efficient data support and specialised CAFL procedures for multiple analytical evaluations.

The second research contribution within this thesis is therefore concerned with making use of University of Liverpool's mainframe computer resources for CAD development. The IBM4341 supporting two CAD packages; CADAM and CATIA. In parallel an IBM3083 supports the major database management system SQL/DS. Both the IBM3083 and the IBM4341 based CAD packages were commissioned in May 1985. The work developed in this thesis is consequently one of the pioneering CAD development on the University's new computing resources. Developing MEHRAN tested many of the CAD facilities, including their eventual usefulness, for the first time, MEHRAN being the largest single application over the period 1985 and 1988.

Making use of new CAD resources has concentrated on the development of a graphics database for use within CAFL. Two reasons prompted this emphasis. Firstly the CAD resources available were new and all persons concerned have no previous experience of running such a sophisticated computer equipment and CAD packages. Therefore, there was going to be a requirement for considerably more effort on development of this pioneering project.

Secondly, work at Liverpool University on CAFL had developed analytical models which were previously dependent on either manual drawings or purpose written graphics routines. Most notable among

those models were the original work of Driscoll [11] without advantage of graphical representation, the work of Abdul-Magid [1], with analytical simulation models and the work of Lilley [34], who undertook interactive GINO-F supported simulation work. Concentration on the development of the new CAD based advanced graphics is seen as a unique identifiable contribution giving new direction to a previous work at Liverpool University.

Before developing the MEHRAN software, a brief introduction of the computer packages and hardware employed, which dictated aspects of experimentation and case study development, would be appropriate.

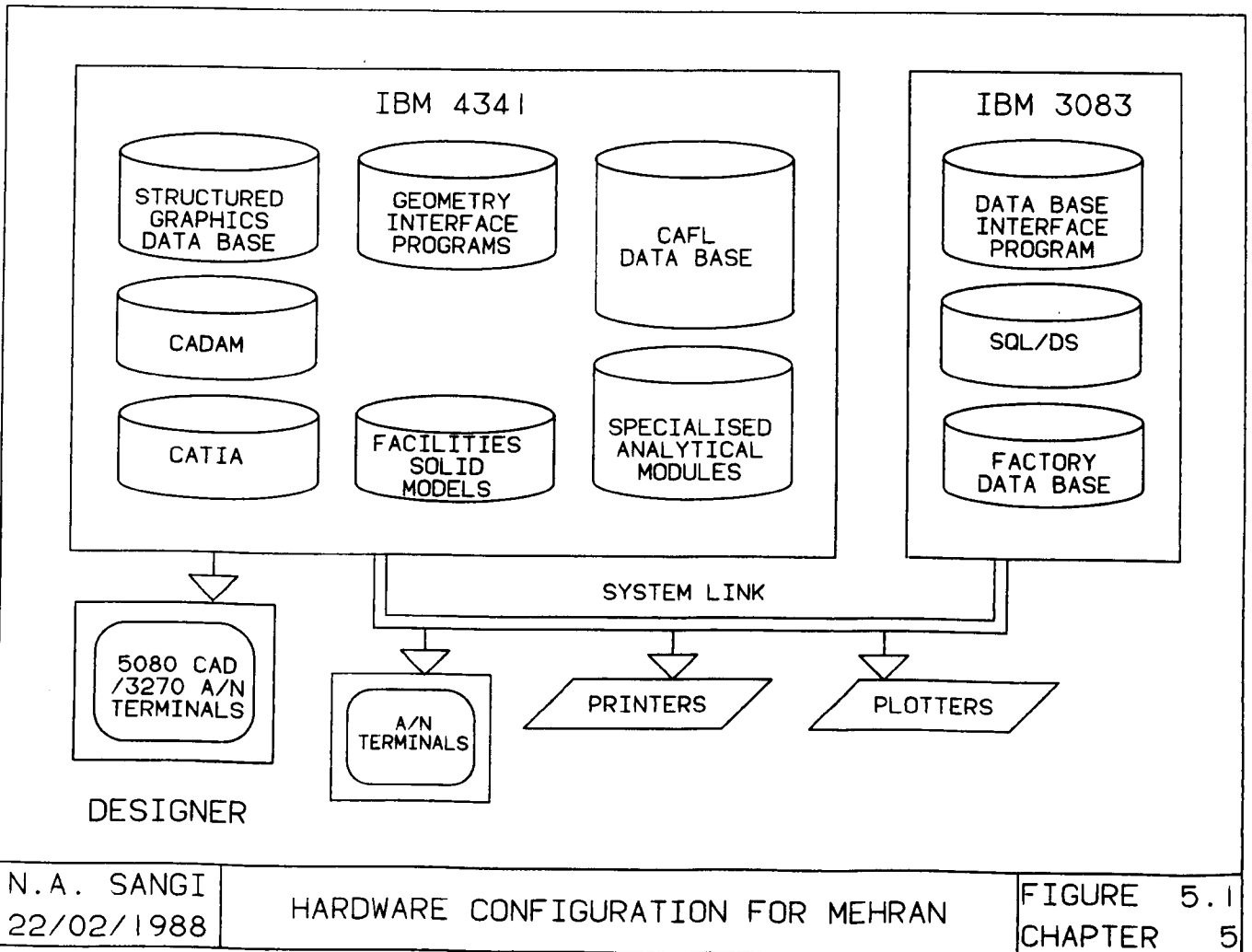
## **5.2. COMPUTER RESOURCES EMPLOYED**

### **5.2.1 Hardware Employed**

Figure 5.1 illustrates the computer resources employed in developing the MEHRAN software model. At the beginning of this research, the University has two mainframe research machines; an IBM3083 and IBM4341. The IBM3083 was commissioned to replace an ICL1906S and the already operational IBM4341 was dedicated to high resolution graphics software, mainly CADAM, CATIA, PATRAN and CBDS, jointly sharing IBM5080 advanced graphics workstation and associated hardware. Both main frames used the same operating system; virtual machine system product (VM/SP), commonly referred to as VM/CMS.

The IBM3083 has 24 Mbytes of main storage, running at 5.9 million instructions per second (mips). This computer mainly supports all other research and database software except the four advanced packages mentioned above. The IBM4341 has 8 Mbytes of main storage and runs at 1.3 mips. Besides being dedicated nature to the software running on IBM5080 graphics terminals, the IBM4341 also runs in parallel, many of the graphics supported scientific software e.g.

GINO and GDDM. The IBM5080 supports seven CAD workstations distributed around the campus. Additionally the IBM4341 can be accessed from any terminal connected to the IBM3083. However, as mentioned earlier, SQL/DS (an IBM DBMS product) was not available via this machine, therefore, generating a necessity to employ two main frames instead of one. The effects of this inconvenience on the research are discussed later in this chapter.



### 5.2.2 Commercial Software Employed

The university computing laboratory offers two advanced CAD packages, namely; CADAM and CATIA both running on a mainframe IBM4341 computer. The two packages are linked to transfer graphics data via

an IGES compatible interface program running from within CATIA. Additionally the university has a proprietary database package, (SQL/DS) running on an IBM3083. These three packages were selected as primary development tools within the philosophy and conceptual model of this work i.e. the applicability of CAD based CAFL.

### **CATIA**

The Computer Aided Three dimensional Interactive Application (CATIA) is a proprietary CAD/CAM package developed by Dassault Systems, France, in the early 80's, and is marketed by IBM. It is a three dimensional solid modelling CAD package which utilises IBM 5080 advanced graphics workstations. This versatile CAD package is primarily developed for 3-D CAD/CAM application and can support mechanical design through 3-D solid geometry construction, visualisation, automatic 2-D view generation and NC program data preparation. At the start of this research, CATIA release 2.1 was installed which was later updated to release 2.2 towards the end of the research period. CATIA provides a comprehensive set of routines for 3-D solid modelling design and manufacture. It allows the kinematic study of mechanisms and supports robot movement programming.

### **CADAM**

The Computer-graphics Aided Design Augmented Manufacture package (CADAM) is a CAD/CAM system developed by Lockheed Corp., USA in the late 60's. Later, CADAM, Inc. was declared as a new subsidiary of Lockheed responsible for the development and marketing of CADAM. Cooperation between IBM and CADAM, Inc. helped place the product as the number one mainframe 2-D CAD package; with over 13000

workstations worldwide and over 1000 CPU installations [21]. Since its launch, it has gone through 20 major editions is applied in mechanical, architectural, electrical and CAD/CAM areas. However, the majority of applications are in the 2-D drafting, design and manufacture areas. This package is fully supported by the 5080 advanced graphics workstation system. The initial installation of CADAM, at the university was release 19, which was updated to release 20 during the middle of the work described in this thesis. The specific CADAM installation at the University is a two and half (2 1/2) dimensional CAD package.

### **SQL/DS**

The Structured Query Language Data System (SQL/DS) is a relational database management system, developed by IBM using the SQL language. This language is now the ANSI standard language for relational databases. This package is an IBM proprietary database product and can be accessed using interactive SQL (also referred to as SEQUEL). The interface programs may be written, by imbedding SQL commands in FORTRAN, COBOL, PL/1, Prolog, ASSEMBLE or REXX languages. There have been local enhancements for report writer and screen based input and update program support. Selection was purely based on its availability. Any other suitable DBMS product could have been equally useful.

In order to understand the development and use of the MEHRAN model, features that were found useful in proprietary software are briefly described here.

### 5.2.3 CAD Within MEHRAN

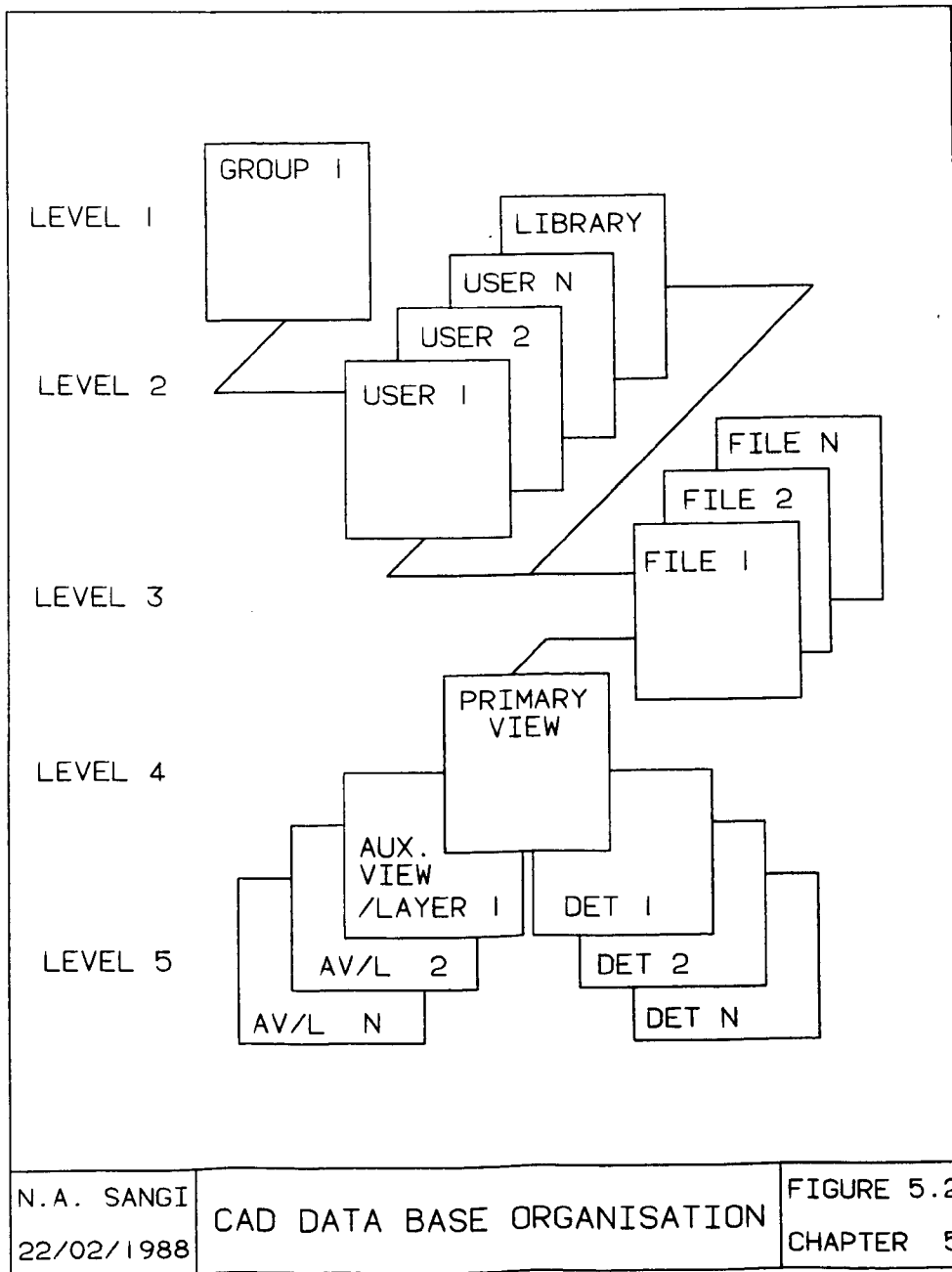
The initial configuration of software combined CADAM and CATIA in a mutually compatible system; with CATIA for solid modelling and CADAM for two dimensional graphics. Within themselves use of the two software systems is structured and menu driven. However, links between CADAM plus CATIA and the outside world are controlled by post processors. In CATIA this interfacing was particularly weak and primarily directed at providing only general information. The use of CATIA was restricted to facility models because of high overheads associated with processing solid models, weak geometry interface ability and the inability to produce 3-D composite CAFL layouts. Therefore, CADAM was selected as the main CAD package for the primary release of MEHRAN model. Only significant role that CATIA has played refers to structured graphics database development.

The development of a CAD based CAFL package requires knowledge of the structure of graphics data base and CAD features within that package. This information can be used for; reducing the processing and storage demands, providing quality visualisation and developing effective procedures for CAD-CAFL system interface. Therefore it would be appropriate to outline the features of CADAM and CATIA, which were used to develop and implement the database and subsequent interface software.

#### **CAD Database Structure**

The method of drawing management employed by CADAM and CATIA is similar and is illustrated in Figure 5.2. In both cases, resources of the CAD system are made available to selected group of users, groups generally being defined by having a common interest in potential use. The key feature within this group is that, each user group has its

own library of standard drawing images that are available to all users. This is of particular interest to MEHRAN, as the standard library within CADAM is the location for the collection of facility (machine tools etc.) images. No uses have been made of the library in CATIA.





Within each user, the only limitation on the number of files is the size of disk storage allocation. Within the work in this thesis, 150 files were made available to each user (i.e. the standard library and CAFL designer).

The most significant effect of CADAM and CATIA structure comes at levels four and five, the internal organisation of drawings. In both cases a primary view, which is the focal point of the drawing, referred to actually as primary view in CADAM and to as layer zero (L000) in CATIA. This is a point at which composition of drawing from different sources of data is undertaken.

The first support for a primary view comes in a form of detail drawing with up to 63 possible on CADAM.

Two types of drawing management structures are common in CAD systems, nodal and nonnodal [46]. The nodal approach allows "ditto" copying of geometrical elements constructed on one detail page, into different drawing pages (views, layers or details) in the same drawing. The visualised ditto image carries an associativity pointer to the original detail and this image can be switched on/off (generated / deleted) as a whole but can not be modified on a drawing where it is being used i.e. "ditto" copy forms a borrowed image which can be visualised but is not a physical part of that model. Any change in original detail will be automatically reflected in all ditto images. Examples of such approach are; symbols, dittos and format drawings, which may be visualised but do not form part of that drawing therefore can be deleted but not modified.

The nonnodal structure does not place any associativity and the copied image remains physically part of the drawing. Any versions of this "use" or "copy" image can be modified or deleted without having an effect on any other copy of the image.

The nodal structure allows greater savings in storage, and is easier to maintain and standardise. This approach is however, inflexible to any modification within the "borrowed" visualisation. Many CAD systems implement both type of database structure at certain levels of database hierarchy. In Figure 5.2, the ditto image of the detail page (similar in CADAM and CATIA) is a nodal type of structure whereas layers (in CATIA) and views (in CADAM) are nonnodal type data structures.

In CADAM a particularly powerful feature is that detail pages can be copied endlessly onto a primary view both as independent drawings or controlled drawing.

An advantage, of "ditto" type copy in CAFL is the ability to use the function to generate a unique entity on primary views. Therefore, these images of facilities can be; identified, selected, moved, rotated, copied, deleted, labelled or processed as a single entity.

Dittos are therefore, space efficient and exercise considerable control over uncontrolled editing of drawings whilst enabling ease of manipulation within composite layout drawings.

The use of CADAM and CATIA can be seen therefore to involve considerable transferring of images between primary views and detail pages. CADAM, working in 2-D has 2-D detail pages. However, at the onset of research, CATIA, the 3-D package, did not have corresponding 3-D details. This ruled out the exclusive use of CATIA and the approach of combining a 3-D facilities database alongside 2-D. Eventually, 2-D facilities planning database was adapted.

In a similar manner to 2-D detail pages, a number of auxiliary views can be held in support of the primary view. Auxiliary views are permanently visible. The permitted total of detail pages plus

auxiliary views is 63, as auxiliary views are not employed in MEHRAN, up to 63 detail pages are possible in support of each primary view.

CATIA equivalent of auxiliary view (CADAM), is referred to as layer. In each solid model up to 1000 layers are possible. These layers can be made actively visible on users choice. No use have been made of CATIA layers in MEHRAN software set up.

### **Overlay**

One further feature available in CADAM, is existence of an "OVERLAY" feature. Overlying allows the primary views of 11 different drawings to be superimposed on to each other. They are not permanently transferred but in practice are used to project very complex and detailed images. The image displays on each of the primary views are designer controlled. In terms of CAFL, this is an alternative option for dealing with the layout area itself where, the structural and service facilities can be overlaid in different combinations to give a high definition, controlled image factory representation. With 11 drawings each holding up to 64 views, the final factory layout could involve 704 designer controlled primary images. The practical limitation on size of an overlaid image, a point examined further later in this chapter, is 880 Kbytes.

The relationships therefore between files, primary view, details and overlays are powerful features of CADAM fully exploited in the structured graphics database developed in this work.

### **Geometry Interface**

Geometry interfaces are application programs designed to communicate information into and out of the graphical database.

There are two types of geometry interface programs; graphical data transfer interface and alphanumerical data transfer interface.

In the first case, the images are transferred between two CAD systems, for example transfer of drawings between CADAM and CATIA. This type of interfaces are mostly written in low level languages and are normally supplied by the CAD system vendors. Most widely used, this type of interface is called, Initial Graphics Exchange System and abbreviated as to IGES. Image data (e.g. lines, circles or points) of the source CAD system is converted into IGES format and the receiving CAD system reconverts image data from IGES format to the format employed by the receiving system. CADAM and CATIA are IGES compatible CAD systems.

In the second case, numerical parameter data (e.g. coordinates of a point and point identifier) defining the image are exchanged with user written geometry interface program. These programs are generally written in high level languages and referred to as (site) application interfaces.

Described simply they can be used as "filters" which search out specific graphical data elements and amend, copy or pass parameters to the user written programs. By this means alphanumeric information can be taken from the drawings and fed to external software. A little more difficult is the ability to send external information back into a graphics database and thereby remotely alter the image (e.g. move or modify). Geometry interface software could operate in interactive or batch mode.

Writing GI software is however very dependant on individual CAD package and even on specific releases of a package. For this reason GI software is difficult to develop.

With the computing resources available to this research the CATIA geometry interface routines were particularly weak. Experimentation with possible applications of GI software has been restricted therefore to CADAM GI routines only.

CADAM geometry interface is a powerful feature which enables access to CADAM drawings, via user written application programs. The geometry interface comprises of three sets of routines, namely; CADCD, CADET and CADMACGM.

- 1) CADCD is a set of FORTRAN routines which construct geometry (e.g. circles, lines or points) by passing the parameter data in a batch mode. In a user written FORTRAN program, these routines can be called to generate various geometric elements in any CADAM drawing.
- 2) CADET is a utility program which passes numerical data comprising the geometrical elements to a user written subroutine called RESOLV. This subroutine is a collection of FORTRAN entry points, which receive parameter data from CADET program. RESOLV is user modifiable subroutine within which commands can be imbedded to process parameter data received by this routine. In its original form RESOLV, provides almost all the information stored within the CADAM drawing. CADET program also runs in a batch mode.
- 3) CADMACGM (usually referred to as macro geometry) is a function within interactive CADAM which enables the execution of user written programs containing either CADCD, CADET or both, from

CADAM interactive terminal. CADMACGM within the CADAM release 20 is substantially enhanced (Table 5.9). CADMACGM in essence is an interactive version of the CADCD utility. Together with CADET it was anticipated to provide a powerful, interactive, modular structure for MEHRAN.

Macro geometry was primarily intended for parametric drafting and design. However, since it provides the mechanism in which data transfer takes place via set of ASSEMBLE macros between the CADAM terminal and user written application program, therefore its potential application to CAFL program running from within CAD was anticipated as a major break through in MEHRAN development, described in detail later.

CADCD and CADET would allow the remote manipulation of the drawing, on alphanumerical terminals. However, this approach would be unwelcome in CAFL as the designer, will not be supported fully with an interactive graphics environment - a key factor in CAFL design. Alternatively CADMACGM allows GI operations as part of CADAM session, therefore offering an interactive, image supported design situation.

#### **5.2.4 Computing Installation Available**

A number of the system capabilities have already been described, in the text. A full list of site set boundaries, relevant to the depth of application possible, is given in Table 5.1.

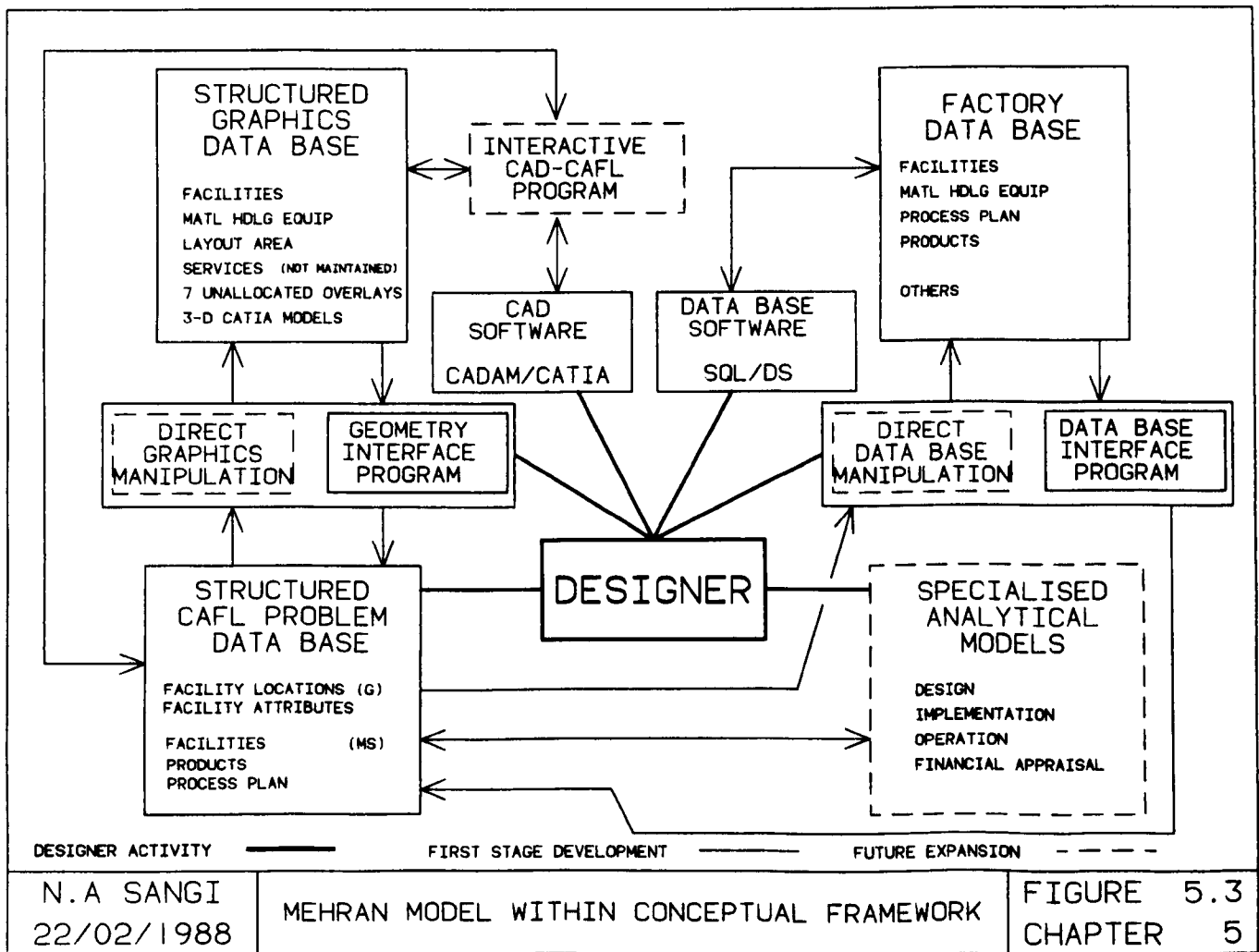
### **5.3. THE MEHRAN MODEL**

#### **5.3.1 An Overview**

The MEHRAN software has been developed and revised within the conceptual framework given in Chapter 4. Figure 5.3 illustrates the

Table 5.1 Installation Computing Boundaries

	CADAM	CATIA	SQL/DS
Mainframe	IBM4341	IBM4341	IBM3083
System memory	8 Mbytes	8 Mbytes	24 Mbytes
User disk space	As required	As required	As required
Software			
User files	As required (150 used)	As required (one used)	As required (12 used)
Max. Number of models per file	(63 details)	(130 Solid models)	-NA-
Storage			
File	20 K words (80 Kbytes)	Disk space (1 Mbyte per model)	-NA-



N.A SANGI  
22/02/1988

MEHRAN MODEL WITHIN CONCEPTUAL FRAMEWORK

FIGURE 5.3  
CHAPTER 5

latest version of MEHRAN, identifying the components of the software along with designer - software relationships within the conceptual framework. MEHRAN consists of the following components :

### 1. Graphics

- CADAM and CATIA software.
- 3-D solid models facilities database (CATIA).
- 2-D structured graphics database (CADAM).

### 2. Manufacturing

- SQL/DS.
- Factory data base (SQL/DS).
- CAFL (problem) database (VM/SP operating system).

### 3. Specialist software

- Batch geometry interface (CADAM).
- Data base interface (SQL/DS).
- Interactive geometry interface (CADAM).
- Specialised analytical models.

Structuring the MEHRAN model in the manner shown allows the identification of three major contributors; the designer, commercial software and specialist software. The structure given has been selected to maintain high level of designer involvement in the layout design process and to allow a modular approach to software development, both key points in the philosophy of this work established earlier.



The commercial CAD packages, CADAM and CATIA were described earlier in this chapter, following is a description of the remaining MEHRAN components.

### **5.3.2 CATIA Solid Models**

The graphics data base of MEHRAN model contains both 3-D and 2-D facility representations. Initially 3-D solid models are constructed using the CATIA package. These models are then prepared for visualisation (screen layout) and for 2-D view stripping. This "stripping" process is the transferring to CADAM of 2-D views for use in the structured graphical database.

#### **Solid Model Generation**

The solid construction geometry feature within CATIA is used to generate solid model images. Initially solid models were constructed for a development test case comprising of 10 solid models (MG-01 through MG-10) of manufacturing facilities. This test case consisted of six machine tools, three robots and one fork lift model.

These new facilities were selected as the prototype test drawings for MEHRAN. They were chosen to represent differing manufacturing resources (Machine tools, Robots and Materials handling equipment) and different levels of detail and complexity.

The geometric data was obtained by three different ways; taking dimensions from manufacturer supplied 2-D plan and isometric views, site measuring up of machine tools and proportional dimension measurement from 3-D iconic models. The individual models are listed in Table 5.2 and the drawings are given in Appendix A. The first method proved the most accurate where as the second method was found to be less time consuming with reasonable accuracy on maximum

dimensions. Facility solid models, would in practice be highly complex if generated to the finest level of detail. In layout studies, identification of the major shape features and accuracy of maximum dimensions are enough, finest detail does not contribute to CAFL design in any but the most detailed problems of workstation design. In the 10 test case examples therefore, major units of facilities were adjusted to solid blocks (cubioids, cylinders or spheres). This approximation produced realistic facility shapes with reduced generation times from 3-4 hours down to 30-60 minutes average. The accuracy obtained was  $\pm 5$  cm on maximum dimensions and an illustrating example is shown in Figure 5.4.

**Table 5.2 Ten Facilities Used In Example Test Case**

<b>S. No.</b>	<b>Figure Identity</b>	<b>Facility Name</b>	<b>Description</b>
1.	MG-01	BPC 630	Bridgeport CNC Mill
2.	MG-02	Solon-1	CNC Machining Centre
3.	MG-03	Solon-2	CNC Machining Centre
4.	MG-04	Cubotic D400	CNC Machining Centre
5.	MG-05	Easiturn 3	CNC Lathe
6.	MG-06	Lathe	Lathe Machine
7.	MG-07	Mitsubishi RM-501	Robot
8.	MG-08	Adept One	Robot
9.	MG-09	Fork Lift	Lift Truck
10.	MG-10	Hazmac L3	Robot

The solid image generated in 3-D space was then stored in two specially developed MEHRAN (set screen) visualisations, one showing a 3-D solid model (Figure 5.4) and other allowing visual images of four views of the solid model (Figure 5.5). The illustrating example is of a Solon-1, CNC machining centre, which took two hours to generate as a CATIA model.

The MEHRAN four view screen image is a necessary step towards preparing the transfer of solid model based 2-D view images to the

FIGURE 5.4

3-D SOLID MODEL IMAGE OF SOLON-1 MACHINING CENTRE



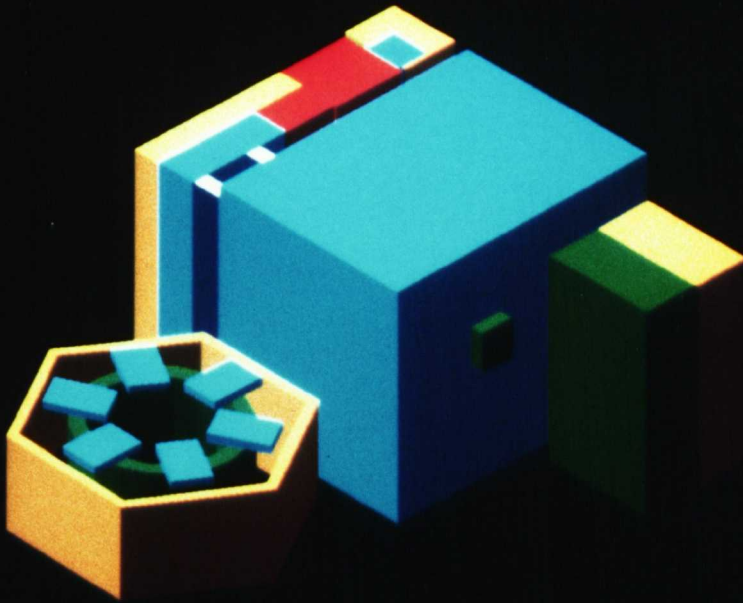
SHADING

APPLY

CREATE

BASIC

ADVANCED



BP SV

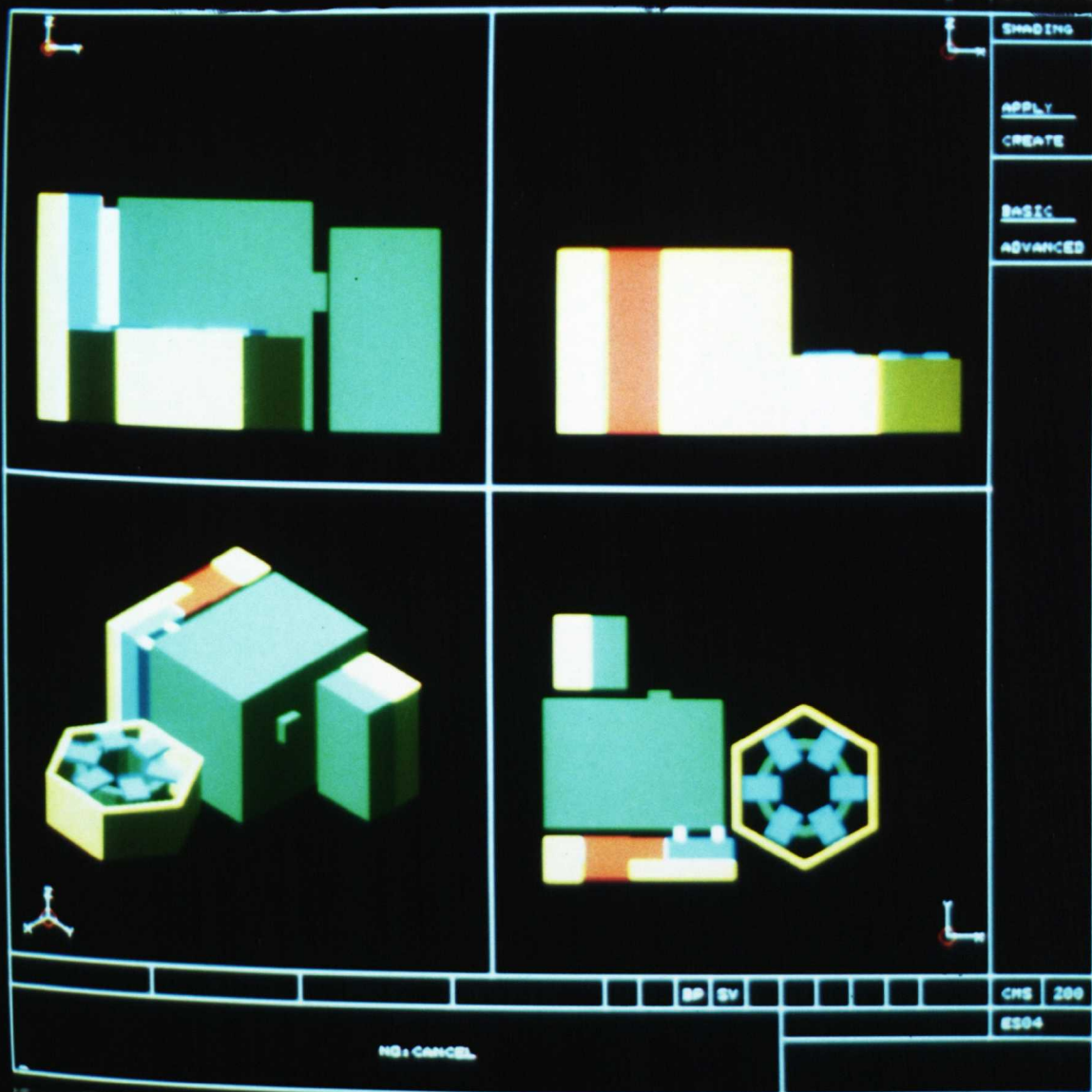
CMS 200

ES04

NO: CANCEL

FIGURE 5.5

FOUR VIEW SCREEN IMAGE OF SOLON-1 MACHINING CENTRE



CADAM database. In release 2.1 of CATIA all four views were transferred without doing any additional work. However, within the latest release (2.2) of CATIA, additional work become necessary to prepare 2-D projections before transfer. The latest procedure for using CATIA within MEHRAN is listed in the Users Manual Appendix C.

The transfer process for the Solon-1 illustrating example is shown in Figures 5.6a and 5.6b. Figure 5.6a representing the CATIA image before transfer and 5.6b showing the image after transfer. Note the transfer, typical of many IGES transfer processes between CAD systems, is not perfect and an ambiguous image is initially trapped by CADAM.

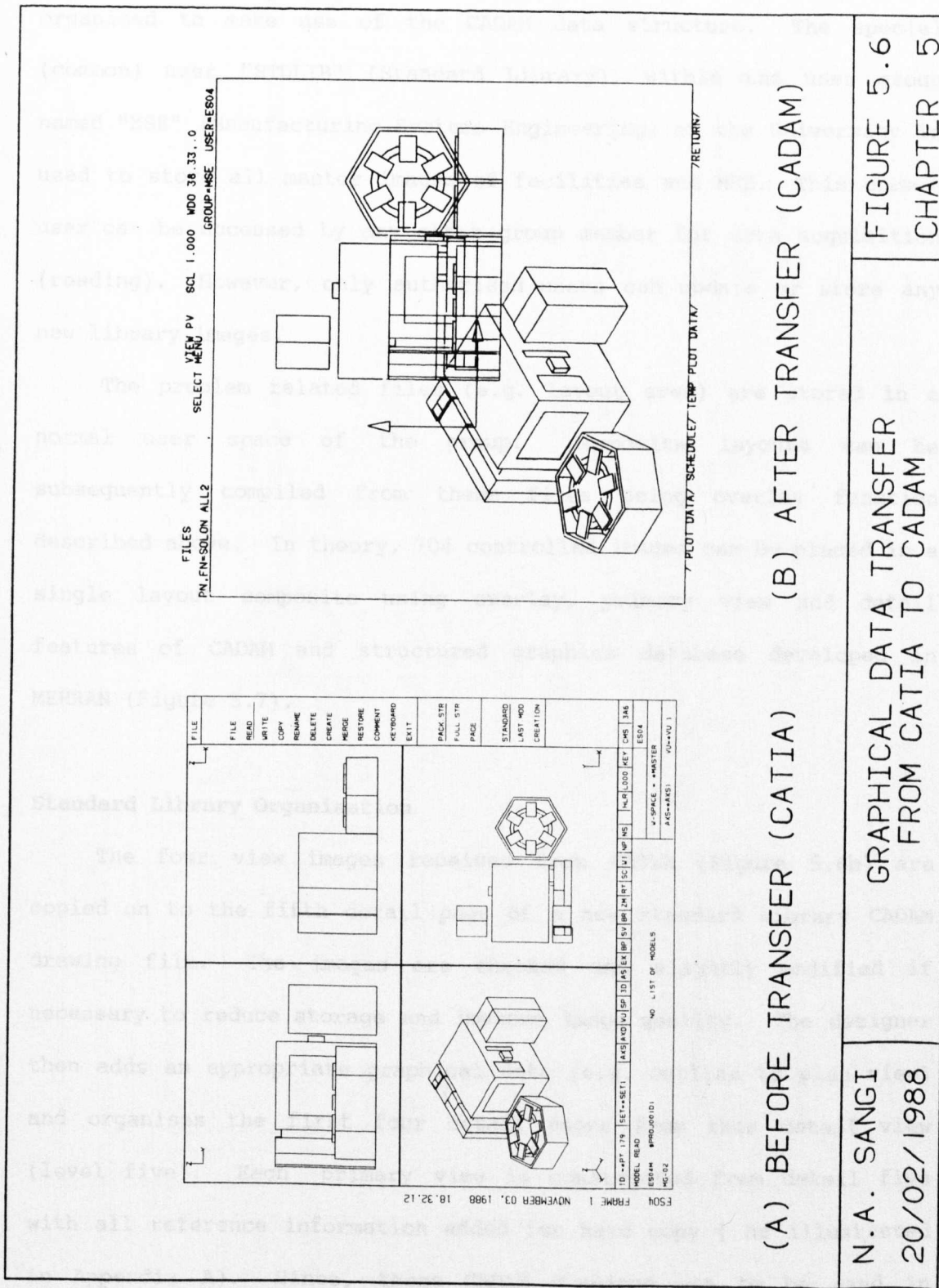
To explain this transfer process in more detail, at the onset of MEHRAN research, no preparation of views was necessary in CATIA. Two dimensional views were stripped off straight from the solid model but ended up superimposed on each other when arrived in CADAM. The latest release of CATIA requires the preparation of the four views whilst still in CATIA but these four views are then transferred appropriately spaced to CADAM.

What happens to facility images in the CADAM, is illustrated in Figures 5.7, 5.8 and 5.12. An explanation of their purpose is given later in this chapter under the heading Standard Library organisation.

### **5.3.3 CADAM Facilities Database**

#### **Overview**

The use of this graphics database is intended for multiple image applications as in layout design, where layout areas, MHE images and service facilities images are combined with workcentre layouts to construct a composite factory image.



N.A. SANGI  
20/02/1988

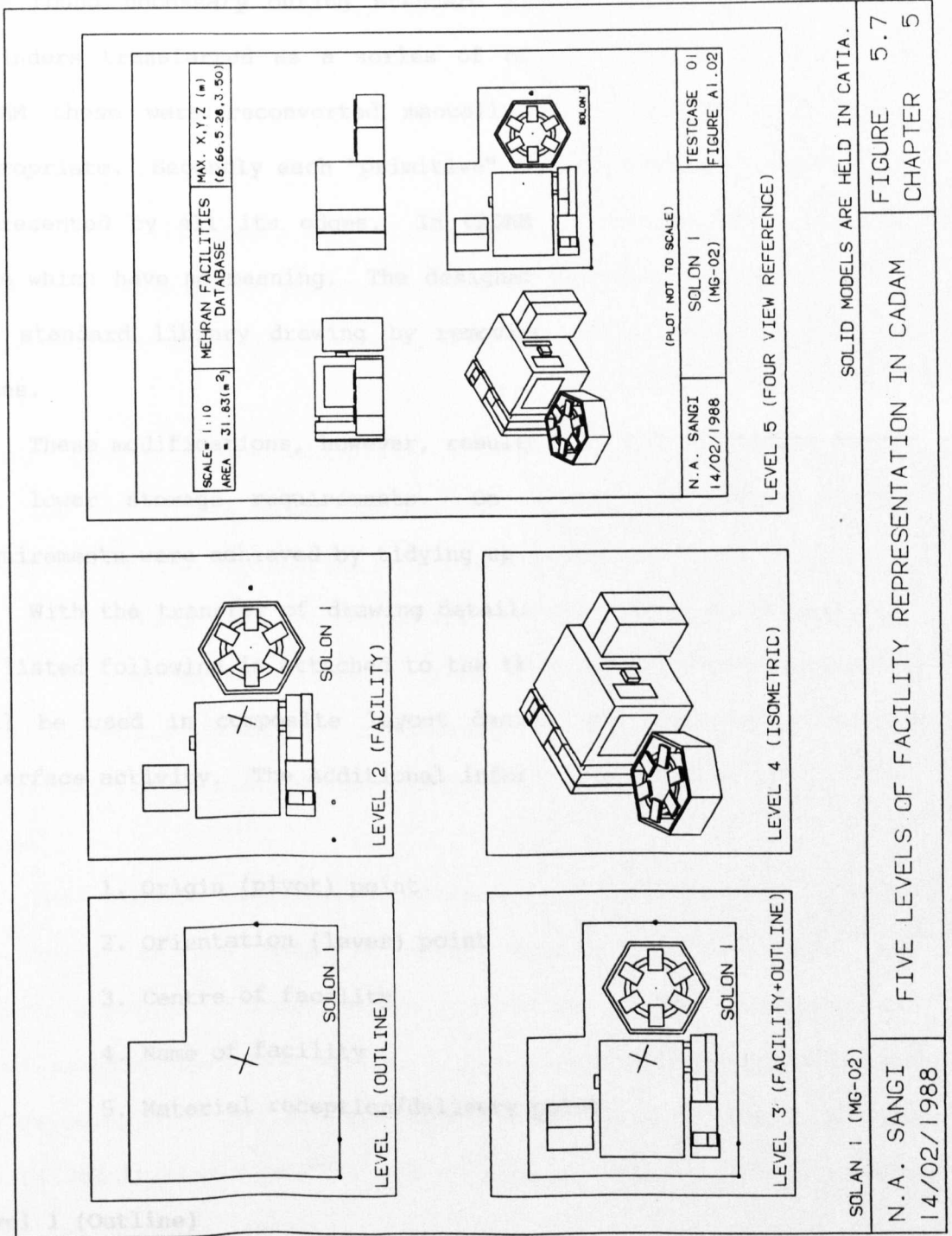


CADAM uses a hierarchical data structure as previously discussed and shown in Figure 5.2. The structured graphics data base was organised to make use of the CADAM data structure. The special (common) user "STDLIB" (Standard Library), within the user group named "MSE" (Manufacturing Systems Engineering) at the University is used to store all master images of facilities and MHE. This common user can be accessed by any other group member for data acquisition (reading). However, only authorised users can update or store any new library images.

The problem related files (e.g. layout area) are stored in a normal user space of the group. Composite layouts can be subsequently compiled from these files using overlay function described above. In theory, 704 controlled images can be placed in a single layout composite using overlay, primary view and detail features of CADAM and structured graphics database developed in MEHRAN (Figure 5.7).

### **Standard Library Organisation**

The four view images received from CATIA (Figure 5.6b) are copied on to the fifth detail page of a new standard library CADAM drawing file. The images are checked and slightly modified if necessary to reduce storage and improve image quality. The designer then adds an appropriate graphical data (e.g. outline to plan view) and organises the first four detail pages from this detail view (level five). Each primary view is constructed from detail five with all reference information added for hard copy ( as illustrated in Appendix A). Since, these CADAM drawings are to be used in conjunction with layout area, a scaling reduction of 10:1 is made to the images.



The transfer from CATIA and development of a standard library is achieved with high accuracy. However, two practical modifications were found necessary during standard library work. Firstly CATIA cylinders transferred as a series of flat "facets". Once into CADAM these were reconverted manually to ellipse or circles as appropriate. Secondly each "primitive" component when transferred is represented by all its edges. In CADAM it results in an overlaid line which have no meaning. The designer therefore manually "tidies up" standard library drawing by removing all unnecessary overlaid lines.

These modifications, however, resulted not only in tidier images but lower storage requirements. On average 54% lower storage requirements were achieved by tidying up images.

With the transfer of drawing details completed, additional data as listed following is attached to the three detail pages (1-3) which will be used in composite layout design and subsequent geometry interface activity. The Additional information attached is:

1. Origin (pivot) point
2. Orientation (lever) point
3. Centre of facility
4. Name of facility
5. Material reception/delivery point

#### **Level 1 (Outline)**

Level 1 shows the lowest form of facility representation used in MEHRAN. The working area of the facility without 2-D facility plan is used in this level. This offers advantages of a low storage, quick method of generating large working layouts. This is equivalent

of 2-D variable outline used in many GINO type graphics based CAFL procedures. However, additional information as listed above makes it highly controllable image as would be explained later in this chapter.

### **Level 2 (Facility)**

Level 2 represents the plan view of the facility along with associated supporting equipment. This level provides a detailed picture of how the layout proposal would look when finished.

### **Level 3 (Facility plus Outline)**

The level three allow the designer to substitute greater detail for production of engineering standard layouts. This level contains all the information available for levels one and two and is illustrated in an exploded detail form in Figure 5.8. Level three is used to allow designer consideration of detailed operational requirements, for example the provision of maintenance and operating space.

The MEHRAN facilities database is designed to operate independent of the level of detail being visualised, using the reference points on location and orientation of the workcentre and other symbols described earlier. The standard library images are master records of the CAD data base and any level of layout problem can be constructed from this set of data by following the procedure described in Users Manual.

### **Level 4 (Isometric view)**

The level four is an isometric image of the workcentre and must not be used for constructing any composite layout.

Level 3 (Reference)

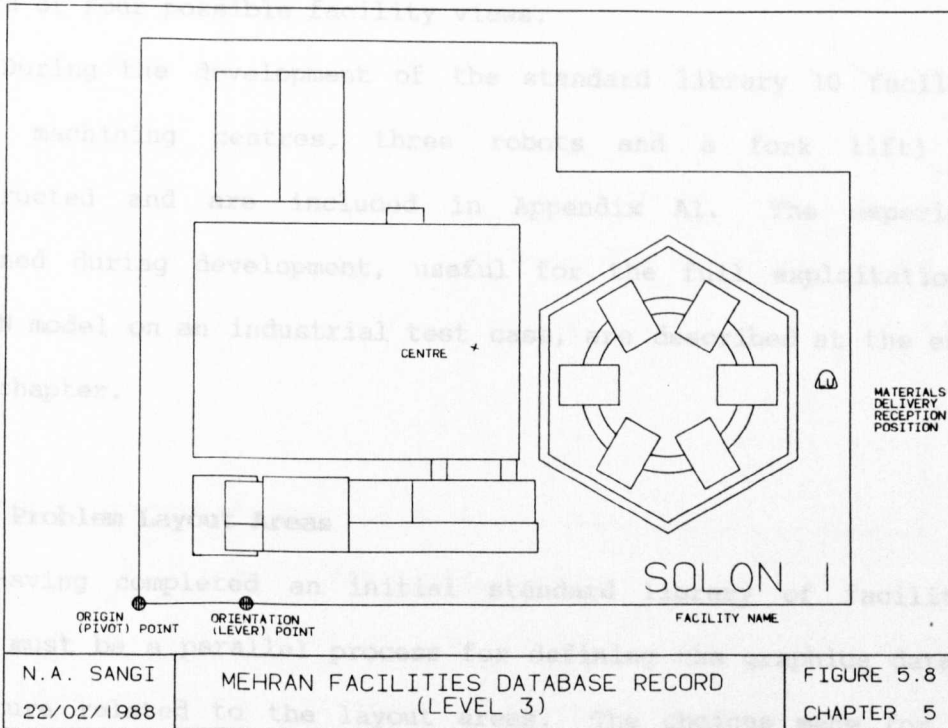
The fifth level (detail page) is maintained as the composition

recording of the facility view.

During the development of the standard library 10 facilities (five machining centres, three robots and a fork lift) were constructed and are included in Appendix A1. The specifications obtained during development, useful for the exploitation of MEHRAN model on an industrial test case, are given at the end of this chapter.

### 5.3.4 Problem layout areas

After having completed an initial standardisation process, there are



activity in MEHRAN model are illustrated in Figure 5.9.

In developing the data structure the CAP related aspects of the

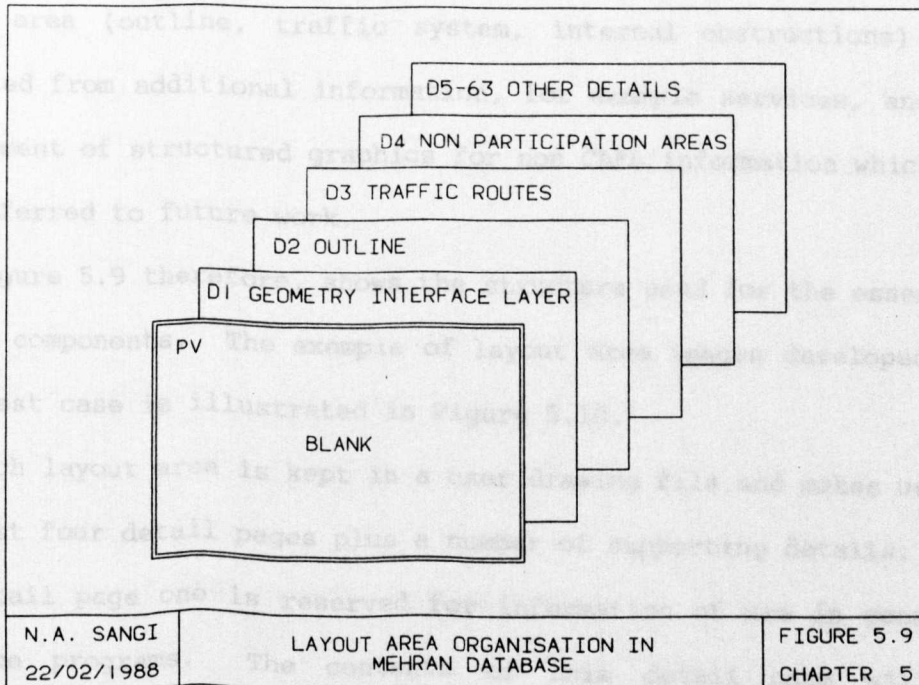
layout area (outline, traffic system, internal obstructions) were separated from additional information (machines, an

development of structured graphical data which has been deferred to future.

Figure 5.9 the example of layout area development for factory component. The example of layout area development for first test case illustrated in Figure 5.9.

Each layout area is kept in a separate file and makes use of the first four detail pages plus a number of supporting details.

Detail page one is reserved for the geometry interface. The geometry interface is generated by the same process as the page view but will be restricted to those elements needed by the geometry interface.



## **Level 5 (Reference)**

The fifth level (detail page) is maintained as the composite record of four possible facility views.

During the development of the standard library 10 facilities (five machining centres, three robots and a fork lift) were constructed and are included in Appendix A1. The experiences obtained during development, useful for the full exploitation of MEHRAN model on an industrial test case, are described at the end of this chapter.

### **5.3.4 Problem Layout Areas**

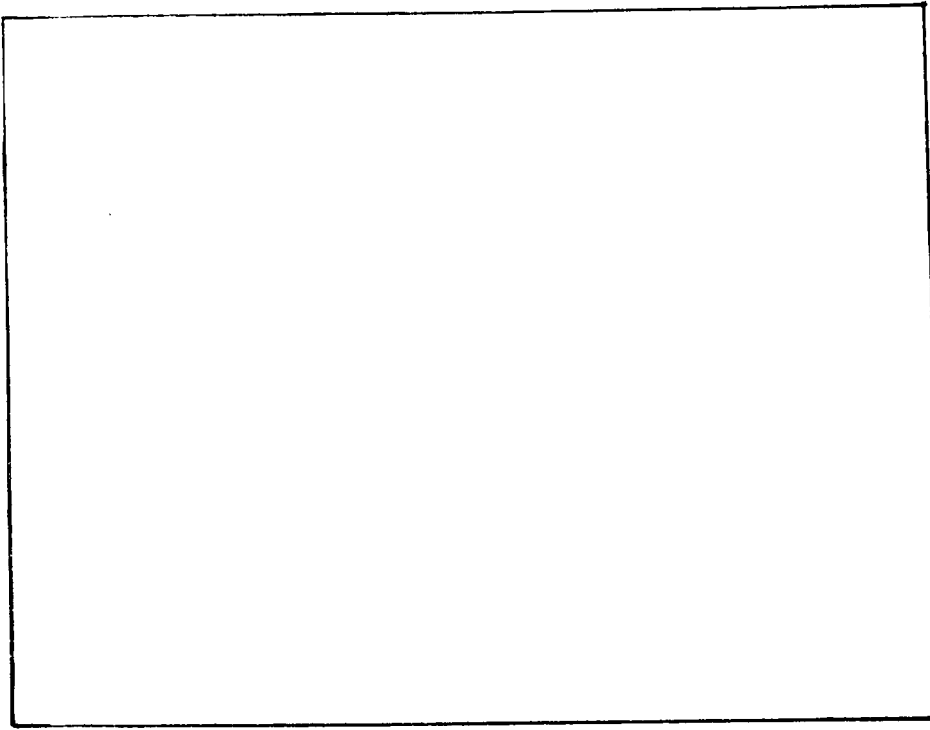
Having completed an initial standard library of facilities, there must be a parallel process for defining the graphics database structure related to the layout areas. The choices made for this activity in MEHRAN model are illustrated in Figure 5.9.

In developing the data structure the CAFL related aspects of the layout area (outline, traffic system, internal obstructions) were separated from additional information, for example services, and the development of structured graphics for non CAFL information which has been deferred to future work.

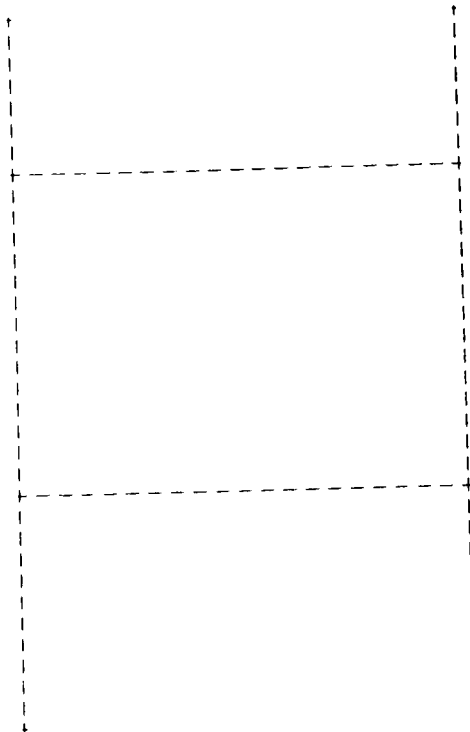
Figure 5.9 therefore, shows the structure used for the essential factory components. The example of layout area images developed for first test case is illustrated in Figure 5.10.

Each layout area is kept in a user drawing file and makes use of the first four detail pages plus a number of supporting details.

Detail page one is reserved for information of use in geometry interface programs. The contents of this detail page will be generated by the same process as the prime view but will be restricted to those elements needed by the geometry interface



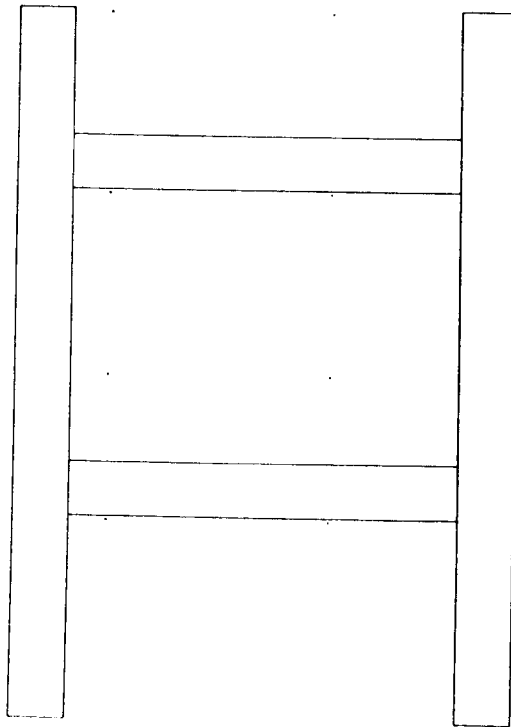
**(A) Outline (D2)**



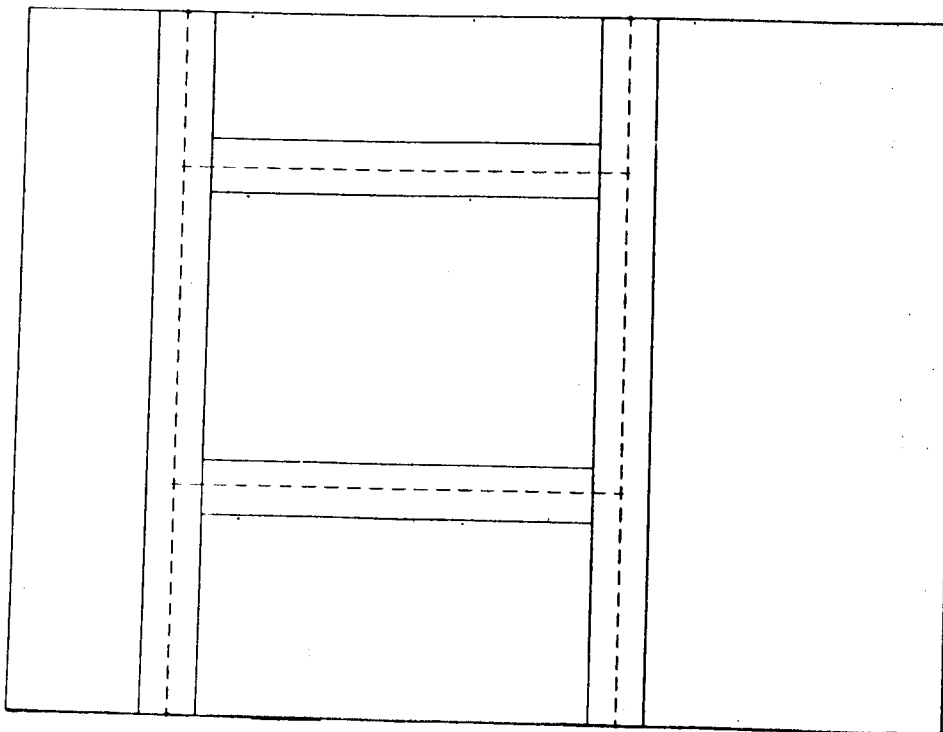
**(B) Traffic Routes (D3)**

**FIGURE 5.10 Illustrated Example of Layout Area Composition.**

**(Continued on next page)**



**(C) Non Participation Areas (D4)**



**(D) Layout Area Composed From Detail Pages D2-D4 (PV)**

**FIGURE 5.10 Illustrated Example of Layout Area Composition.**



software i.e. columns and unwanted details will be removed. This detail page is specially reserved to utilise effectively the filtering ability of geometry interface programs.

Detail page two will contain the outline of the layout area for the specific problem. This can be developed by direct drafting or can be stripped out of an existing site plan. The layout area in the prototype test case for MEHRAN was constructed directly and the layout area in the industrial test case (Chapter 6) was taken from a site plan.

Detail page three contains the traffic system within the layout area. A special feature of this detail is the use of the "rivet" symbol to identify the nodes of the traffic system. These symbols are carried onto detail page one, and subsequently through to the composite drawings. "Rivets" are subsequently used to extract materials movement data through a geometry interface program.

Detail four contains the composite of all non participation areas. Non participation areas include offices, walls, partitions and structural details. As many repeats of these (e.g. columns) occur each individual construction is held in one of the supporting detail pages (detail pages 5-63) and they are brought forward and assembled out on detail four.

The prime view therefore can be compiled from details two to four and it is this image that is overlaid to produce a layout design.

### **5.3.5 Composing Layouts**

The relationship between facilities drawings and the layout area drawing is illustrated in Figure 5.11. The initial step is to transfer each facility or material handling resource required by individual layout problems onto the detail pages, of the facilities

and material handling files, using the "STDLIB" (standard library function within CADAM. Note that this is a point at which the level of facility representation is decided as only one of the three possible representations should be transferred.

The process for developing the final layout area representation, the second stage in composing layout plans has been described in section 5.3.4.

The final composite layout is produced by declaring a parent overlay file, which starts and remains empty (no geometry in it), but which acts as the storage for each overlay member. Into this file is transferred, using the "Overlay" function, the prime view of the layout area, facilities and material handling files. Other detail for example services could also be added. Working within the overlay file it is possible to switch from the overlaid primary view to another whilst still viewing the composite image.

The third stage of the layout design therefore involves switching to the facilities prime view and "ditto" copying detail page facility drawings onto the required positions. Figure 5.12 shows an example of the high quality layout design that can be produced by this method.

The final act in creating the layout design is to label each individual facility by attaching an attribute to the "ditto" image and thereby storing another source of information extractable by geometry interface software.

One further point on construction of layout designs. Once the designer is experienced at using the MEHRAN approach, many visualisations of particular problem can be generated by permutations of the overlay levels, files, details and dittos.

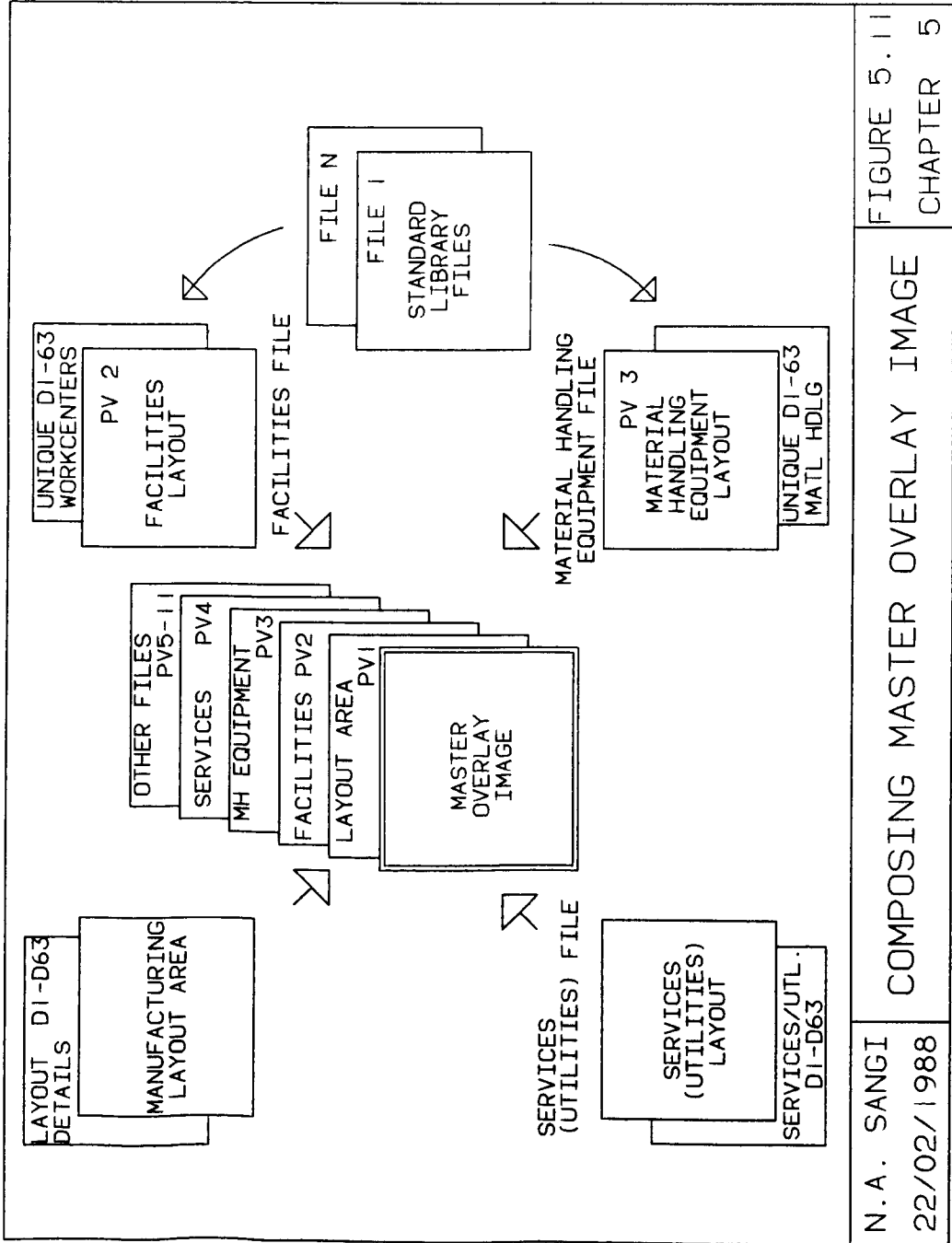


FIGURE 5.11  
CHAPTER 5

COMPOSING MASTER OVERLAY IMAGE

N.A. SANGI  
22/02/1988

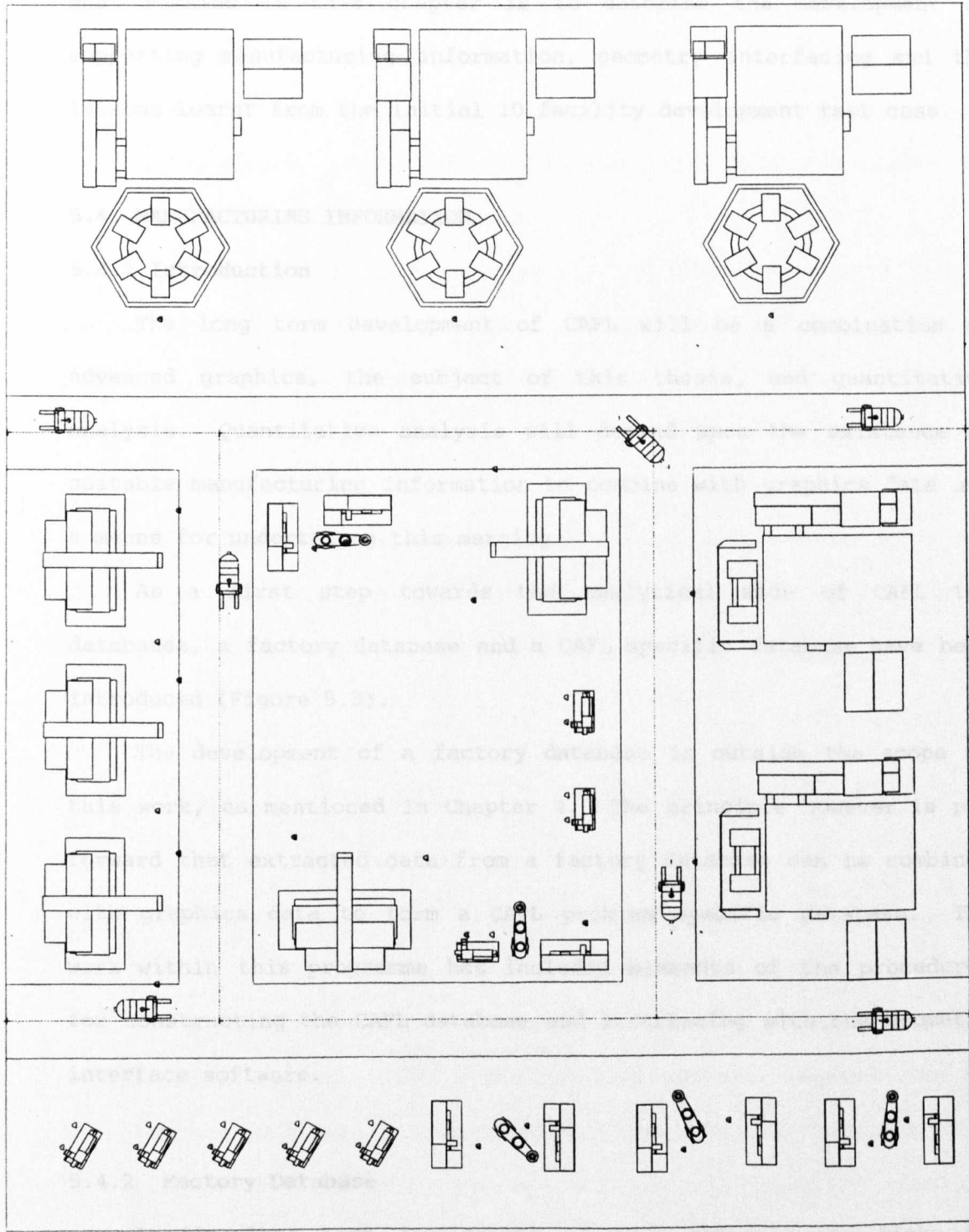


FIGURE 5.12  
CHAPTER 5

PROTOTYPE TEST CASE COMPOSITE LAYOUT

N.A. SANGI  
12/02/1988

The procedure for developing the graphical images of facility layout designs using the MEHRAN model has now been fully described. What remains in this chapter is to describe the development of supporting manufacturing information, geometry interfacing and the lessons learnt from the initial 10 facility development test case.

## **5.4. MANUFACTURING INFORMATION**

### **5.4.1 Introduction**

The long term development of CAFL will be a combination of advanced graphics, the subject of this thesis, and quantitative analysis. Quantitative analysis will depend upon the existence of suitable manufacturing information to combine with graphics data and a means for undertaking this merging.

As a first step towards the analytical side of CAFL two databases, a factory database and a CAFL specific database have been introduced (Figure 5.3).

The development of a factory database is outside the scope of this work, as mentioned in Chapter 4. The principle however is put forward that extracted data from a factory database can be combined with graphics data to form a CAFL problem specific database. The work within this programme has included elements of the procedures for constructing the CAFL database and interfacing with the geometry interface software.

### **5.4.2 Factory Database**

In the long term development of this software the links to permanent corporate databases are envisaged as the means of obtaining

manufacturing information, for transfer to the CAFL problem database. At this point in the experimental programme, with concentration on graphics representation using the 10 prototype facilities, the factory database is not needed.

In view of any work in this area being dependent on individual company databases, the factory database has been restricted to comments in the future work section.

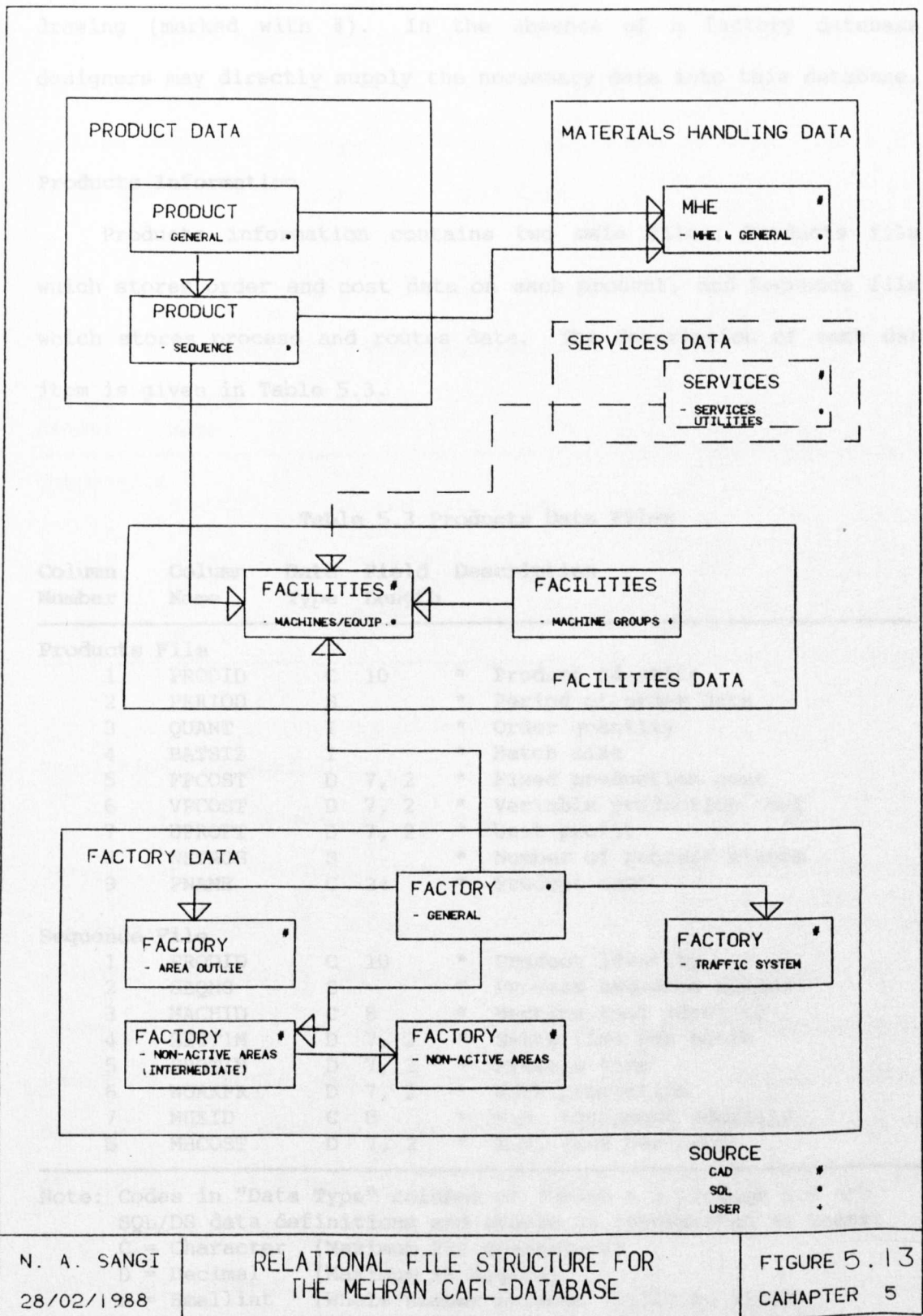
In the industrial test (Chapter 6), the factory data will be bypassed by the direct construction of the CAFL data files from a selective collection of manufacturing information.

#### **5.4.3 CAFL Problem Database**

The CAFL problem database file structure is maintained with the SQL/DS package and is illustrated in Figure 5.13. The main categories of information held are :

- Products information
- Facilities information
- Layout area information
- Materials handling equipment information

The core of information defined in this file structure (detailed in Tables 5.3 through 5.6) is derived from the data requirements of the programs developed at the University of Liverpool (most notably by Lilley [34]). The file structure has been redefined and extended to accommodate multiple design and evaluation models. Modular structure of this database will allow easy future extensions to many other specialised analytical programs.



In each table, the primary source of data is identified as either from the factory database (marked with \*) or from the CADAM drawing (marked with #). In the absence of a factory database, designers may directly supply the necessary data into this database.

### Products Information

Products information contains two main files; Products file, which stores order and cost data on each product, and Sequence file, which stores process and routes data. The description of each data item is given in Table 5.3.

Table 5.3 Products Data Files

Column Number	Column Name	Data Type	Field Length	Description
<b>Products File</b>				
1	PRODID	C	10	* Product identity
2	PERIOD	S		* Period of order data
3	QUANT	I		* Order quantity
4	BATSIZ	I		* Batch size
5	FPCOST	D	7, 2	* Fixed production cost
6	VPCOST	D	7, 2	* Variable production cost
7	UPROFT	D	7, 2	* Unit profit
8	NSTAGS	S		* Number of process stages
9	PNAME	C	24	* Product name
<b>Sequence File</b>				
1	PRODID	C	10	* Product identity
2	SEQNO	S		* Process sequence number
3	MACHID	C	8	* Machine tool identity
4	SETTIM	D	7, 2	* Setup time per batch
5	PROTIM	D	7, 2	* Process time
6	WORKPR	D	7, 2	* Work proportion
7	MHEID	C	8	* M.H. equipment identity
8	MHCOST	D	7, 2	* M.H. cost per batch

Note: Codes in "Data Type" columns of Tables 5.3 through 5.8 are SQL/DS data definitions and should be interpreted as under:

- C = Character (Maximum 254 characters)
- D = Decimal (Maximum 15 digits)
- S = Smallint (Whole number between -32767 to 32768)
- I = Integer (Whole number between -2,147,483,648 to +2,147,483,647)

\* Source factory database



An example of combining data in both files is a subset file "Prodseqs", which stores relationship between two main product files (i.e. Products and sequence data files) using a common data field "Prodid". Combined data from this will then be transferred to CAFL problem database for eventual use in analytical models. Table 5.4 shows the source of data within this file.

**Table 5.4 Prodseqs View File**

<b>Column Number</b>	<b>Column Name</b>	<b>Source</b>
Components :		
1	PRODID	Common data field
2	PNAME	Products
3	SEQNO	Sequence
4	MACHID	Sequence
5	PROTIM	Sequence
6	MHEID	Sequence

### **Facilities Information**

Facilities information is kept under a data file MACHINE, the description of the data items is given in Table 5.5. This file typically provides all information on facilities, extracting from two sources, the factory database and the geometry interface. Of 38 items of data, 22 ( 1,15-37) are geometrical information, the remaining elements are received from the theoretical factory database. Note that the geometrical information fields are capable of handling 3-D information. Present geometry interface assigns zero value to these fields, in future, it may be used for multi story or 3-D layout information.

The machine groups file illustrated in Figure 5.13 was not constructed and is left for future work.

### **Layout Area Information**

The layout database consists of three sets of information; traffic system, factory outline and offices (non production areas) outline. One intermediate file for linking the three main layout area information sets is defined. Table 5.6 lists the structure of the four information files.

### **Materials Handling Equipment Information**

This file is seen as long-term development of CAFL database when a combined study of handling system together with layout will be performed. The information in this file can be used to directly calculate the cost of handling. Any of the three fields; load time, load cost per batch or unit load cost can be used in calculating handling cost. Additionally load time field, together with design speed data can be used in operational performance studies. Future extensions of this file may contain graphical data on fixed material handling equipment (e.g. conveyor). Table 5.7 lists the structure of this file.

Additionally one overall project control file is defined. The contents of this file are intended to setup parameters for software control in future versions of MEHRAN model.

All nine of these data sets, which can be seen to be the basis of a materials movement analysis model, are prepared and displayed in variable combinations under SQL software.

Geometry interface program is used to provide an addition of 22 sets of information on facilities, extracted from drawings. The 22 items are indicated (with #) on Table 5.5. Geometry interface software again can be used to import layout information on the layout area outline, traffic system and office (non participation) areas as

CADAM layout information structure is defined to allow extraction of this data (marked with #) in Table 5.6.

Table 5.5 Machine Data File

Column Number	Column Name	Data Type	Field Length	Description
1	MACHID	C	8	* Facility identity
2	CELLID	C	3	* Cell identity
3	DISCOS	C	7, 2	* Facility disconnection cost
4	MOVCOS	D	7, 2	* Facility moving cost
5	CONCOS	D	7, 2	* Facility connection cost
6	TOTCOS	D	7, 2	* Total relocation cost
7	CAPCOS	D	7, 2	* Capital cost
8	OVHCOS	D	7, 2	* Facility overheads
9	DISTIM	D	7, 2	* Facility disconnection time
10	MOVTIM	D	7, 2	* Facility moving time
11	CONTIM	D	7, 2	* Facility connection time
12	TOTTIM	D	7, 2	* Total relocation time
13	MACGRP	C	3	* Facility group
14	REMLIF	S		* Years remaining in replacement
15	XIPIV	D	7, 2	# Initial X- of origin
16	YIPIV	D	7, 2	# Initial Y- of origin
17	ZIPIV	D	7, 2	# Initial Z- of origin
18	XFPIV	D	7, 2	# Final X- of origin
19	YFPIV	D	7, 2	# Final Y- of origin
20	ZFPIV	D	7, 2	# Final Z- of origin
21	XILEV	D	7, 2	# Initial X- of orientation
22	YILEV	D	7, 2	# Initial Y- of orientation
23	ZILEV	D	7, 2	# Initial Z- of orientation
24	XFLEV	D	7, 2	# Final X- of orientation
25	YFLEV	D	7, 2	# Final Y- of orientation
26	ZFLEV	D	7, 2	# Final Z- of orientation
27	XICEN	D	7, 2	# Initial X- of centre
28	YICEN	D	7, 2	# Initial Y- of centre
29	ZICEN	D	7, 2	# Initial Z- of centre
30	XIRMAT	D	7, 2	# Initial X- of Load/unload
31	YIRMAT	D	7, 2	# Initial Y- of Load/unload
32	ZIRMAT	D	7, 2	# Initial Z- of Load/unload
33	XFDMAT	D	7, 2	# Final X- of Load/unload
34	YFDMAT	D	7, 2	# Final Y- of Load/unload
35	ZFDMAT	D	7, 2	# Final Z- of Load/unload
36	DETNO	S		# Detail page number of image
37	FACTID	C	8	* Factory identity
38	MACNAM	C	24	* Facility name

\* Source factory database

# Source geometry interface

The CAFL problem database therefore have been constructed from SQL written routines and geometry interface software written in this research programme and described following. This database will be the key to analysis and therefore also be accessed by modular specialist software (Figure 5.3).

**Table 5.6 Layout Area Information**

<b>Column Number</b>	<b>Column Name</b>	<b>Data Type</b>	<b>Field Length</b>		<b>Description</b>
<b>Factory Outline Data File</b>					
1	FACTID	C	8	*	Factory identity
2	OLPID	S		#	Outline point identity
3	XOUTL	D	7, 2	#	X- coordinate of outline point
4	YOUTL	D	7, 2	#	Y- coordinate of outline point
5	ZOUTL	D	7, 2	#	Z- coordinate of outline point
6	FACNAM	C	24	*	Factory name
<b>Office Areas</b>					
1	FACTID	C	8	*	Factory identity
2	OFFCID	S		*	Office identity
3	OFFPID	S		#	Office outline point identity
4	XOFF	D	7, 2	#	X- coordinate of office outline
5	YOFF	D	7, 2	#	Y- coordinate of office outline
6	ZOFF	D	7, 2	#	Z- coordinate of office outline
<b>Traffic System Data File</b>					
1	FACTID	C	8	*	Factory identity
2	JUNCID	S		#	Traffic junction identity
3	XTR	D	7, 2	#	X- coordinate of junction
4	YTR	D	7, 2	#	Y- coordinate of junction
5	ZTR	D	7, 2	#	Z- coordinate of junction
6	WIDTR	D	7, 2	*	Width of traffic route
7	TYPTR	S		*	Type of traffic route
8	XTRCEN	D	7, 2	#	X- coordinate of centre
9	YTRCEN	D	7, 2	#	Y- coordinate of centre
10	ZTRCEN	D	7, 2	#	Z- coordinate of centre
<b>Intermediate Linking File</b>					
1	FACTID	C	8	*	Factory identity
2	OFFCID	S		*	Office identity
3	OFFNAM	C	24	*	Office name

\* Source factory database

# Source geometry interface

Table 5.7 Material Handling Equipment Data File

Column Number	Column Name	Data Type	Field Length		Description
1	MHEID	C	8	*	MHE identity
2	LOATIM	D	7, 2	*	Load time
3	LOACOS	D	7, 2	*	Load cost per batch
4	FOCOST	D	7, 2	*	Fixed operating cost
5	VOCOST	D	7, 2	*	Variable operating cost
6	ULCOST	D	7, 2	*	Unit load cost
7	MOVTYP	S		*	Movement type
8	DESSPE	D	7, 2	*	Design speed
9	CAPCOS	D	7, 2	*	Capitol cost
10	REMLIF	S		*	Years remaining in replacement
11	WTCAP	D	7, 2	*	Weight capacity
12	VOLCAP	D	7, 2	*	Volume capacity
13	MHENAM	C	24	*	MHE name

\* Source factory database

# Source geometry interface

Table 5.8 Overall Project Information File

Column Number	Column Name	Data Type	Field Length		Description
1	FACTID	C	8	*	Factory identity
2	AREA	D	11,2	*	Maximum area
3	FLOORS	S		*	Maximum number of floors
4	CELLS	S		*	Maximum number of cells
5	TROUTS	S		*	Maximum number of traffic routes
6	MACHS	S		*	Maximum number of machine tools
7	NEWMAC	S		*	Maximum number of new facilities
8	OBSMAC	S		*	Maximum obsolete facilities
9	REPMAC	S		*	Maximum replacement of facilities
10	REMARKS	C	24	*	Designer comment

\* Source factory database

## 5.5 INTERFACE SOFTWARE

### 5.5.1 CADAM Geometry Interface

All the advanced graphics features described in the second part of this research programme (MEHRAN) would remain incomplete until communication of information in and out of the proprietary database is accomplished.

Communication in an outward direction allows external validation of layout designs without change within the protected database. Communications inwards would allow the automated alteration or construction of layout designs. Both should be theoretically possible with CADAM.

This communication can be background (frequently the only choice) or interactive (the preferred approach). Four pieces of software were written to test out the potential of the choices, listing of each program is given in Appendix B.

1. ATTRES (Batch mode- Extraction)
2. ANALYS (Interactive- Extraction)
3. IMPROV (Batch mode - Input (Improvement))
4. DESIGN (Interactive - Input (Design))

The experience of writing and applying these preliminary GI software examples is given in this section.

Tests were carried out in both batch mode and interactive mode geometry interface. In first phase, data extraction (CADET) and geometry construction (CADCD) using ATTRES and DESIGN (an early batch version) were tested separately, followed by a combined extract and construct capabilities testing in both batch and interactive modes of operation. Initially these tests failed for three reasons; the

specific CADAM setup at the University, lack of experience and the poor error diagnostic ability of GI module. Three examples can be given of this difficulty. Firstly, CADCD and CADET did not work in the same load module because of particular CADAM setup at the University. This single problem took nine months to solve. In a second test CADET failed to run under CADMACGM because of ambiguity between similar parameters in CADCD and CADET. Poor error diagnostics hindered the resolution of this difficulty. Third major problem resulted from a systems changeover at the University of Liverpool, where the twin computer system (IBM4341 and IBM3083) was replaced by a single processor (IBM3081) and the vital FORTHX compiler being withdrawn. This resulted in a communication failure from the interactive geometry interface to the operating system. Before the changeover interactive programs were able to read and write into the file structure of MEHRAN. This new limitation, still continuing, stopped read and write activity within interactive macro programs. Owing to these systems limitations, interactive programs ANALYS and DESIGN were separated and work on geometry interface software remained "small programs" working separately and lacking integration.

Testing and development of geometry interface software was performed in four stages:

1. Data extraction in a batch mode (ATTRES)
2. Automatic layout generation (DESIGN (batch version))
3. Interactive data extraction and calculations (ANALYS program within CADMACGM).
4. Interactive design (DESIGN within CADMACGM).

Following the design process described in Chapter 2 and the conceptual framework described in Chapter 4, the overall design

activity within MEHRAN is illustrated in Figure 5.14. The number above the top right hand corner of software/designer activity identifies corresponding stage of the original design process described in Chapter 2. Each design stage is described in the following.

### **Proposition : Design Stage 3**

#### **Test case preparation**

##### **(DESIGN application)**

The first task in proposing a layout design is generation of layout images following either of two approaches; improvement (starting from an initial layout) and construction (generating a new layout). Both can be developed using the facilities database and designer controlled placement of facilities. The CADAM based method of generating a layout from MEHRAN facilities database was described earlier (section 5.3.5).

In addition to defining the CADAM based method of layout composite construction, a mechanism for generating layouts through geometry interface program is developed using an interactive designer led approach.

This designer controlled placement method was developed in interactive mode. Available as a menu option "interactive" within the MEHRAN interactive GI program DESIGN (Figure 5.15), this routine requires the designer to initially setup an overlay composite file structure (section 5.3.5). After selecting "DESIGN" option within CADAM function key "MACRO", the default sub menu "interactive" is automatically selected. The designer is asked four questions; definition of two points determining location of the facility, CADAM detail page number where that particular facility image is stored



within facilities file and identity attribute data.

The first of the two designer defined points (either selected, keyed-in or indicated using CADAM tablet and puck) sets X,Y coordinates of the origin point (as illustrated in Figure 5.8). The second point defines the vector direction (related to origin point) for orientation of facility image, i.e. facility can be orientated in any position using defined origin (1st. point) as pivot point along the vector originating from first point and passing through second point.

The third menu input, detail number defines storage location of facility image within detail pages (1-63) of the facilities file. The final input, facility identity stores input as attribute text which can later be extracted in the next stage analysis, using ATTRES program.

The process is repeated until all facilities are located on the layout. The interactive features of CADAM geometry interface allow to reinitiate the process one step backwards (if a mistake is realised during data input), the repeating complete cycle of placing single facility (if facility is placed at wrong position), or cancelling a complete session (if not satisfied by the final layout design). This is an example of custom design CAFL menus that will appear during normal CADAM interactive sessions.

#### **Analysis and Improvement : Design Stage 4**

##### **a) Data extraction (4A)**

###### **(ATTRES and ANALYS application)**

Analysis starts with the extraction of data from the composite layout. The initial data extraction task involved extraction of database information via a batch program (ATTRES). This program

comprises of two parts; CADMAIN and CADET utility RESOLV imbedded within the program ATTRES. Prototype test case facilities were assigned five sets of attribute data, and program extracted all five sets of attribute data plus location (origin and orientation) data from the mass of drawing information. The example of the location coordinates and the first attribute (facility identity) as retrieved from the (39 facilities plus material handling equipment) prototype composite layout (Figure 5.12) was reported in an earlier paper [12] and is reproduced in figure 5.16. The facility identity is the key field for combining the manufacturing and location information for later use in specialised evaluation programs.

A new program, ANALYS was later written to extract data and perform preliminary calculations in an interactive mode. This program allowed extraction using specialised symbols stored within the facilities database (section 5.3.3). Both origin (pivot point) and centre (rivet) location data were extracted for potential use in specialised analytical programs.

#### **b) Analytical calculation and improvement (4B-C2)**

##### **(IMPROV and ANALYS application)**

With location data being available, the next step was to compute distances and perform simple analysis. Two programs were written to undertake this work; a batch mode IMPROV, and interactive mode ANALYS. The batch mode program operates as follows:

1. Read location and machine identity data
2. Read production sequence data
3. Compute rectilinear and straight line distance matrices
4. Compute material flow and material flow cost matrices
5. Compute "flow times distance" or "flow times cost" matrix

6. Read facility name, and temporarily move coordinates of facility in unit distance (in eight directions) to search the direction of minimum sum of either flow X distance or cost X distance matrix.
7. Move coordinates of facility in the minimum sum direction by specified amount of deflection in each iteration until total sum starts increasing.
8. Optimise location coordinates between last two iterations.
9. This process is repeated for each facility until designer terminates the improvement process.

The IMPROV program can be seen as a preliminary improvement and optimisation model, validating layout designs outside database. This test discovers the potential of developing and linking further sophisticated analysis and evaluation algorithms within the overall MEHRAN model.

In the interactive program ANALYS, only distance calculations were implemented before the withdrawal of IBM4341 and FORTHX compiler, which resulted in failure of the external file reading and writing process. It was therefore difficult to fully develop and test interactive analysis and improvement process within CADAM. Nevertheless, calculation and data extractions performed before the computer resource damage suggest that CAFL analysis routines can be imbedded within interactive geometry interface.

#### **Compare and Select : Design Stage 5**

##### **Layout evaluation (5)**

The IMPROV program discussed above provided the information on total material handling cost or total flow. It was decided to

provide a mechanism, whereby, the designer can display the results on the CAD terminal. This feature would be a test example of knowledge based support for layout designs. Two options were experimented; use of routine MSGGEN to display results in message area of CADAM screen and use CADCD routines to display results on pre set screens.

The MSGGEN routine primarily allows the display of a 60 character message on the screen. However, for this CAFL application of the MSGGEN routine, a mechanism for updating the message array with appropriate numbers calculated elsewhere in the analytical program was required. The program subsequently written to update message array before calling MSGGEN was unfortunately unable to produce results within the CADAM environment, although the same program worked outside CADAM.

In the second case, a CADAM drawing containing data templates for information useful to the designer was created and numbers were read from a file and written as a series of notes. This routine produced satisfactory results, but care in form design was needed as the number of digits, size of characters (height and width) have to be considered in designing the screens. Four screens which were developed for this routine are given in Appendix D. However, as explained above, subsequent failure of the read and write communication between CADAM and the host computer operating system disabled this mechanism as an area for further investigation.

#### **Approval and Presentation : Design Stage 6**

##### **Layout drawings and reports (6)**

No programming was considered necessary to produce layout drawings. CADAM interactive plotting features were considered sufficient to produce drawings at any stage of the design process.

The quality of layout drawings produced can be evidenced from the drawings shown in this thesis.

### **Summary**

The interactive version of geometry interface software (ANALYS and DESIGN) did provide the essential capabilities needed to combine graphics and evaluation features for layout design. The latest version of MEHRAN interactive geometry interface was thus able to provide interactive CAFL design environment.

The geometry interface comprising of two programs; the ASSEMBLE macro and FORTRAN routines are listed in Appendix B. The ASSEMBLE part is used to display menus, sub menus, prompts, messages and screens for inputting parameters. Whereas the FORTRAN routines are used to retrieve geometry from the CADAM database, perform calculations, display results on the screen, and data handling. It is possible to combine both creation and retrieve functions within one geometry interface program however, well defined and highly structured approach is imperative for efficient operation.

### **5.5.2 Database Interface**

Without the need for a full factory database as part of this research programme database interface experiments were performed on the CAFL problem database. This experimentation involved testing of SQL/DS facilities for the following tasks:

1. Ability to load and unload bulk data from files.
2. Ability to interactively display and modify individual data items.
3. Ability to combine data from different data sets for retrieval.

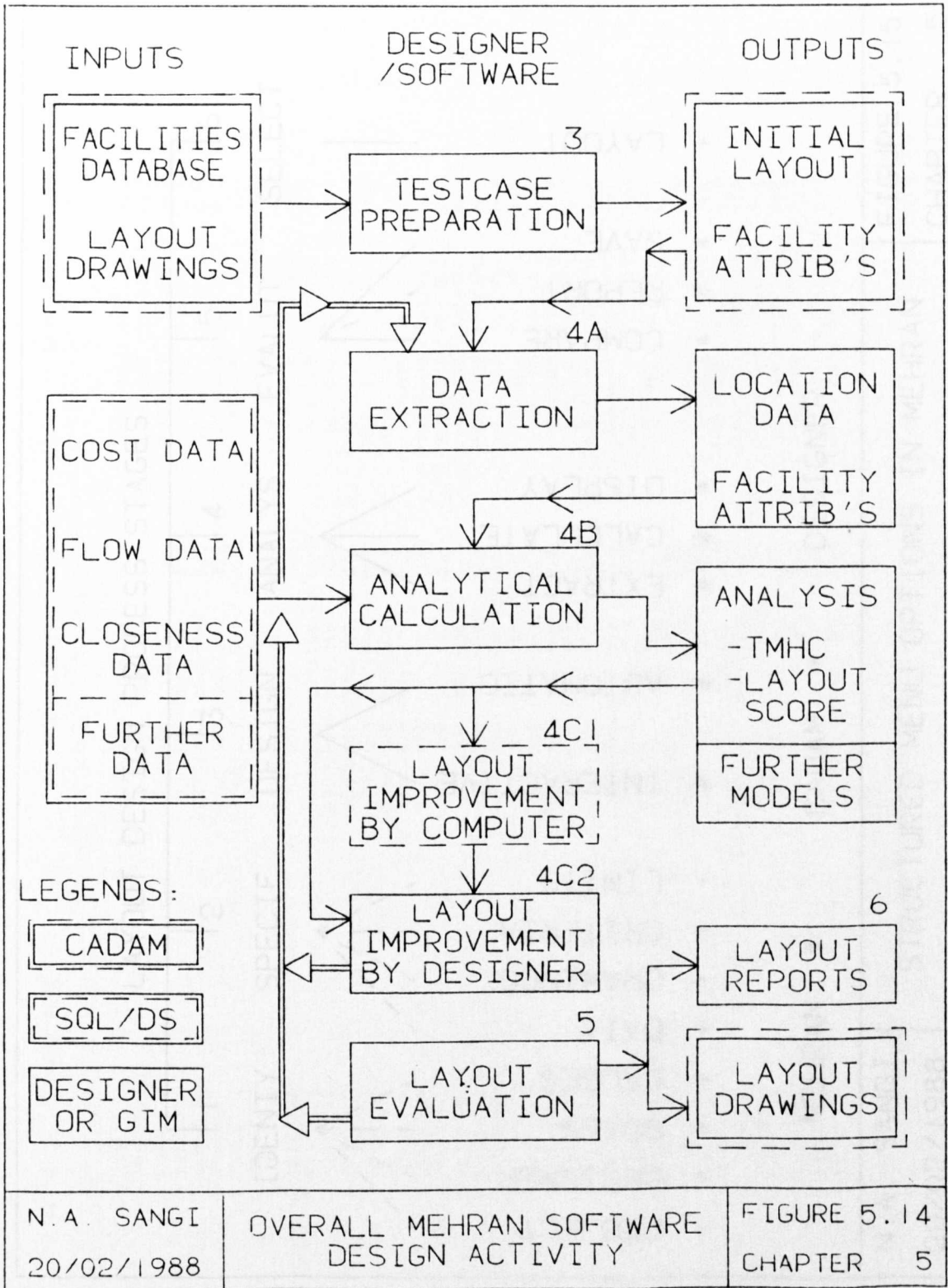
4. Ability to customise screens and output report formats.

It was found that the use of standard SQL commands in a form of routines was easy and convenient when compared to developing direct interfaces in FORTRAN or any other high level language. Since computing facilities did not allow direct (automatic) data acquisition and loading due to CADAM and SQL/DS running on different computers.

### **5.5.3 Analytical Software**

In undertaking this graphics research programme, the existence of previous work on analytical software was acknowledged. The CAFL data base has been designed to produce the data items used in previous programs. This will allow the eventual "remarrying" of research programmes, a point taken up under future work as the development of this merged analytical software was not considered part of this research.

The analytical modules will utilise data collected in the CAFL problem data base and would be running whilst visualisation would be generated at CAD screens. Use of the software would be interactive and modular, repeating evaluation tasks on a menu selection basis. mainframes, attempts at direct data acquisition are identified as future work. However, standard SQL/DS routines were experimented with to judge ease or difficulty in employing SQL/DS. Bulk loading and unloading of data (Reading and writing using files), amending an individual record, defining relationships and interactive query facilities were tested. Standard features were found satisfactory. Three specialised SQL/DS routines were written, two for generating specific report formats and third for combining data from two files for unloading as shown in Table 5.6.

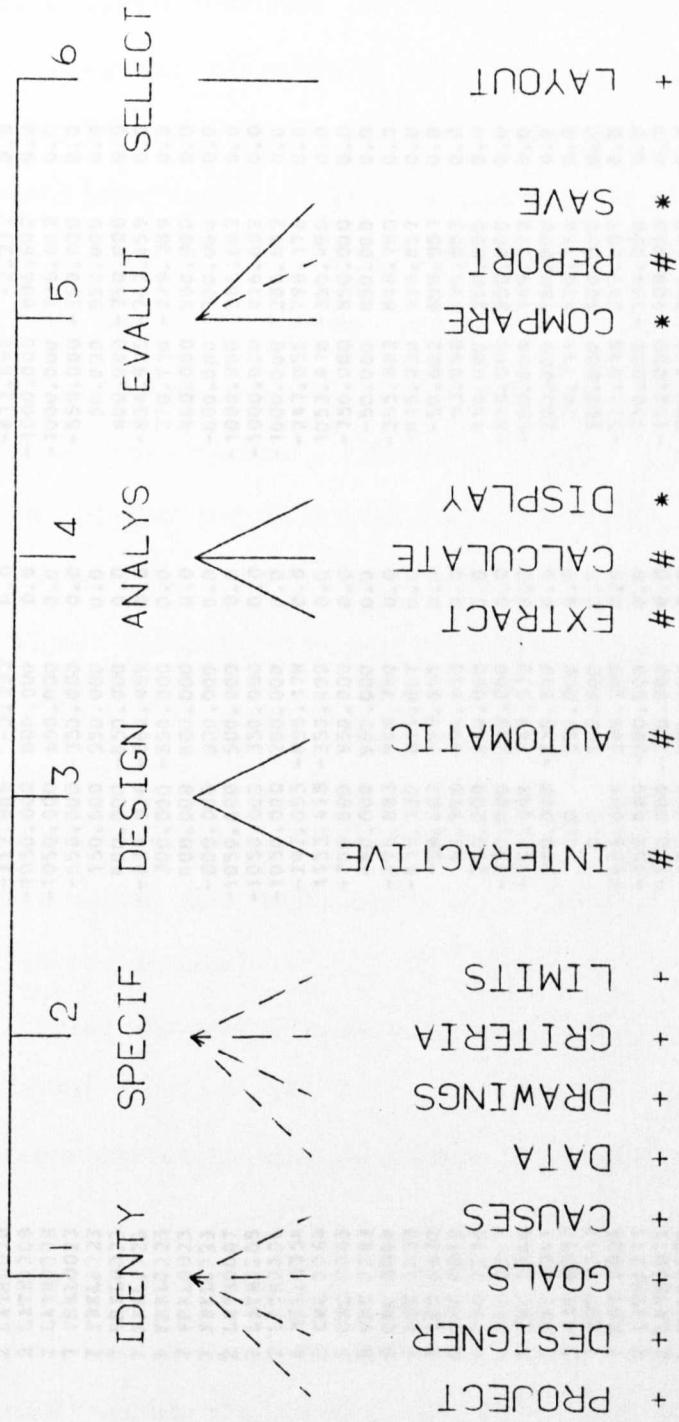


N.A. SANGI  
20/02/1988

OVERALL MEHRAN SOFTWARE  
DESIGN ACTIVITY

FIGURE 5.14  
CHAPTER 5

### LAYOUT DESIGN PROCESS STAGES



MEHRAN # CADAM \* DESIGNER +

FIGURE 5.15  
CHAPTER 5

STRUCTURED MENU OPTIONS IN MEHRAN

N.A. SANGI  
20/02/1988



DETNO	MACHINE NAME	PIVOT POINT			LEVER POINT		
		X	Y	Z	X	Y	Z
3	CNC 0062	1150.000	900.000	0.0	1050.000	900.000	0.0
3	CNC 0063	1150.000	300.000	0.0	1050.000	300.000	0.0
2	LATH0010	-712.886	-2.232	0.0	-612.886	-2.232	0.0
2	LATH0009	-1050.000	800.000	0.0	-1000.000	886.602	0.0
2	LATH0008	-1050.000	650.000	0.0	-1000.000	736.602	0.0
7	FRKL0023	-650.000	-350.000	0.0	-550.000	-350.000	0.0
7	FRKL0023	150.000	550.000	0.0	50.000	550.000	0.0
7	FRKL0023	400.000	-850.000	0.0	400.000	-750.000	0.0
7	FRKL0023	-834.926	-862.459	0.0	-834.925	-762.459	0.0
7	FRKL0023	300.000	-350.000	0.0	370.710	-279.289	0.0
7	FRKL0023	400.000	800.000	0.0	400.000	900.000	0.0
2	LATH0007	-800.000	800.000	0.0	-800.000	700.000	0.0
2	LATH0005	-1050.000	500.000	0.0	-1000.000	586.602	0.0
2	LATH0006	-1050.000	350.000	0.0	-1000.000	436.602	0.0
2	LATH0006	-1050.000	200.000	0.0	-1000.000	286.602	0.0
6	HILL0054	-247.055	-898.178	0.0	-247.055	-798.178	0.0
3	CNC 0064	1153.418	-350.490	0.0	1053.418	-350.490	0.0
5	CNC 0045	-750.000	950.000	0.0	-750.000	850.000	0.0
5	CNC 0043	-50.000	950.000	0.0	-50.000	850.000	0.0
5	CNC 0044	-395.883	948.780	0.0	-395.883	848.780	0.0
1	RBT 0033	-415.230	811.857	0.0	-415.230	711.857	0.0
1	RBT 0032	-50.602	799.951	0.0	-50.602	699.951	0.0
4	CNC 0019	63.996	494.853	0.0	63.996	394.853	0.0
4	CNC 0018	250.000	250.000	0.0	150.000	250.000	0.0
4	CNC 0017	-750.000	-250.000	0.0	-650.000	-250.000	0.0
5	CNC 0046	-750.094	149.572	0.0	-650.094	149.572	0.0
5	CNC 0041	300.000	-250.000	0.0	300.000	-150.000	0.0
1	RBT 0037	0.0	250.000	0.0	70.711	320.710	0.0
1	RBT 0012	0.0	100.000	0.0	100.000	100.000	0.0
1	RBT 0034	-425.648	249.287	0.0	-525.648	249.287	0.0
2	LATH0011	-350.000	-200.000	0.0	-350.000	-100.000	0.0
2	LATH0012	-150.000	-200.000	0.0	-150.000	-100.000	0.0
6	HILL0055	302.121	-896.690	0.0	302.121	-796.690	0.0
4	CNC 0024	-1159.371	-634.752	0.0	-1159.371	-734.751	0.0
4	CNC 0021	-967.383	-174.873	0.0	-967.383	-74.873	0.0
4	CNC 0023	-958.453	-585.638	0.0	-958.453	-485.638	0.0
4	CNC 0025	-964.406	-948.780	0.0	-964.406	-848.780	0.0
4	CNC 0020	-1157.883	164.455	0.0	-1157.883	64.455	0.0
4	CNC 0022	-1166.813	-252.264	0.0	-1166.812	-352.264	0.0

FIGURE 5.16 Example of Facility Location Data Extracted by ATTRES Program.

The level of integration of software modules is dependent on the operating system, which communicates between the three databases, analytical and commercial software, the computer and the designer. The operating system provides the required common environment. The alternative approach of direct communication would be extremely difficult in practice, as it can not be assumed that the CAD, DBMS and analytical programs will directly communicate with each other.

Therefore integration can be achieved by using software as sub modules of the operating system, providing a common environment to all the commercial and purpose written programs. This arrangement is realistic for two reasons. Firstly, many commercial software packages are written for multiple operating systems and probability of a CAD package and DBMS package running under any one operating system is high. Secondly, the use of a single operating system is a common practice in many organisations.

#### **5.6. EXPERIENCE OF INITIAL DEVELOPMENT WORK**

The development and application of a CAD based system has been undertaken in two stages :

1. Initial prototype work with a selected 10 facilities and layout drawings set.
2. Experimentation with an industrial test case

The results and comments from the initial prototype work, described in this chapter, are given at this point. This part of test programme records the process of development and implementation of MEHRAN. It describes the justifications and decisions that were taken, at any point in time regarding further development of the MEHRAN system.

### **5.6.1 Selection of CAD Systems**

#### **Choice Between 3-D and 2-D CAD Layout Design**

This research has provided an opportunity to assess the usefulness of two alternative advanced CAD packages; 2-D CADAM and 3-D CATIA, for CAFL application. The eventual selection made for MEHRAN was to use the CATIA package as the basis of a solid model library and to use CADAM for the layout design database plus geometry interface work.

The experiences that led to the "combination" choice were :

1. CATIA could not be used for composing 3-D layout designs, on the basis of layered drawings in CATIA release 2.1.
2. The merging of CATIA drawings to form a layout design was uncontrollable, with merged facilities appearing in a random position, requiring substantial subsequent manipulation.
3. As a consequence of the layering and merging difficulties of CATIA, layout plans would need to be constructed in one file, with a systems limit of 1 Mbyte. This limit would not have allowed any reasonable sized layout problem, as explained later in this section.

For these reasons the layout design process was undertaken in 2-D, with CATIA retained as the host for 3-D facility models, a useful starting point for future 3-D work when CATIA improvements appear.

#### **Choice Between CADAM and CATIA for 2-D Layout Design**

The CADAM system was preferred to host the main CAD-CAFL compilation of layout designs for the following reasons:

4. CATIA requires substantially more storage for 2-D drawings than CADAM requires for equivalent images (approximately 10:1 ratio).
5. CATIA geometry interface facilities in release 2.1 were substantially weaker than the equivalent CADAM geometry interface features. The CADAM geometry interface allowed detailed filtering of specially selected information. CATIA simply provided a list of standard general information e.g. number of solids, model size.
6. The availability of overlay, file and detail page data structures in CADAM matched the structured graphics database approach described in the conceptual model. CATIA, previously identified as not being able to overlay, requiring all images in a single file.
7. The CADAM menu system was designed for composite drawings, and therefore allowed direct designer control over placement of facilities. CATIA would place details automatically at the origin and required direct entry of location coordinates (X,Y,Z) in order to relocate facilities.

Additional points supportive of the choice (CATIA plus CADAM) found during the experimentation with the initial 10 test facilities include :

8. An adequate 2-D transfer facility from CATIA to CADAM was established early after implementation of the CAD systems. Thus security of transfer was available and the two software packages could be used together.

9. Reversing the process, i.e. generating 3-D solid models from CADAM 2-D isometrics was found to be virtually impossible. Difficulties were encountered in both CAD packages. The CADAM procedure for generating isometric views was extremely difficult and the CATIA process of converting isometrics into solids resulted in continued error messages. The attempt to go from 2-D CADAM to 3-D CATIA lasted for three weeks and failed to produce a single solid model.
10. Solid models could be constructed from the 2-D drafting elements of CATIA itself. However this proved to be time consuming, open to errors and a higher memory consumption process. Figure 5.17 shows the relative storage required by the 10 test models. The Lathe machine, with nearly double the space requirement of other facilities, was constructed by this 2-D CATIA method, taking six design hours to construct. No benefit was seen therefore in this approach over direct use of CATIA solid modelling.

For these reasons CADAM was confirmed as the host of 2-D layout design and CATIA was confirmed as host of 3-D solid model library.

### **5.6.2 Use of the CAD Systems**

#### **Memory Requirements**

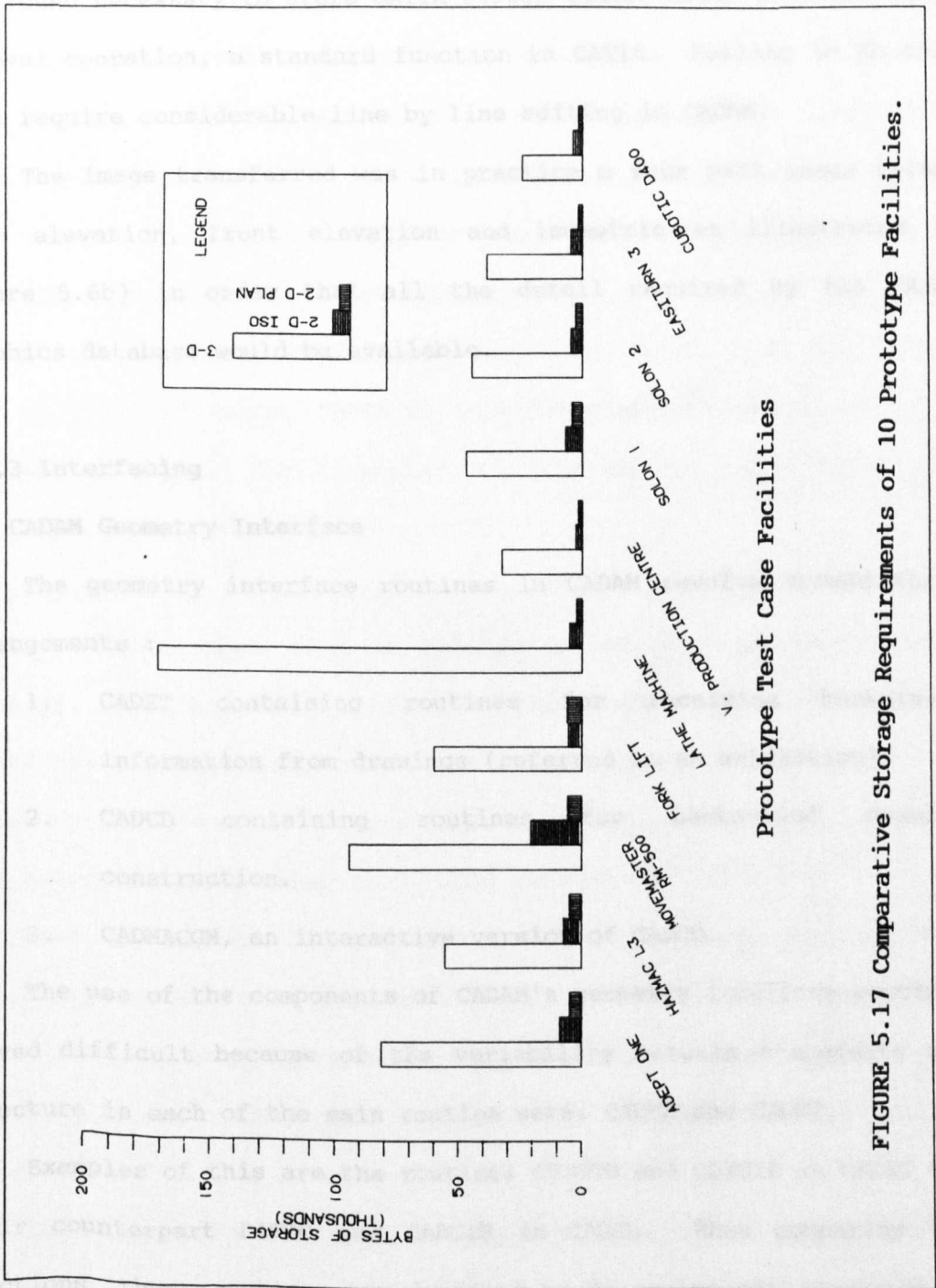
A key task in examining the early test programme was the demand on storage space generated by differing CAD approaches. For this reason each of the 10 facility prototypes were transferred in 2-D plan, 2-D isometric and 3-D solid model for comparison purposes, the results being shown in Figure 5.17.

The storage demands were found to be as high as 80 times for 3-D models over their 2-D images. In the prototype 10 facilities, CATIA solid models required on average 22.5 times the storage memory required by a plan view of the same facility transferred in CADAM. With an average requirement of 63.74 Kbytes for each facility and a one Mbyte limit on CATIA models, problems would be limited to 15 facilities, excluding the layout area itself. Thus the conclusion was drawn that 3-D composites layout design is not yet practical and the 2-D composition approach is appropriate.

Notice that the Lathe machine shows the greatest solid model memory requirement (with a ratio of 1:80.6). This is because the Lathe was constructed from 2-D CATIA as explained earlier. This method requires the definition of edges, declaration of faces, conversion to volume and eventually conversion to solid format. Therefore more information is stored in the CATIA database for models constructed by 2-D to 3-D than for models generated using solid geometry construction. 2-D to 3-D CATIA design was found cumbersome because the declaration of faces, volumes and finally solids produced several error messages where slight tolerances existed, thus requiring additional designer work.

#### **Transfers Between CADAM and CATIA**

It was experienced that both way transfer between two systems was highly satisfactory at the 2-D to 2-D level. The installation at Liverpool did not have 3-D (wire frame) CADAM, therefore 3-D to 3-D image transfer was not required. 3-D CATIA to 2-D CADAM was reasonably successful, requiring only the modification of cylindrical solids as discussed in section 5.3.3.



Prototype Test Case Facilities

FIGURE 5.17 Comparative Storage Requirements of 10 Prototype Facilities.

The 3-D CATIA to 2-D CADAM transfer process only moved the visible screen image, which could be any combination of views. It was found necessary to store CATIA screen images after a hidden lines removal operation, a standard function in CATIA. Failing to do this will require considerable line by line editing in CADAM.

The image transferred was in practice a four part image (plan, side elevation, front elevation and isometric as illustrated in Figure 5.6b) in order that all the detail required by the CADAM graphics database would be available.

### 5.6.3 Interfacing

#### The CADAM Geometry Interface

The geometry interface routines in CADAM revolve around three arrangements :

1. CADET containing routines for receiving background information from drawings (referred to as extraction).
2. CADCD containing routines for background drawing construction.
3. CADMACGM, an interactive version of CADCD.

The use of the components of CADAM's geometry interface routines proved difficult because of the variability between statements and structure in each of the main routine sets; CADCD and CADET.

Examples of this are the routines CDTDTO and CDT CIR in CADET and their counterpart DITTO and CAD CIR in CADCD. When comparing the functions, these routines are designed to do equivalent (reversible) jobs, the argument lists were found to vary in definition and to have differing order of entry. This lead to considerable confusion.



A more significant restriction is that the GI routines did not cover all the menu functions available in interactive CADAM. Thus complete off line mirroring of the design process was discovered not to be possible. The strongest example of this was the discovered absence of a "Move" equivalent in the GI routines, this effectively prohibited programmed (off line) layout design alteration.

Use of geometry interface programs was further restricted by differing formats for password information.

At the beginning of the research, with CADAM 19.2, this meant that only one of CADCD, CADET or CADMACGM (interactive CADCD) could be used at once. Two examples of this failure will bring the significance of the point.

In the first instance, interactive CADMACGM, which contained no CADET routines, means that no information could be extracted from drawings. This has to be achieved by background CADET work. In the second instance, without CADET (for extracting data) and CADCD (for inserting data) working at the same time, making changes to drawing from external source other than CADAM becomes too difficult.

When the current CADAM release 20 was installed, some of this difficulty was overcome with an enhanced version of CADMACGM, which now contained both CADET and CADCD routines for interactive use. Additionally, both CADCD and CADET could be used at the same time in background.

The extent to which CADAM was improved between release 19 and 20 is shown in Table 5.9.

The emphasis placed earlier (section 5.33 - 5.34) on adding symbol labels to key information is confirmed here as a substantial benefit. The process of filtering and interpreting data with a

Table 5.9 CADMACGM Enhancement in CADAM Release 20

Function	Release 19	Release 20
<b>User Function Key</b>		
Message Facility	No	Yes
Menu Facility	No	Yes
Geometry Display	No	Yes
Executes as F.K.	No	Yes
<b>Directories</b>		
Multiple pages	No	Yes
Multiple parameters typed	No	Yes
Non selectable entries	No	Yes
Pass geometry	No	Yes
Default parameter	No	Yes
<b>Recovery mechanism</b>	No	Yes
<b>Drawing management</b>		
Create	Yes	Yes
Modify	Yes	Yes
Delete	No	Yes
<b>Drawing index</b>		
Display	No	Yes
<b>View detail manipulation</b>		
Creation of new	Yes	Yes
Modification of existing	No	Yes
<b>Element manipulation</b>		
Add element	Yes	Yes
Delete	Yes	Yes
Retrieve	Yes	Yes
Modify	No	Yes
Show/No show	No	Yes
<b>Scope input control</b>		
Indicate	No	Yes
Select geometry	No	Yes
Y/N function	No	Yes
Key in data	No	Yes
Select menu	No	Yes
<b>Coordinate systems</b>		
Paper	Yes	Yes
View	Yes	Yes
3-D Absolute	Yes	Yes
3-D Planar	No	Yes
<b>Debugging Aids (Trace)</b>	No	Yes

Note: This Table has been compiled from Reference [51].

FORTRAN based CADET program was considerably simplified by being able to "latch on" to these symbols. An example of information drawn out from the prototype test case is given in Table 5.16.

The structured approach to the graphics database, with identified special symbols for key CAFL information (e.g. facility locations) meant that modular CADET routines could be written to extract information related to each individual symbol. These modular routines could then be combined easily to extract data in any format required by the CAFL software.

The efficiency of this approach is shown in relation to Table 5.16 , where the locations of facilities was extracted by a 180 line program (ATTRES FORTRAN) from over 14000 lines of information supplied by default CADET routine.

### **Manufacturing Information Through SQL/DS**

When working with the prototype test case a difficulty was encountered as no actual industrial information was available for the construction of a factory database.

The opportunity was taken however to experiment with the advanced SQL/DS database system by developing a CAFL problem database using information structures on products, facilities, layout area and materials handling equipment. Core of this information was taken from previous research work at the University, which was added to and modified to match modular structure explained in Chapter 4.

The facilities information was to be comprehensive and to be linked to the facilities graphics database by attaching one label to the composite drawing machine tools.

As a choice of policy, all facility alphanumeric data was directed to the database and not placed as attribute information

(referred to as labelling) on composite drawings.

No actual data was filled in these files at this point, rather the process of defining, manipulating and viewing files was examined, i.e. SQL functions and routines were thoroughly examined. The following comments were drawn from this initial use of SQL/DS.

The first point concerns the ease of use of SQL routines. The language proved to be easy to understand and use. Generating report formats, defining search queries and data loading unloading was experienced as an easy task.

A database containing 103 data fields grouped into nine data files with cross relationships was defined in three weeks. Three SQL routines, for generating reports and combining data were completed.

Whilst initial use of SQL proved very satisfactory, the computing environment in which it worked was far less helpful. The computing organisation at Liverpool University (as explained in section 5.2), placed all graphics work on an IBM4341 and all database work on IBM3083. Cross linking was not easy.

The eventual solution was to run SQL to produce a data file. This was then dumped into the operating system, the file was then transferred to the IBM4341. The same problem data on one computer and software on another was to beset the construction of specialist CAFL analysis programs. This would have to have both graphics extracted data and manufacturing data (i.e. the combined CAFL database) placed into VM/CMS (operating system) where the analysis programs would be waiting.

The conclusion is that SQL/DS is a worth while complement to the CADAM and CATIA software, but the University computing arrangements were a considerable limitation.

#### **5.6.4 Other Experiences**

##### **Kinematics**

One feature of CATIA solid modelling, not introduced up to this point in this research, is the use of kinematics. By specifying the movement mechanism, a short duration task, solid models can be used to study kinematics. Each of the 10 prototype facilities have been constructed to make use of kinematics feature in CATIA. However at this stage kinematics is identified as peripheral to establishing the CAFL database and therefore was not pursued further than conducting a preliminary experiment using the Adapt 1 robot to confirm kinematics possibility.

##### **Drawing Management**

With the MEHRAN approach the number of drawings grows rapidly. The prototype test cases produced 13 drawings. A system was introduced therefore for naming each drawing that would allow easy identification and selection from the CADAM drawing index.

The experience gained with the prototype programme has prepared the ground for a fuller examination of the role of CAD in CAFL. The next chapter describes work done on a selected industrial test case examined to test out the limitations and potential of the MEHRAN philosophy.

**CHAPTER 6**

**AN INDUSTRIAL TEST CASE**

## CHAPTER 6

### AN INDUSTRIAL TEST CASE

#### 6.1 OBJECTIVES

Within this chapter details will be presented of a full size industrial test case applied to the MEHRAN software. The objectives of this second test programme are:

1. To examine if MEHRAN is capable of holding a full size industrial test case, expected to involve more than 20 facilities.
2. To observe the designer learning experience in developing an industrial test case.
3. To assess the role played by MEHRAN in an actual manufacturing system design exercise.
4. To identify future work by way of developments identified from an industrial test case.

Presentation of the industrial test case will start with an introduction to the company. This will be followed by a precis of the timetable of events leading to a new manufacturing system on the test site.

The remainder of the chapter will concentrate on firstly the MEHRAN application process, particularly with respect to design time and computer usage. This will be followed with comments on solutions generated. Development will be reserved for future work chapter.

## **6.2 THE INDUSTRIAL APPLICATION OF MEHRAN**

### **6.2.1 The Company**

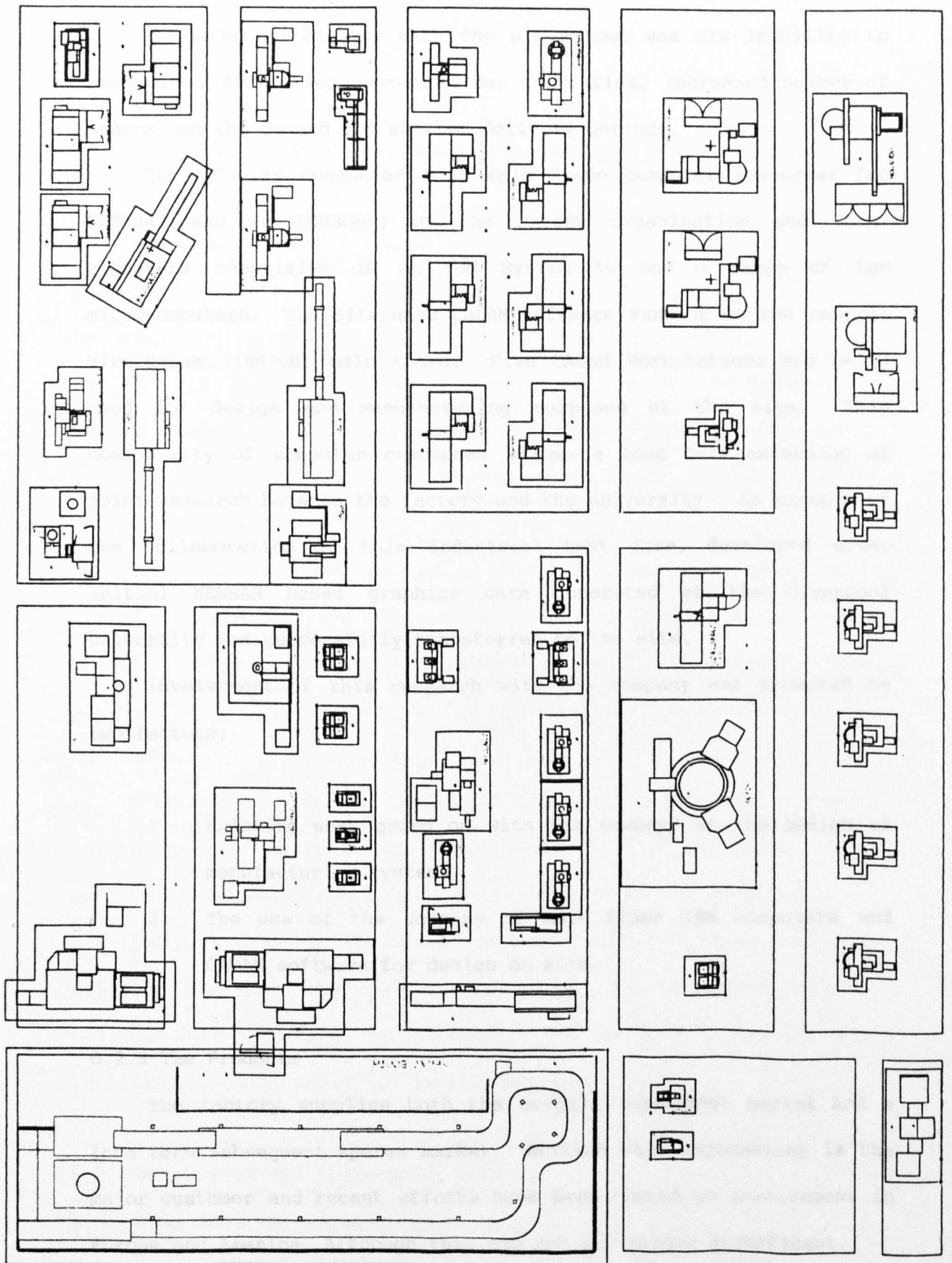
Lucas Industries is a multinational company comprising 83 subsidiaries operating in 32 different countries around the world and with annual sales of £1.5 billion in 1985. Within 20 subsidiaries operating in the United Kingdom, Lucas industries plc. controls 28 factory sites. Lucas Automotive (formerly Lucas Girling), has three main manufacturing sites, Cwmbran, Pontypool and Bromborough. The South Wales factories (Cwmbran and Pontypool) are involved in the design and manufacture of braking systems for passenger car, heavy duty off-road and commercial vehicles. The third site, Bromborough, specialises in railway braking products and this site has become the basis of the industrial application of MEHRAN.

### **6.2.2 The Factory**

Lucas Automotive, Bromborough has a turnover in excess of £16 million and employs over 250 people. On site is marketing, design, development and production facilities for railway braking systems.

Lucas Automotive, Bromborough is a classic batch manufacturing company with 60 machine tools employed on production. Thirty seven unique facilities are in use on a two shift basis. There are four CNC machining centres, 19 numerical control machines and two specialist production facilities. The remainder are conventional machines and the whole shop was laid out in a series of three aisles, with process layout grouping. Using MEHRAN, the original layout of the site was produced and part of this is shown in Figure 6.1. The site is a 1960 built modern single floor building with site area approximately 18,000 square metres.





N.A. SANGI  
28/04/88

LUCAS AUTOMOTIVE BROBOROUGH  
PART SITE PLAN 1985

FIGURE 6.1  
CHAPTER 6

The major difficulty with the old layout was its inability to respond to decreasing average order quantities, increased number of orders and the demand for shorter delivery periods.

The site is connected with main frame computer resources (an IBM4341 and an IBM3081) of the parent organisation and local computers comprising of an IBM System 34 and a range of IBM microcomputers. The site uses CADAM software running on the central Birmingham, IBM3081 main frame. Five CADAM workstations are being used for design and manufacturing purposes at the site. This commonality of computer resources allows a long term extension of joint research between the factory and the University. An example of the collaboration is this industrial test case, developed after initial MEHRAN based graphics data generated at the Liverpool University was successfully transferred to the site.

Involvement of this research with the company was prompted by two factors:

1. Existing work going on with the company on the design of manufacturing systems.
2. The use of the company of main frame IBM computers and CADAM software for design on site.

### **6.2.3 The Products**

The factory supplies both the original equipment market and a long term subsequent spares market. British Rail Engineering is the major customer and recent efforts have been placed on involvement in Europe and America. Although this has not yet become significant.

The product (disc brakes) can be considered as three major component groups plus miscellaneous parts. The three groups are:

1. Disc
2. Calipers (Yoke and Flange)
3. Components (mainly turned components)

Brake shoes are factored and are therefore not involved in production at this site. The spares after market consists of orders for discs (which wear out on trains) and maintenance parts.

Through the factory moves a wide variety of the three main product groups; Calipers (81 types), Discs (49 types) and Components (125 types). The volume of regular repeating orders averages 89% for each group, the remainder being new products.

The main disc module volume is around 1900 discs per month, with nine disc types of high sales value. An illustration of a braking system is given in Figure 6.2. Discs can be of the ventilated type as shown or can be flat annular (or split annular) shape for mounting on wheels.

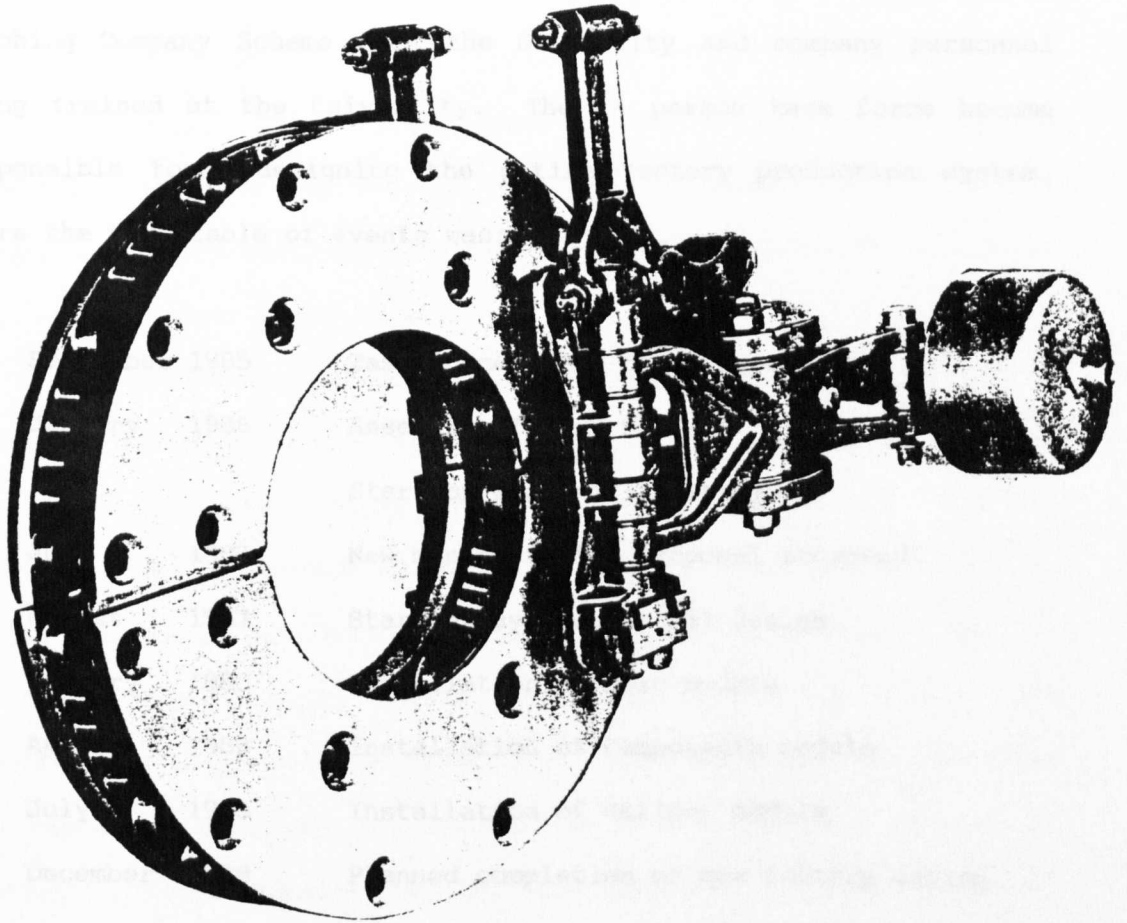
Disc production is therefore based on receiving castings, machining the top and bottom surfaces, drilling customised hole pattern for mounting and finally splitting into two if required.

Calipers again arrive as castings and are bored, machined along assembly surfaces and assembled into original equipment orders. Dealing with products can therefore be seen as substantially machining, some assembly and finally painting.

## **6.3 REDESIGNING THE BROMBOROUGH FACTORY**

### **6.3.1 Timetable of Events on Site**

Manufacturing Systems Engineering (MSE) at Bromborough is a continuation of two earlier major manufacturing reviews within the Railway Products Group of Lucas Automotives, namely a Manufacturing



**FIGURE 6.2 An Example of A Disc Brake Manufactured At The Site**

Strategy developed in 1983 and subsequent Competitive Achievement Plan (CAPS) of 1985. The 1985 CAPS review led to the establishment in 1986 of a Manufacturing Systems Engineering (MSE) task force and the first involvement of Liverpool University.

The task force started work in January 1986, involving a Teaching Company Scheme with the University and company personnel being trained at the University. The 14 person task force become responsible for redesigning the entire factory production system, where the time table of events was:

September	1985	Task force terms of reference.
January	1986	Assembly of task force. Start of feasibility study.
July	1987	New manufacturing proposal accepted.
August	1987	Start of systems detail design.
January	1988	Installation of Disc module
April	1988	Installation of Components module
July	1988	Installation of Caliper module
December	1988	Planned completion of new factory design.

### **6.3.2 The MEHRAN Timetable**

#### **Initial Layout Area Preparation**

An initial activity with the new manufacturing design was the training of production engineering staff on the University's CADAM system. This led to the construction for the first time of a site layout database on CADAM, started as part of this research programme and completed at the University, by site personnel. The first tangible output from MEHRAN therefore was a set of site drawings.

These architectural drawings were transferred to the company in May 1987. The site layout drawings were later organised according to the MEHRAN structured database and became the basis of the layout area in this industrial test case. Construction of layout drawings required three months to complete.

### **Facilities Database**

In January 1987, preliminary work on the manufacturing facilities database was started, by on-site measurement of the 37 unique production facilities at Bromborough. Detailing facilities in this way took four weeks on site.

With graphics data collection complete, work started within MEHRAN on the construction of the 3-D solid model library. With the need to revise models, when CATIA 2.2 replaced CATIA 2.1, combined with refinement of MEHRAN in the light of experience (discussed later in this chapter), work on facilities was completed in four months.

The first facility drawing set completed (Disc module) was transferred to the site in July 1987. The MEHRAN graphics database was therefore available at the University for parallel studies on generating layout designs whilst the task force completed layout designs, working on site. Eventually the company received layout area and facilities images developed by using MEHRAN database.

### **Manufacturing Information**

Acquiring the accompanying factory and subsequent CAFL database required special consent from the company, given in December 1987. However a review of the information proved that the volume and content of data was beyond the needs of this research programme. The financial data was withheld and the format of data was unsuitable for direct transfer into the SQL/DS based CAFL database at the

the University. As a consequence, data was extracted only on the main disc module for use in this test programme.

The basic information on products and product routings has therefore been supplemented by theoretical financial data where required.

### **Composite Layout Design**

With the concentration of work in this research programme on the CAD aspects of design, the old and new plant layouts were accepted as the two ends of the application of MEHRAN. The paralleling of task force work and this research programme therefore provided the opportunity for the industrial test case.

The initial layout drawing with facilities was completed in December 1987. By that time the task force, has officially agreed on a new layout design and installation of the disc module was nearing completion. Three modules have been implemented to date in the factory. In parallel at the University MEHRAN has produced final images of each module from the high quality graphics database.

By the end of June 1988, manufacturing information and provisional designs for factory layout have been completed and sent to the company.

### **6.3.3 Design of The New Factory**

Having assisted the task force work by aiding the factory production engineers in constructing their site layout drawings, design of the new manufacturing system passed to the task force. With the objective of utilising the principles of Just in Time (JIT) manufacture and modular layout, simulation was applied to examine manufacturing information and to bring forward a four module JIT

JIT system. Layout of the modules was undertaken on site using 2-D templates, and at the university using MEHRAN graphics database.

The task force applied simulation technique on an identified nine products representing the high demand products. Flow planning, reduction in production time and inventory level were the design objectives. The proprietary simulation software HOCUS was used to identify bottlenecks in flow and layout designs. The working layout drawings were prepared using conventional templates on a layout schematic diagram as illustrated in Figure 6.3a. The MEHRAN graphics provided a contribution to this working practice by providing a graphics database and a strategy for constructing layout design from the database. MEHRAN principles were used to construct an equivalent of the task force solution (Figure 6.3a) during design, as illustrated in Figure 6.3b.

Flow planning rather than quantitative models was used to place facilities. The principles of pre-grouped sets of machine tools and relative simplicity of movement, inherent in university work, was evident in the design approach adopted by the task force.

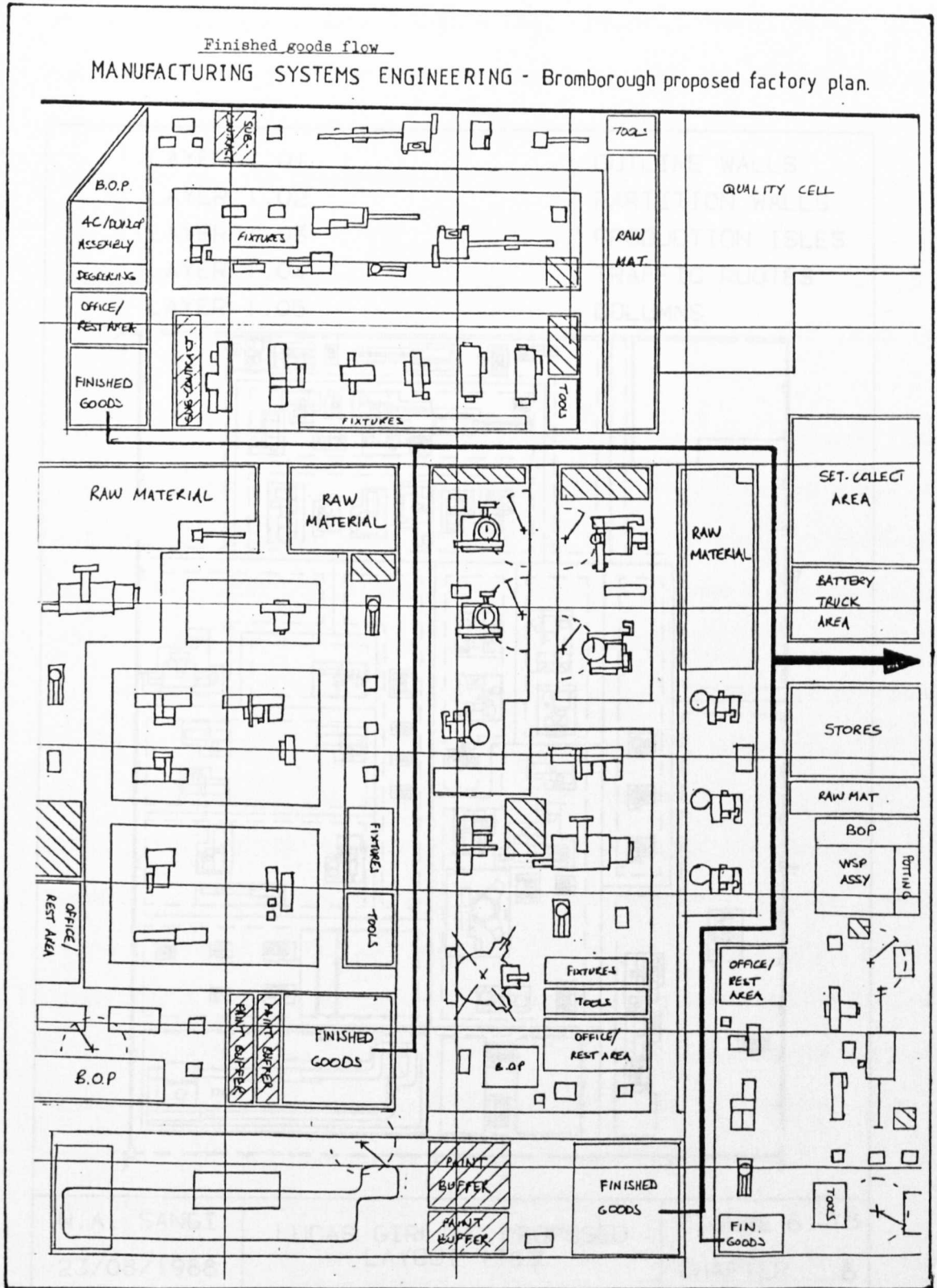
At this point, with the initial layout available, and selected manufacturing or factory database information provided, work on the MEHRAN test programme become independent of the industrial company and was completed at the University, taking advantage of the 3-D CATIA modelling not available in the company.

## **6.4 BUILDING UP THE MEHRAN GRAPHICAL DATABASE**

### **6.4.1 Machine Tools**

The largest task in developing the MEHRAN graphical database was the preparation of the CATIA solid model images. Each model had eventually to be constructed from measurements taken with the actual facilities on site.

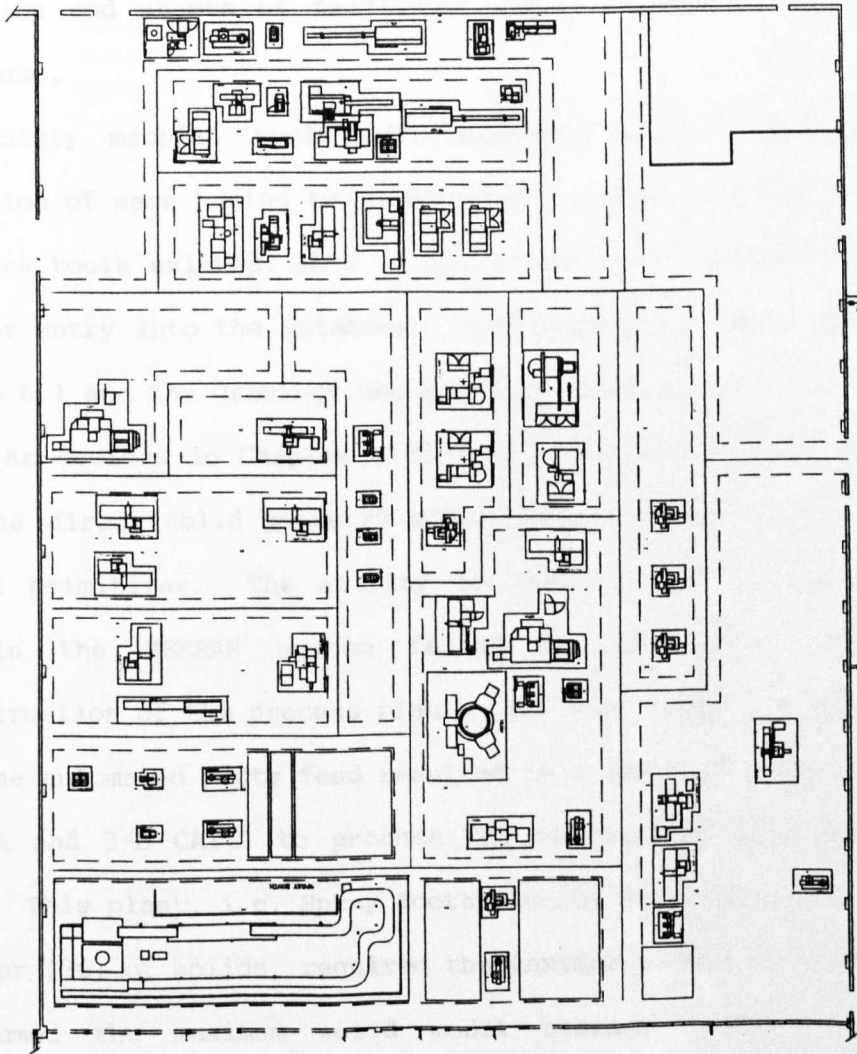




**FIGURE 6.3(A) Proposed Layout Plan Prepared At The Site.**

LAYER 1.01  
 LAYER 1.02  
 LAYER 1.03  
 LAYER 1.04  
 LAYER 1.05

OUTLINE WALLS  
 PARTITION WALLS  
 PRODUCTION ISLES  
 TRAFFIC ROUTES  
 COLUMNS



N.A. SANGI  
 23/08/1988

LUCAS GIRLING PROPOSED  
 LAYOUT 1987

FIGURE 6.3B  
 CHAPTER 6

Originally a search was made for previous drawings. The absence of these drawings, combined with a high number of identified on site modifications (e.g. control boxes, pump units) to the arrangement of facilities, meant the preparation of the graphical database had to be started by on-site measurement of facilities.

A secondary advantage of measuring all facilities was the subsequent guarantee that highly accurate information on the position and shapes of facilities would be stored in the graphics database.

Sixty machine tools were employed within the factory, the location of each having to be recorded. Thirty seven unique types of machine tools existed, each of which had to be individually measured up for entry into the database. The individual models are listed in Table 6.1 and the drawings are given in Appendix A2.

As decided in Chapter 5 earlier, each solid model was produced by the direct solid geometry construction method, using basic solid model primitives. The ability to construct solid models directly within the MEHRAN system failed on only one occasion; the construction of the process plant. The high number of complex curves in the automated parts feed resulted in a use of a combination of 2-D CATIA and 3-D CATIA to produce the representation shown in Figure 6.4. This plant, i.e. Spray Booth (LG-39) eventually had the maximum number (36) of solids, required the maximum number of sessions (six), consumed the maximum solid model storage (228.08 Kbytes), and required 4.33 hours of design time to complete.

The process of construction of the facilities database will be thoroughly reviewed later in this chapter. At this point it is worth noting that the average model construction time, at the terminals, was just under one hour, significantly down from the time required to develop the prototype test case models (3.1 hours).

Table 6.1 Lucas Automotives Test Case Facilities

Serial Number	Facility Name	Facility Identity	Facility Type
1.	Mollart	LG-01	Gun Drill
2.	Batchmatic	LG-02	Misc.
3.	Webster & Bennet	LG-03,64-68	Manual Mill
4.	Morando	LG-04	NC Lathe
5.	Linisher	LG-05	Misc.
6.	Eisele	LG-06	Saw
7.	AMT	LG-07	Misc.
8.	Pollard	LG-08,26	Drill
9.	Cincinnati	LG-09	Mill
10.	Jones Shipman	LG-12	Grinder
11.	Oerlikon	LG-13	Drill
12.	Pollard	LG-14, 16	Drill
13.	BSA Taper	LG-15	Taper
14.	Vero	LG-19	Drill
15.	Cincinnati IOV	LG-20	Mill
16.	Pollard	LG-22,45,75	Drill
17.	Funditor	LG-23	Date Stamper
18.	Archdale R/Arm	LG-24,31,56	Drill
19.	Hosan Drill	LG-25	Drill
20.	Cincinnati 400 Mill	LG-27,59, 60,63,69,70	Mill
21.	Hey Face & Center	LG-30	Face
22.	Bar Ender	LG-33	Saw
23.	Warner & Swasey	LG-34,52,53	Mill
24.	CTC 4	LG-35,37	CNC Lathe
25.	Hi-Ton Press	LG-36	Press
26.	Spray Booth	LG-39	Paint Spray
27.	Matrix V50	LG-40,41	CNC M. Centre
28.	Webster & Bennet	LG-46,47	NC Lathe
29.	Dorries	LG-48	NC Lathe
30.	Cintimatic	LG-50	NC Drill
31.	Kitchen R/Arm	LG-55,71,72	Drill
32.	Spin Rivetter	LG-57	Rivetter
33.	Wavis	LG-58	Drill
34.	Fritz Werner	LG-61,62	Mill
35.	Lapointe	LG-73	Broach
36.	Ideal hardener	LG-76	Hardener
37.	Snow Grinder	LG-77	Grinder

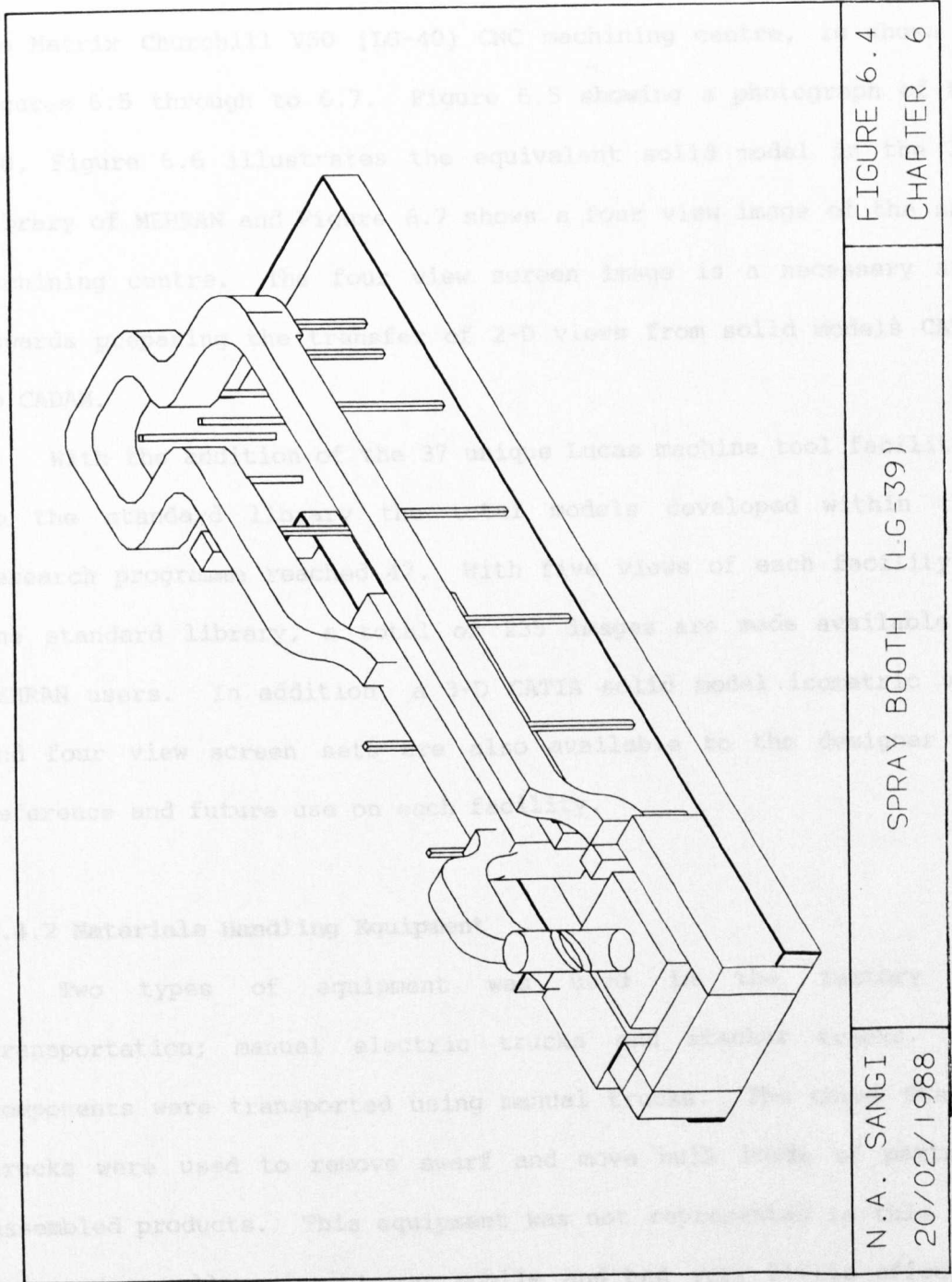


FIGURE 6.4  
CHAPTER 6

SPRAY BOOTH (LG-39)

N.A. SANGI  
20/02/1988

The solid image generated in 3-D space was then stored in two specially developed MEHRAN (set screen) visualisations as described in section 5.4.3. An illustrating example of this design process, the Matrix Churchill V50 (LG-40) CNC machining centre, is shown in Figures 6.5 through to 6.7. Figure 6.5 showing a photograph of the V50, Figure 6.6 illustrates the equivalent solid model in the 3-D library of MEHRAN and Figure 6.7 shows a four view image of the same machining centre. The four view screen image is a necessary step towards preparing the transfer of 2-D views from solid models CATIA to CADAM.

With the addition of the 37 unique Lucas machine tool facilities to the standard library the total models developed within this research programme reached 47. With five views of each facility in the standard library, a total of 235 images are made available to MEHRAN users. In addition, a 3-D CATIA solid model isometric view and four view screen sets are also available to the designer for reference and future use on each facility.

#### **6.4.2 Materials Handling Equipment**

Two types of equipment was used in the factory for transportation; manual electric trucks and stacker trucks. All components were transported using manual trucks. The three Stacker trucks were used to remove swarf and move bulk loads of parts or assembled products. This equipment was not represented in this test case, since all equipment was mobile and had very little effect on the graphical visualisation of layout designs.



FIGURE 6.5

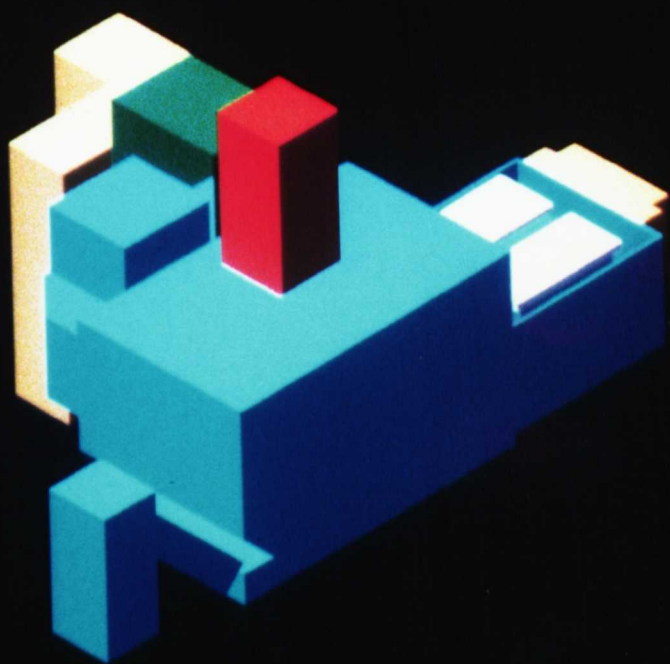
PHOTOGRAPH OF THE MATRIX CHURCHILL V50 MACHINING CENTRE





FIGURE 6.6

MEHRAN SOLID MODEL ISOMETRIC IMAGE OF  
THE MATRIX CHURCHILL V50 MACHINING CENTRE



SHADING

APPLY

CREATE

BASIC

ADVANCED

BP SV

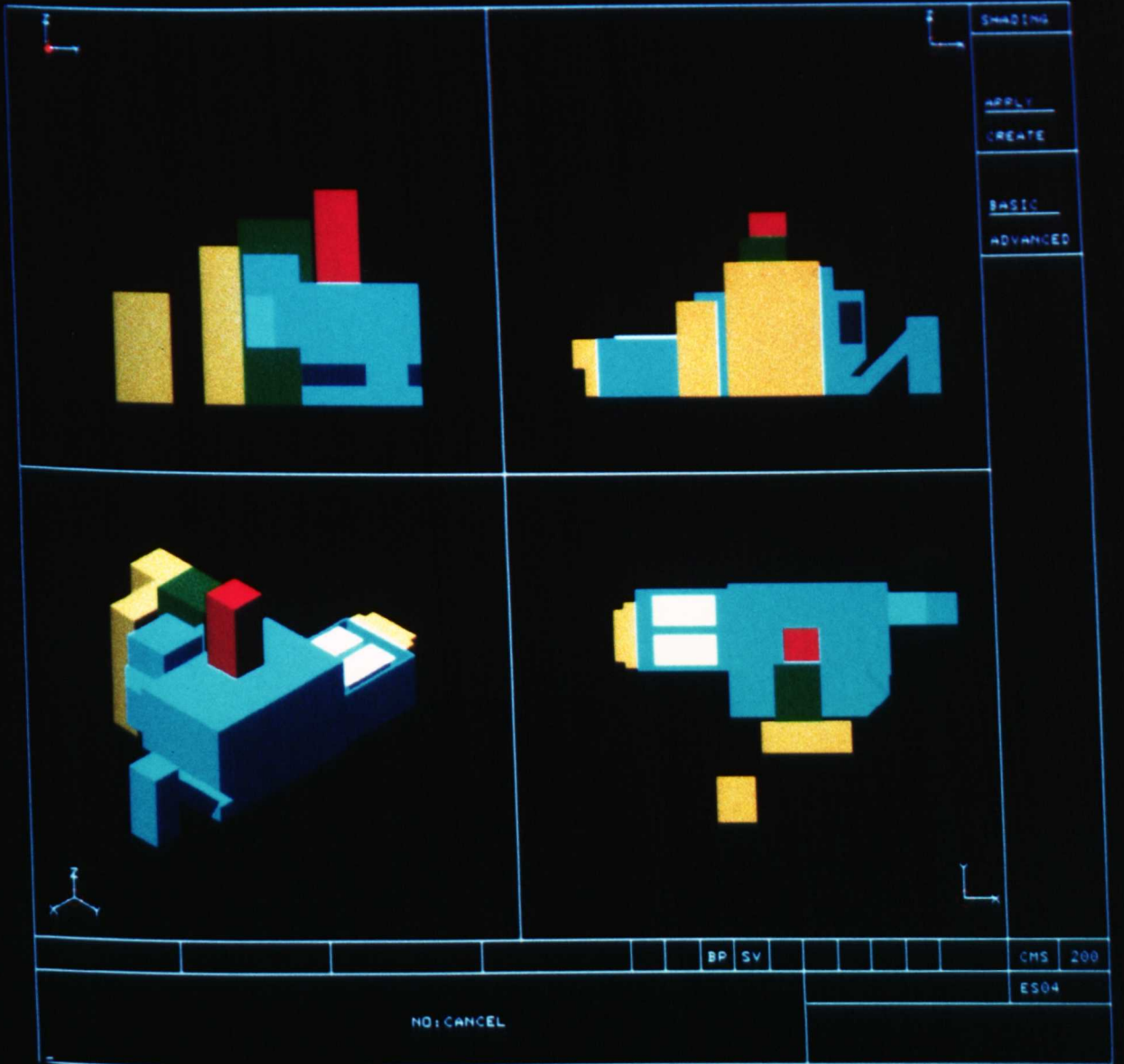
CHS 200

ES04

NO | CANCEL

FIGURE 6.7

FOUR VIEW MEHRAN SCREEN IMAGE OF  
THE MATRIX CHURCHILL V50 MACHINING CENTRE



### **6.4.3 Layout Area**

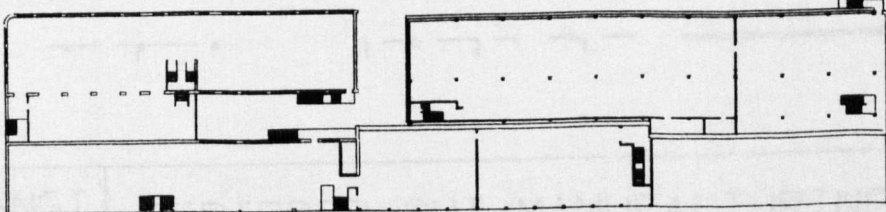
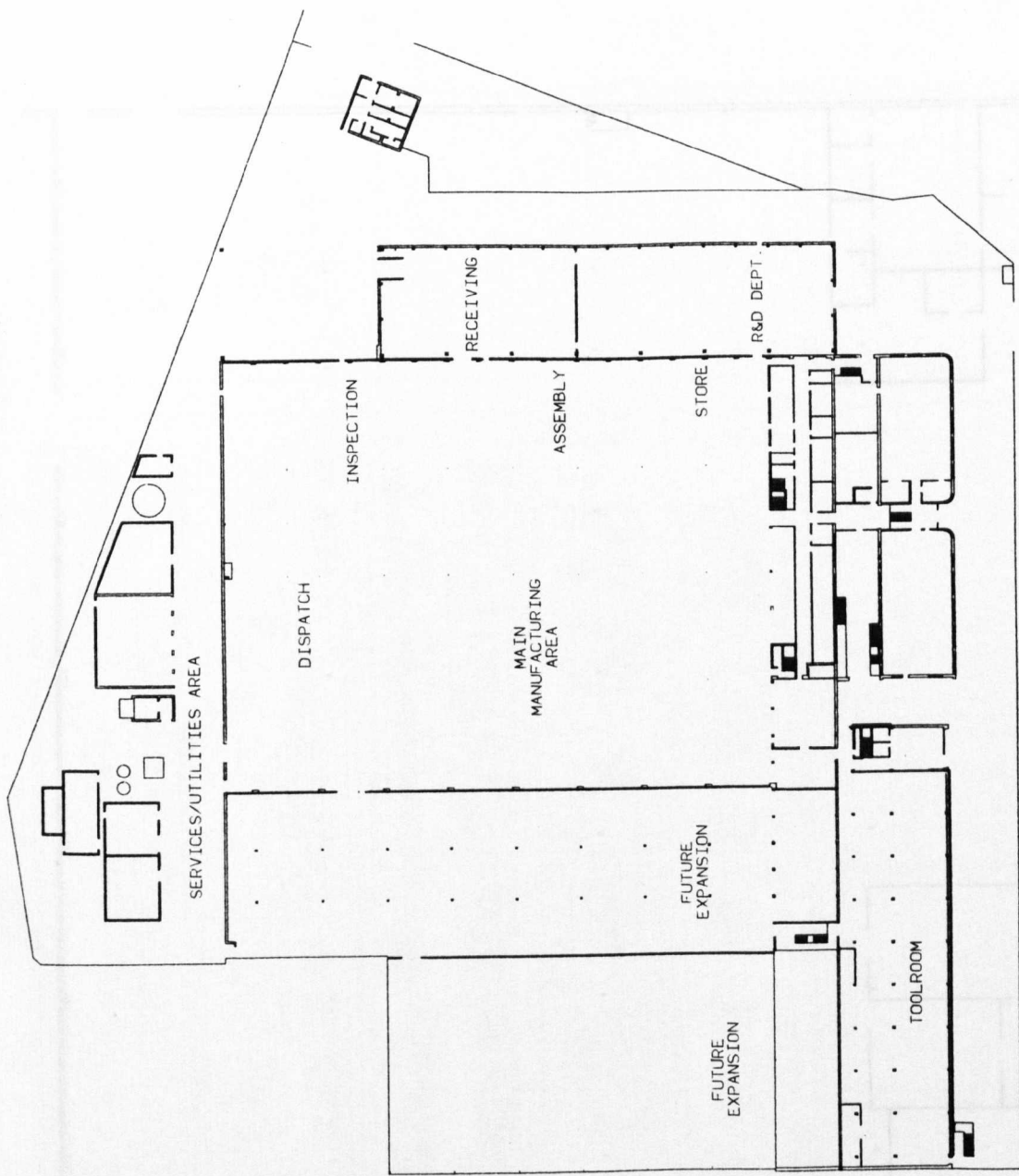
The important contribution of aiding the development of accurate site drawing has been mentioned in explaining the relationship with the test case site. The development process started with 1985 version of a factory drawing. The unrecorded changes mentioned earlier (section 6.4.1) led as stated to the development of new factory plans as part of this work. The layout area drawing initially developed without the benefit of MEHRAN thinking was subsequently unstructured and highly inefficient (excessive overlay and duplication). This initial site layout was subsequently reviewed and revised to generate a 6:1 reduction in storage required.

The site plan just discussed (Figure 6.8) was produced as two drawings, each using a separate prime view, one for the building and one for partitions. Out of this site plan was stripped the manufacturing area drawing (Figure 6.9), with each level of detail (section 5.3.4.) being placed in the appropriate detail pages as defined in the MEHRAN model (Figure 5.9).

### **6.4.4 Composing Layouts**

At the end of studying the process of developing the facilities standard library and layout plans the contribution to designing the new factory layouts for the company was made. In all six composite layout (facilities plus layout area) drawings were composed as detailed below :

1. Original 1985 complete site layout (Figure 6.1)
2. Test case version of original layout (Figure 6.10)

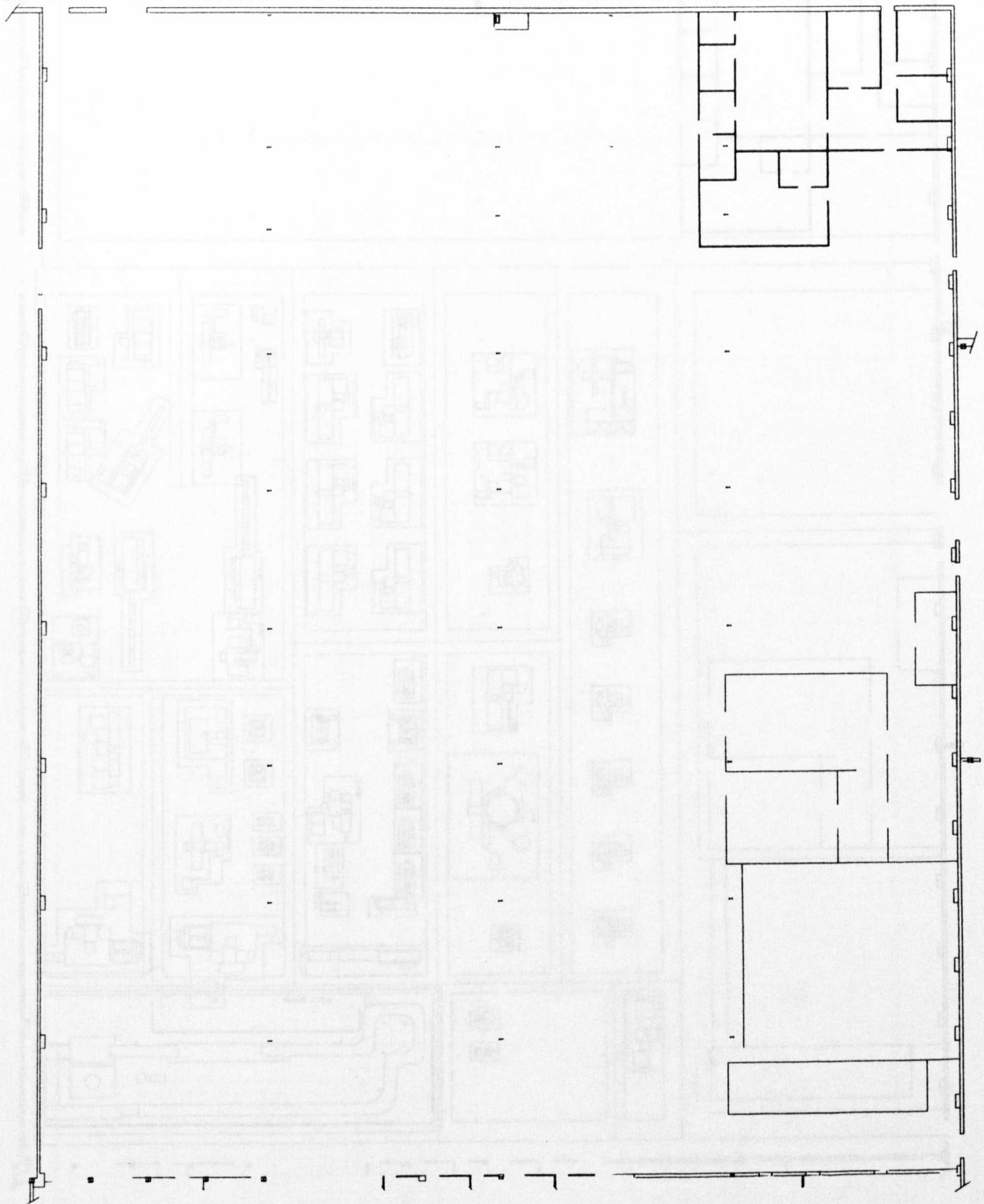


FIRST FLOOR  
(OFFICES)

N.A. SANGI  
28/04/1988

SITE DRAWING WITH OUT PARTITIONS

FIGURE 6.8  
CHAPTER 6

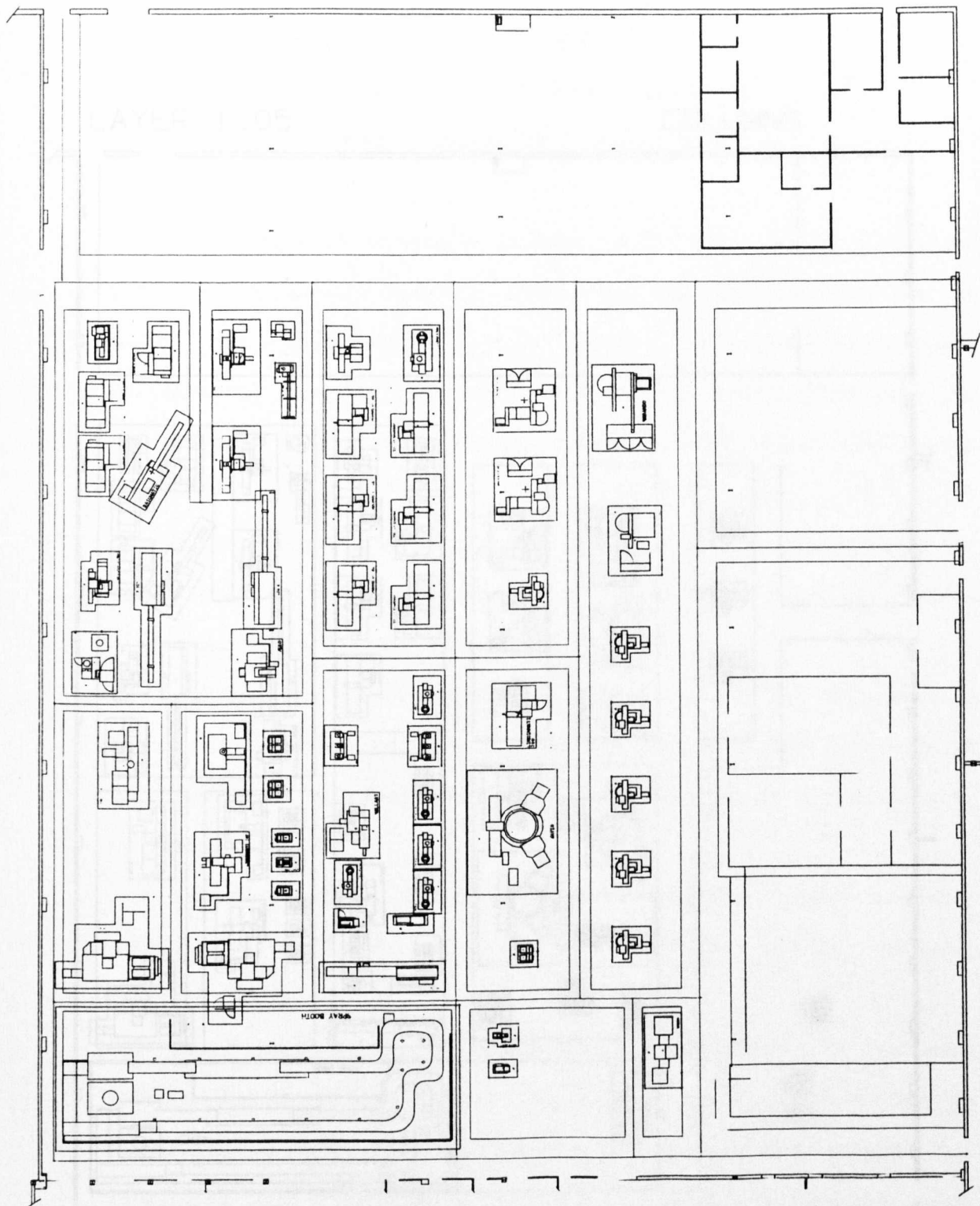


N.A. SANGI  
20/02/1988

STRIPPED OUT MANUFACTURING  
AREA AND PARTITIONS

FIGURE 6.9  
CHAPTER 6





N.A. SANGI  
20/02/1988

TEST CASE VERSION OF  
ORIGINAL LAYOUT

FIGURE 6.10  
CHAPTER 6

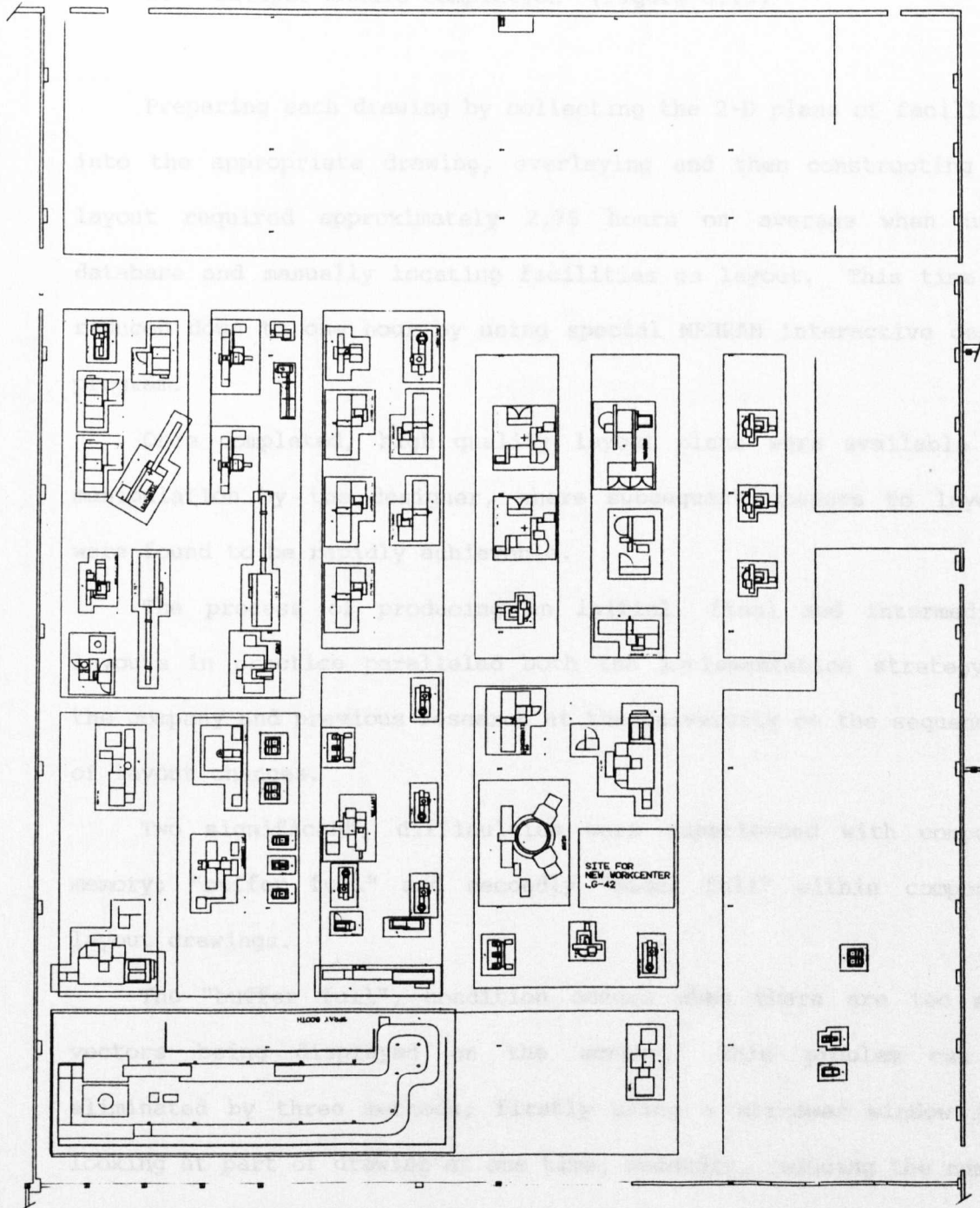


LAYER 1.01

OUTLINE WALLS

LAYER 1.05

COLUMNS



N. A. SANGI  
23/08/1988

DISC MODULE INSTALLED

FIGURE 6.11  
CHAPTER 6

3. Proposed final design (Figure 6.3b)
4. Disc module completion (Figure 6.11)
5. Component module completion (Figure 6.12)
6. Caliper module completion (Figure 6.13)

Preparing each drawing by collecting the 2-D plans of facilities into the appropriate drawing, overlaying and then constructing the layout required approximately 2.75 hours on average when using database and manually locating facilities on layout. This time was reduced down to one hour by using special MEHRAN interactive design program.

Once completed, high quality layout plans were available for manipulation by the designer, where subsequent changes to layouts were found to be rapidly achievable.

The process of producing an initial, final and intermediate layouts in practice paralleled both the implementation strategy at the company and previous research at the University on the sequencing of layout changes.

Two significant, difficulties were experienced with computer memory; "buffer full" and secondly "model full" within composite layout drawings.

The "buffer full", condition occurs when there are too many vectors being displayed on the screen. This problem can be eliminated by three methods; firstly using a narrower window i.e. looking at part of drawing at one time, secondly, reducing the number of vectors within any drawing and thirdly saving the drawing more frequently to refresh buffer memory.

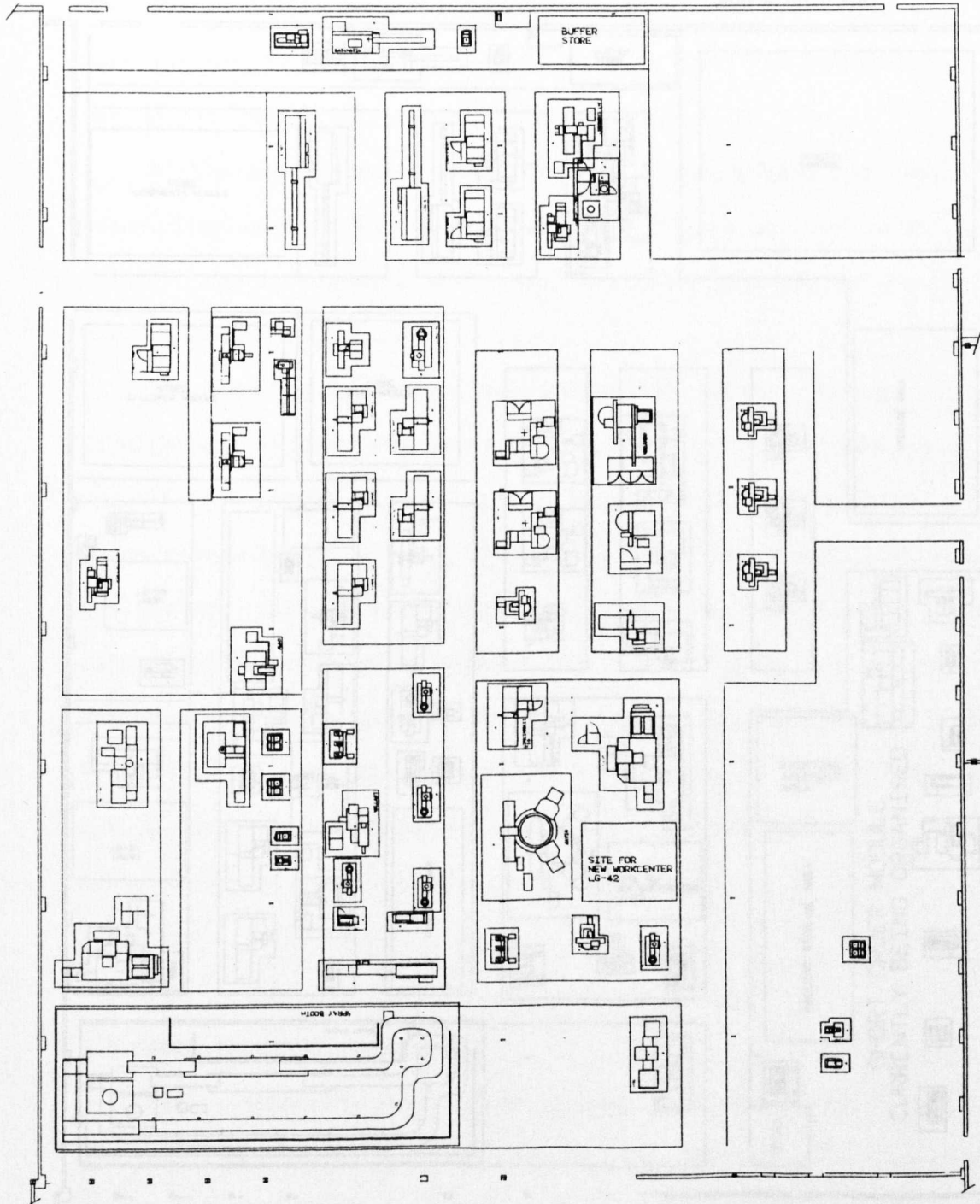
The "model full" condition occurs when file size limits are crossed, (80 Kbytes in the case of CADAM at Liverpool University).

LAYER 1.01

OUTLINE WALLS

LAYER 1.05

COLUMNS



N. A. SANGI  
23/08/1988

COMPONENTS MODULE  
INSTALLED

FIGURE 6.12  
CHAPTER 6

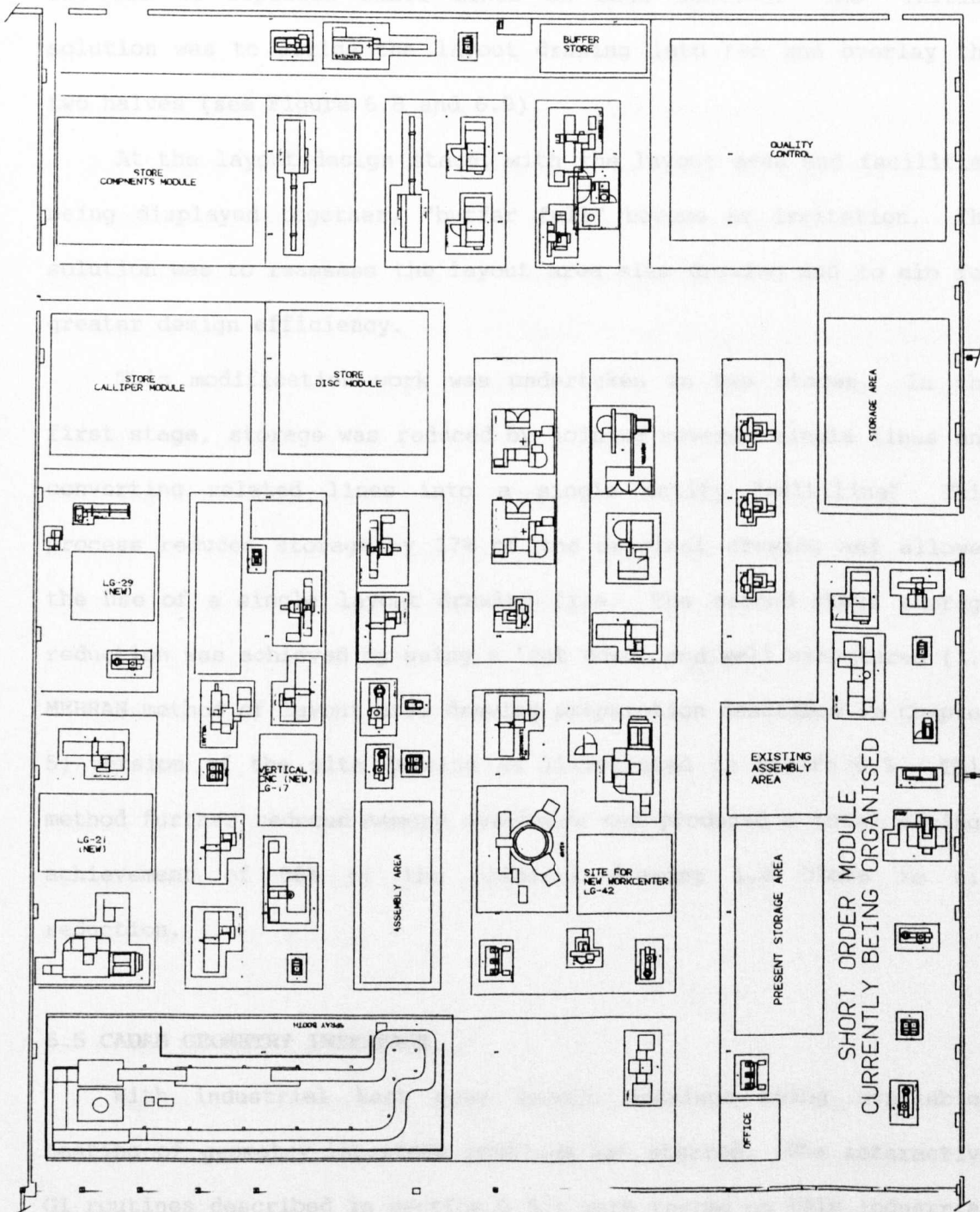
LAYER 1.01

OUTLINE WALLS

The initial drawing of the site layout was developed by concentrating on a small sections of factory, one at a time, from a period of three weeks. This process, involved a high degree of detail because

LAYER 1.05

COLUMNS



N.A. SANGI  
23/08/1988

CALIPER MODULE INSTALLED

FIGURE 6.13  
CHAPTER 6

The initial drawing of the site layout was developed by concentrating on a small sections of factory, one at a time, during a period of three months. This process, generated a high storage demand because the use of repeated small lines on each section. The initial solution was to divide the layout drawing into two and overlay the two halves (see Figure 6.8 and 6.9).

At the layout design stage, with the layout area and facilities being displayed together, "buffer full" became an irritation. The solution was to reassess the layout area site drawing and to aim for greater design efficiency.

This modification work was undertaken in two stages. In the first stage, storage was reduced by joining several single lines and converting related lines into a single entity "multiline" This process reduced storage by 17% of the original drawing and allowed the use of a single layout drawing file. The second stage storage reduction was achieved by using a 'cut down' and well structured (i.e MEHRAN method of layout area drawing preparation described in Chapter 5) version of the site drawing as illustrated in Figure 6.9. This method further reduced memory overheads and produced a total savings achievement of 86% of the original drawing i.e close to 6:1 reduction.

## **6.5 CADAM GEOMETRY INTERFACE**

With industrial test case layout drawings being available, testing of geometry interface routines was started. The interactive GI routines described in section 5.5.1 were tested on this industrial test case and no additional problems were encountered in extracting facilities data. Coordinate values both from origin and centre of facilities were extracted by the program "ANALYS". Program "IMPROV"

later calculated distances between facilities for use in a simple analytical model to optimise a single facility within a cell. A sample output of distance calculation in interactive mode is given in Appendix D. In order to apply a sample analytical model on the test case, the "IMPROV" program was modified to calculate distance between facilities and optimise single facility location within each cell. Sample output of "IMPROV" program is given in Appendix D.

As explained earlier, due to systems changeover and failure of the interactive GI routines after this changeover it was not possible to extensively test, refine and develop a single overall program working from within CADAM terminal. The "DESIGN" program only interactive is presently operational because it does not require any read and write statements. The "DESIGN" program was applied to the industrial test case for generating original and three intermediate layout drawings, assisting the designer in generating a variety of layout drawings in a shorter time period as evidenced in Table 6.2.

Present geometry interface and analytical routines, therefore can be seen as the beginning of a more wide and comprehensive CAFL software, applied in parallel to CAD based facilities database. Further work on the geometry interface is identified as future work and discussed in Chapter 7.

#### **6.6 LEARNING EXPERIENCES - TIME**

During the industrial test case exercise, the time spent on construction of CATIA solid models, the CADAM standard library and on the generation of layout design composites was recorded. This section discusses the results of this time analysis, summaries of which are included in this text and the supporting full results are given in Appendix D.

### 6.6.1 CATIA 3-D

#### Actual Design Time

In all, 47 test facilities were constructed during the two phases of this research. The resulting facilities generation times are shown in figure 6.14. This figure shows, in a ranked time order, a classic Pareto or ABC curve. The generation of solid models varied with the complexity of the object. For the two test programmes, prototype and industrial, twenty seven facilities (57.4%) required one hour or less. At the other extreme, 19% facilities required more than two hours. On average 85 minutes were needed per facility.

From this design time, any industrial problem can be seen to be within the scope of MEHRAN. Typically, for example, a large 100 unique facility problem would require under four weeks to complete. The majority of real industrial problems have fewer unique facilities and increasingly more could be selected straight from the database. The industrial test case described in this thesis contained 37 unique facilities out of 60, a 38% facilities repeating.

The time required to prepare drawing details for transfer from CATIA to CADAM proved to be independent of facility complexity, with an average half an hour per facility.

The effect of learning experience can be gauged from Figure 6.14. Both the initial prototype design phase and the industrial test case contained a representative spread of complexity. With this similarity, the average design time reduced from 3.1 hours to one hour (58.11 minutes). Thus at the end of the research, industrial test case original solid models can be produced in one third of the starting time. Undoubtedly the decision to include an industrial test case allowed the confirmation of potential rapid design with experienced personnel.



# Comparison of Times (All Facilities)

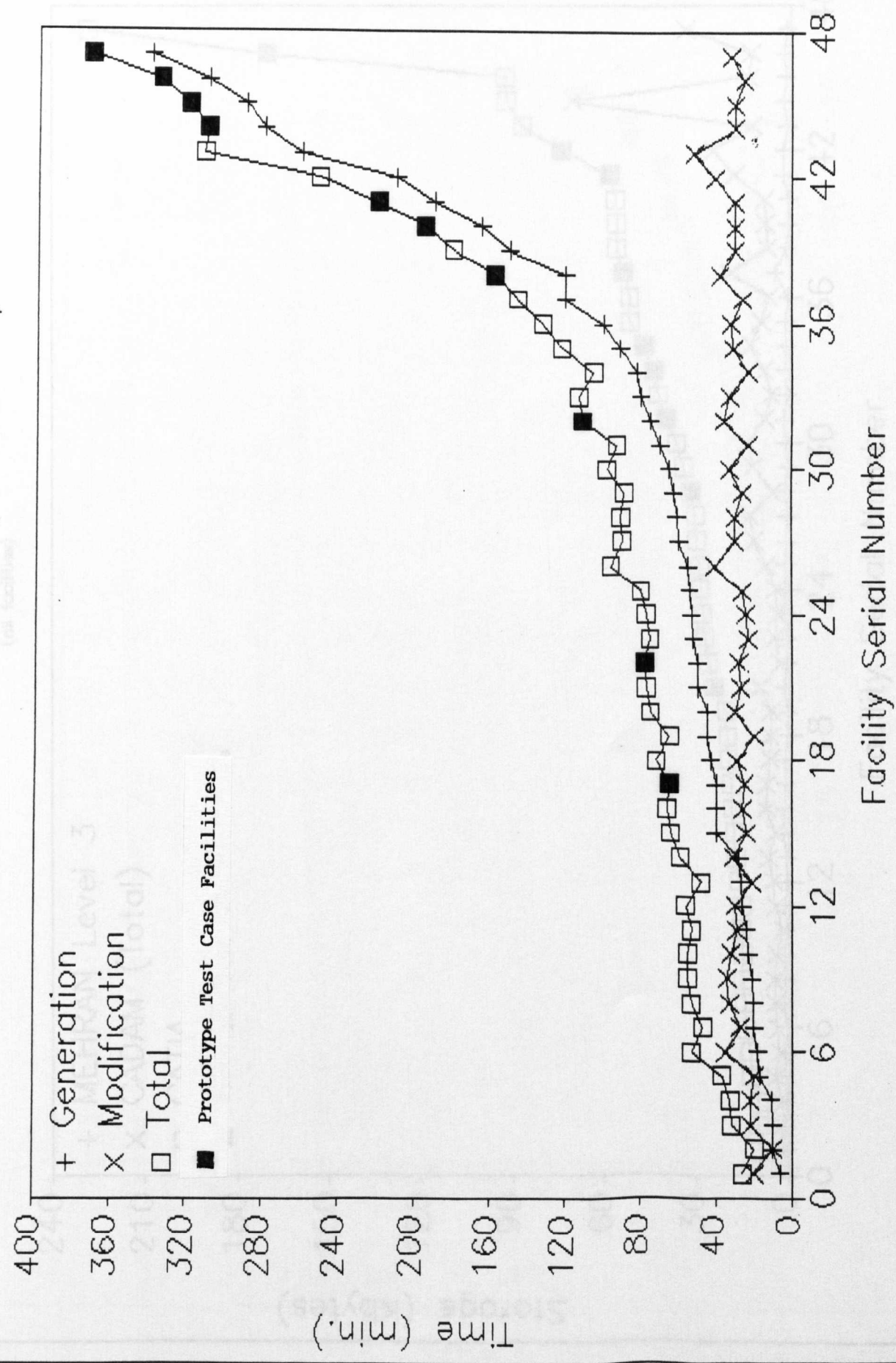


FIGURE 6.14 Comparison of Times.



# CADAM and CATIA Storage Comparison (all facilities)

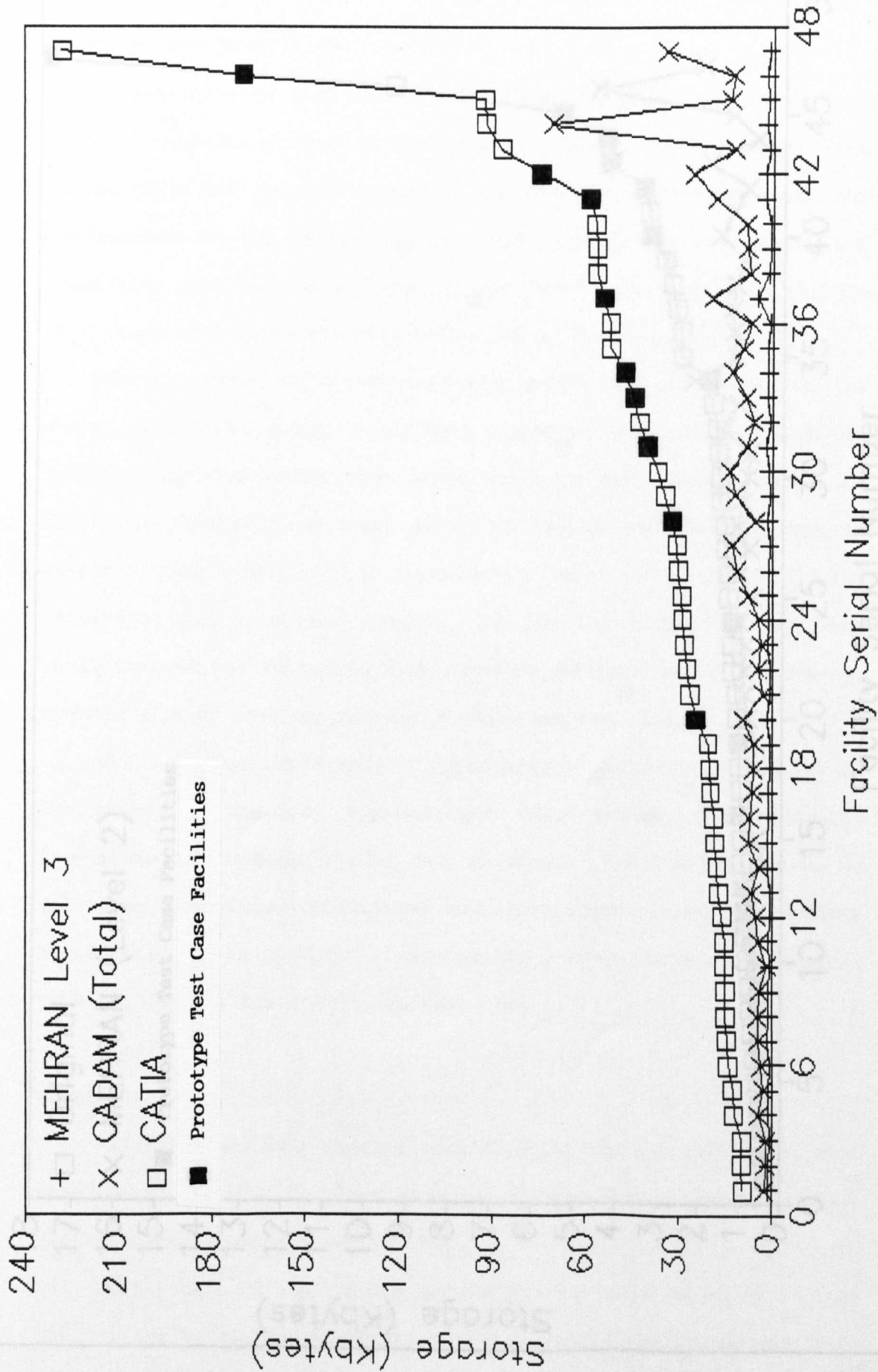


FIGURE 6.15 CADAM and CATIA Storage Comparison.

# CADAM Storage Comparison

(All Facilities)

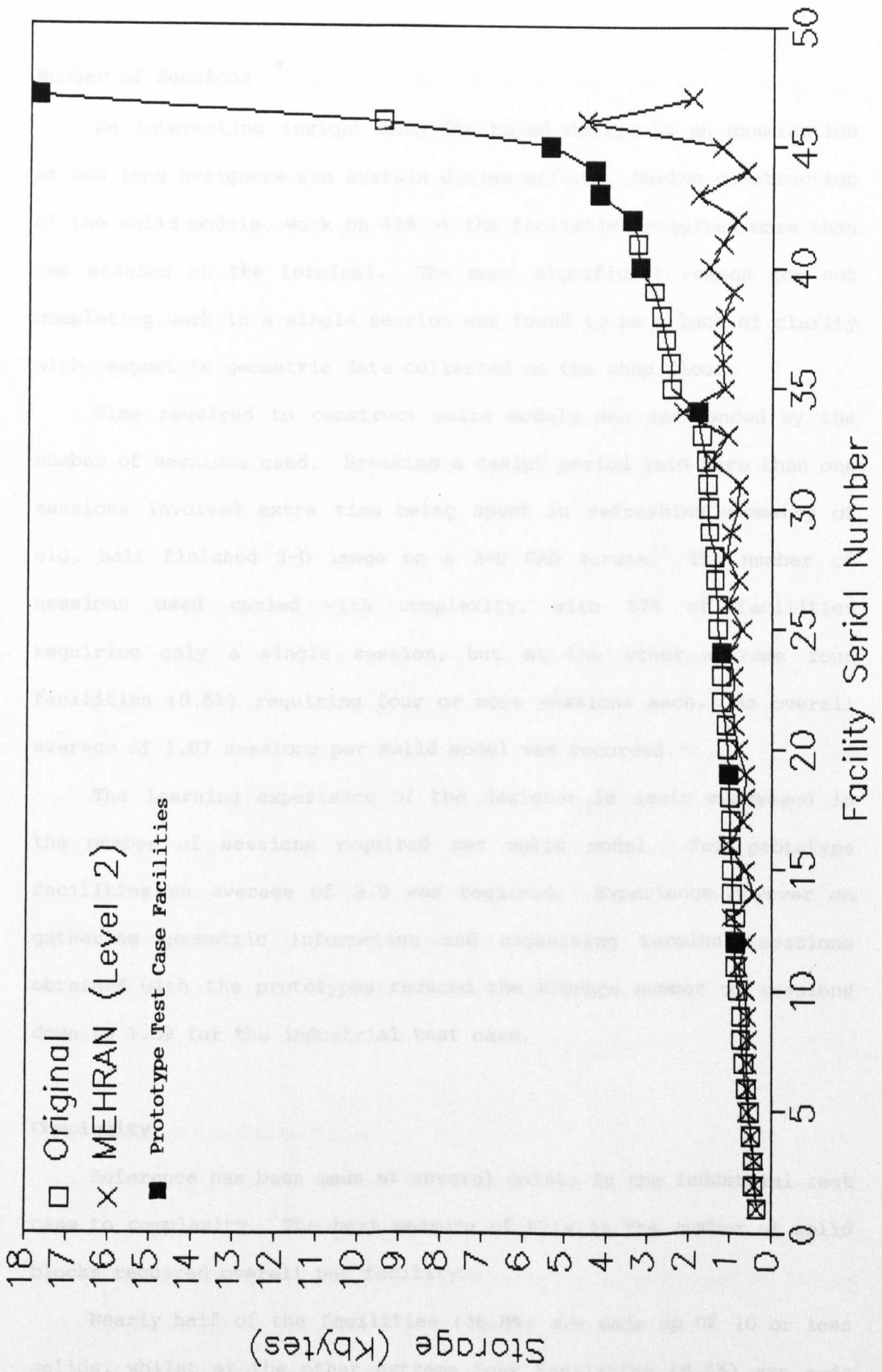


FIGURE 6.16 MEHRAN Facility and "Transferred Facility" Storage Comparison.

## **Number of Sessions**

An interesting insight into CAD based design is an examination of how long designers can sustain design effort. During construction of the solid models, work on 43% of the facilities required more than one session at the terminal. The most significant reason for not completing work in a single session was found to be a lack of clarity with respect to geometric data collected on the shop floor.

Time required to construct solid models was influenced by the number of sessions used. Breaking a design period into more than one sessions involved extra time being spent in refreshing geometry of old, half finished 3-D image on a 2-D CAD screen. The number of sessions used varied with complexity, with 57% of facilities requiring only a single session, but at the other extreme four facilities (8.5%) requiring four or more sessions each. An overall average of 1.87 sessions per solid model was recorded.

The learning experience of the designer is again expressed in the number of sessions required per solid model. For prototype facilities an average of 2.9 was required. Experience however on gathering geometric information and organising terminal sessions obtained with the prototypes reduced the average number of sessions down to 1.59 for the industrial test case.

## **Complexity**

Reference has been made at several points in the industrial test case to complexity. The best measure of this is the number of solid blocks required overall per facility.

Nearly half of the facilities (46.8%) are made up of 10 or less solids, whilst at the other extreme four facilities (8.5%) are made from more than 20 solids. An average of 12 solids per model is recorded for all 47 facilities.

The number of solids is dictated by two considerations; efficiency of the designer and the accuracy of presentation. In the early prototype study the average was 14.8 solids per model. Unnecessary dividing of facilities into excessive numbers of solid blocks was eliminated with experience bringing down the average in the industrial test case to 11.3 whilst maintaining good representation.

Time required to transfer CATIA models to CADAM was few seconds for each model and therefore was not significant to be discussed further.

#### **6.6.2 CADAM Standard Library Times**

This time represents the time required to separate the CATIA transferred composite showing four views in to appropriate detail pages, modify plan views (removing extra lines and finishing cylindrical images of solid transfers) and attach appropriate symbols. Figure 6.14 illustrates the CADAM times for preparing all 47 facilities. Overall average is moderate at 28.72 minutes. Only 6% required more than 40 minutes of time, which is the result of extra finishing work required by these three facilities in order to reduce storage, and clarify image.

#### **6.6.3 Layout Composite Times**

The composition process involved the initial collection of facilities from the MEHRAN standard library into the detail pages of the problem file for "facilities". Overlaying is then used to locate facilities at their designated positions.

Collection of facilities is a simple task, deciding upon which facilities are to be collected and which level of MEHRAN database is

required preempt this activity. Using the "STDLIB" feature of CADAM, all three levels were collected in three separate files. The average for all 47 facilities was recorded as 18 seconds per facility, enabling collection of a problem's total facilities in less than 15 minutes.

Composing layout designs was a more time consuming task. The first, i.e. the original layout required, the most time, (Figure 6.10) taking five hours to complete in three sessions. This time included, appropriate geometry construction on the layout drawing e.g. traffic system and boundaries of production isles. The four subsequent layouts however, took on average only 2.75 hours to complete.

This time was further improved later by customising the process of layout design by using interactive geometry interface routines ("DESIGN"). On average 0.81 minutes per facility were estimated by reconstructing the four layouts using interactive design of MEHRAN. It is however, acknowledged that during this experiment, facilities locations were approximated using a grid and actual layout area modifications were available in advance. Nevertheless, this approach provided a less time consuming method of generating layout composites and resultant layouts were reasonably accurate to those generated by CADAM only.

Having examined the time requirements of each of the three design stages an estimate of overall design time is available. In the representative, industrial test case a series of progressive layout designs can be produced by MEHRAN in approximately two hours. This figure is based on 37 facilities at 18 seconds each for collection, 1.5 hours for layout assembling and the layout areas modifications at 0.25 hours each.

**Table 6.2 Estimated Design Times**

<b>Composite Layout</b>	<b>CADAM Design Time (Hours)</b>	<b>GI-Design Time (hours)</b>	<b>Facilities Located</b>
1. Original	5.0 *	1.0	60
2. Proposed design	4.0 #	-	65
Intermediate			
3. Disc module	2.5 #	0.26	18
4. Component module	2.0 #	0.23	10
5. Caliper module	2.5 #	0.33	23

\* First experience

# Include subsequent layout area modifications.

This time is well within conventional plant layout times and has the added benefits of first class drawings and a permanent database of facilities.

## **6.7 LEARNING EXPERIENCE - STORAGE**

The models constructed in the two parts of the test programme covered 3-D solids down to 2-D plan outlines. CAFL programs have always been sensitive to computer memory, required for graphical images of facilities and layout area, which are the major consumers of computer memory. Therefore, record of storage of images was closely observed to improve overall system performance, and estimate the maximum number of images that MEHRAN based composite layouts can handle. The average storage required generated by this CAFL test is shown in Table 6.3.

### **6.7.1 CATIA Storage**

#### **Initial Memory Requirement**

The prototype 10 facilities gave the first experience of problem capacity. The average storage requirement was found to be 63.74

Kbytes per facility. However, experience on using CATIA for the prototype facilities led to a programme of space reduction as described following.

**Table 6.3 Average Storage of Facilities**

<b>Description</b>	<b>Prototype Test Case (Kbytes)</b>	<b>Industrial Test Case (Kbytes)</b>	<b>Overall Average (Kbytes)</b>	<b>Maximum Possible Facilities *</b>
3-D Solids	63.74	34.76	40.93	24
2-D Total	18.91	7.04	9.56	-NA-
2-D Plan (original)	4.32	1.51	2.11	37
2-D Plan (Facility+Outline)	1.34	1.03	1.10	72 #
2-D Plan (Facility)	1.26	0.91	0.98	81 #
2-D Plan (Outline)	0.24	0.27	0.27	296 #

\* Based on CATIA file size (1000 Kbytes) and CADAM file size (80 Kbytes).

# Limited to 63 unique machine tools by number of details.

### **Solid Model Storage Reduction**

Storage was reduced in the industrial test case by three methods:

1. Direct solid construction as opposed to 2-D to solid conversion.
2. Replacing with cubic solids, of cylindrical and spherical solids.
3. Reducing solid surface finishing (i.e. the number of facets) in those cylinders and spheroids that could not be replaced.

Two examples, put forward in support of first argument are the Lathe (MG-06) and Spray Booth (LG-39). These two facilities were constructed partly from 2-D CATIA converted into 3-D solids, due to complex contouring. The result can be seen in Figure 6.15, where these two facilities required the maximum storage values illustrated.

Incidentally, it is not the number of solids which greatly affects the storage, but type of solid is the one which matters most. The degree of image finishing of the solid has an effect on the storage required. The finishing on a cubic solid is not a question since cube always has six flat faces. The degree of finishing of cylinders and spheres however is dependant of the number of facets defined per quadrant, which varies from one to 10.

The effect of reducing the number of facets was examined by varying the number of facets on a cylinder and an sphere as shown in Table 6.4. The ratio of the average storage for each indicates, cylinders and spheres take three and 27 times storage respectively, as compared to cube. The lowest storage is obtained with single facet per quadrant in each case which is roughly equivalent in all

**Table 6.4 Storage Comparison of CATIA Solid Model Primitives**

<b>Facets</b>	<b>Cube</b>	<b>Cylinder</b>	<b>Sphere</b>
1	1080	1048	1008
3		1992	6016
5		2936	16400
7		3880	32160
9		4824	53296
10		5296	65880
Total	1080	19976	174760
Average	1080	3329	29127
Ratio	1.00	3.08	26.97



three solid primitives (i.e. cube, cylinder and sphere). Slight difference in the lowest entry in each case is because, in the CATIA cube, cylinders and spheres are represented as having six, four and two facets respectively.

The three measures were applied in developing the industrial test case facility models and resulted in a substantially lower average 34.7 Kbytes.

### **Solid Model Layout**

With the 3-D facilities database complete, the possibility of being able to construct 3-D layout designs was considered. The physical difficulties found in placing 3-D models on a layout have been described in section 5.6. With respect to storage constraints, Table 6.3 shows the maximum number of facilities that could appear on a CATIA layout design (ignoring layout area storage). As can be seen that maximum of 24 facilities would not allow any very practical problem.

### **6.7.2 CADAM Storage**

The Storage requirements for each of the three forms of MEHRAN standard library plan views (outline, facility, and facility plus outline) were recorded. The 2-D outline proved a consistent value for all facilities averaging at 0.27 Kbytes per facility.

In addition figures were noted for the storage requirements of the original image "as received" from CATIA. All 47 facilities were covered and the results for the most significant values ( as received and facility plans) are illustrated in Figure 6.16

A significant improvement in reducing the storage is observed in MEHRAN transition from "as received" to "facility plan". The

facility plan (i.e. MEHRAN level 2 representation) requires less than half (1:2.15) on average than the image it has originated from, even after adding symbols and identities to these plan views. Therefore, a combination of better representation with lower storage is achieved by using the MEHRAN approach. Lower storage is significantly important in compiling large size composite layouts.

The effects of learning are apparent in Table 6.3 where the 10 prototype facilities can be seen to be the highest storage users.

### **Layout Composites**

Composite layout plans can be constructed from plan views transferred in CADAM. The plan view of "as transferred" drawings requires on average of 2.11 Kbytes each time it is used. This directly restricts use of this image to only 37 facilities in any composite facilities layout design file. With the three levels of facilities representation produced by MEHRAN, the average storage requirements have come down to 0.98 Kbytes for the equivalent MEHRAN facility representation (i.e. level 2), an improvement of 53.5%. A more detailed MEHRAN representation (facility plus outline ) requires 52% lower storage on average.

Therefore, for each of the three MEHRAN standard library detail images, even after occupying all 63 details (i.e. 63 unique facilities problem) of any CADAM file, the system will leave 13.4%, 22.8% and 78.7% of CADAM file space respectively for composing layout on the primary view. Maximum facility layout problem size even with the most detailed representation (level 3) would allow 382 facility images to be placed on the primary view of this file. With the less detailed remaining two levels, i.e. facility and outline, a total of 648 and 2248 facilities could be placed respectively.

The efficiency of MEHRAN, which can now be seen to be well capable of handling industrial problems, allows two way choices. Firstly, a reduction in the memory required per design (e.g. 80Kbytes to 40Kbytes). Alternatively, considerable additional graphical detail could be added.

#### **6.8. LEARNING EXPERIENCE - GEOMETRY INTERFACE**

Learning experiences of the geometry interface programs; ANALYS, IMPROV, DESIGN and ATTRES for the prototype test case were described in Chapter 5. Additional experiences gained during the industrial test case are described in this section.

##### **Language Compatibility**

CADAM is one of the earliest CAD packages developed in the 60's and was written in FORTRAN 66 (latest release CADAM 21, not available at the University, is written in FORTRAN 77). This drawback therefore did not allow the use of FORTRAN 77 programs within geometry interface. Four examples are given as to the significance of this point.

Firstly, CAFL programs developed at the University would have required extensive modifications to be linked as specialised analytical models within the overall MEHRAN structure. Therefore owing to extensive work in this direction of interfacing, no effort was made to link these already tested analytical models within MEHRAN model. Possibility of linking however exists and has been identified in future work.

Secondly, the majority of software and other systems utilities available at the University are FORTRAN 77 compatible, e.g. Graphics Data Display Manager (GDDM) and SQL/DS FORTRAN interface module.

This meant that combined geometry interface and database interface or screen designing for CADET interface programs was not possible within a single integrated program. Additionally since FORTRAN 77 has been in use at the University for over eight years, little support was available for tackling FORTRAN 66 related problems.

Thirdly, formatted input and output statements and parameter definitions are restricted to FORTRAN 66 level. This caused many errors during geometry interface testing, particularly with read and write tasks. The lack of character variable definition restricted geometry interface capability within the four programs developed.

Finally, when the University did not renew FORTHX licence, interactive geometry interface read and write communication failed. The expert opinion obtained suggests language incompatibility being the most likely cause.

Parameter definition ambiguity between CADCD and CADET routines was discussed earlier in Chapter 5. One significant problem encountered during geometry interface program development merits highlighting. CADET uses 3-D mode parameters i.e. a point in CADET is defined as X,Y,Z value whereas, CADCD uses 2-D parameters. This incompatibility required the unnecessary definition and equating of 3-D and 2-D arrays within programs using common data items. This in turn required additional memory and processing overheads and increased complexity within programs.

### **Input and Output Statements**

The CADAM and geometry interface programs operate alternatively i.e either actual CADAM is operating or the geometry interface is operating at any one time. Consequently there is a restriction on a processing time available to geometry interface programs. Although

occasional problems were encountered due to this restriction, it was experienced that such problems occurred when continuous read and write tasks were undertaken by the program. The eventual solution was to use arrays to store CADET or CADCD values and write or read one array at a time. This however, further complicated read and write tasks by decreasing the amount read each time and increasing the number of times the program had to be run. Eventual solution was to submit selected small jobs each time.

#### **6.9. SUMMARY LEARNING EXPERIENCE**

The learning experiences gained during the two test cases are summarised as follows:

1. Designer learning efficiency has improved with actual industrial test case application.
2. Solid model composite layouts require high memory overheads and with this industrial test case and CATIA model size limitations, generation of 3-D layout composite was not possible.
3. Facilities images "as received" in CADAM require more storage on average than any of the MEHRAN visualisation.
4. MEHRAN imaging system allows the construction of highly detailed better quality industrial layouts within practical limitations of storage and design times.
5. Geometry interface software can be applied to industrial size layout.
6. Simple analytical models can be implemented within interactive MEHRAN geometry interface.
7. Design time can be further reduced by using MEHRAN customised design process in an interactive mode.

3. MEHRAN facilities database can be used in parallel to CAFL analytical programs on practical industrial problems.

#### **6.10 MANUFACTURING DATA**

As mentioned earlier, difficulties were encountered in acquiring and preparation of manufacturing data, Therefore data was developed only for the main disc module, comprising 49 types of disc components and 18 facilities. This data was loaded into SQL/DS based Factory database, details of this data is given in appendix D.

Collected manufacturing data comprises of product order information and process information and is stored in two separate database files; Products and Sequence. Using SQL/DS relational definitions, a combined relational file "Prodseqs" has been generated and loaded into the CAFL database for analytical purposes.

It was difficult to work out distance related costs, and fixed cost per move, since this data was not supplied. Therefore a theoretical transportation cost taken from earlier test cases described in the work of Lilley [34] was used.

#### **6.11 THE INDUSTRIAL DESIGNS**

MEHRAN procedures have provided evidence that an actual industrial size layout problem can be handled within a CAD-CAFL model. MEHRAN has also demonstrated that a well structured and highly defined approach to the layout is highly fruitful in reducing computational demands, increasing designer efficiency and effectively generating layout solutions.

The design work within MEHRAN started with the development of databases and defining procedures for using these databases.

Efficiency of the graphics database content of MEHRAN has been proved within this chapter and the industrial practicality of the approach has been demonstrated.

The MEHRAN system should therefore be seen as a foundation research work for widely applicable CAD-CAFL models development within industrial concerns. Two way development is envisaged; individual companies developing CAD-CAFL software for their customised application and CAD software houses benefiting from versatile and structured approach of MEHRAN developing a general purpose CAD-CAFL module within their CAD products. This point along with other identified areas of future work are further discussed in Chapter 7.

## **CHAPTER 7**

### **FUTURE WORK**



## **CHAPTER 7**

### **FUTURE WORK**

#### **7.1 CHAPTER OBJECTIVES**

This research has made use of three design tools ( CAD, CAFL and DBMS), in order to identify and test the individual and combined benefits of commercial software in layout design. The size and the breadth of the work carried out in this thesis allows the opportunity to identify future developments in four areas :

1. Computer system changes
2. MEHRAN model development
3. Further industrial applications of MEHRAN
4. Miscellaneous developments

#### **7.2 COMPUTER SYSTEM CHANGES**

Two main frame computers (IBM4341 and IBM3083) and three commercial packages ( CADAM, CATIA and SQL/DS) were used in this research work. The special experiences of using this variety of hardware and software merit comments as they influence the direction of future work.

##### **7.2.1 Computer Hardware System**

1. All future work related to MEHRAN should be developed on a single hardware system.

This will have the advantages of direct data communications between all pieces of software and no duplication of data or programs. The long-term objective of integrating the MEHRAN model, factory data and graphical data would be easier to develop within a single processor.

### **7.2.2 Commercial CAD Software**

2. Work should be transferred to a single CAD package for the future development of the MEHRAN software system.

Three possible tools of future development are; 3-D solid model CATIA, 2-D CADAM and 2-D micro based CAD packages. Micro based application development will be discussed later in this chapter.

Initially, CADAM and CATIA were two complementary packages dedicated to 2-D drafting and 3-D design respectively. However, recent releases (CATIA 2.2 and CADAM 20 onwards) show a growing overlap of features. CADAM enhancements are directed at 3-D and CATIA changes at 2-D, thus the opportunity to concentrate on one or the other now exists. The relative merits and limitations of each choice are :

#### **CADAM**

- Computationally more efficient than CATIA.
- Good 2-D representation of facilities and layout area.
- Powerful geometry interface, in interactive and batch mode, very crucial in CAFL application development.
- Interactive geometry interface in CADAM offers both error recovery mechanism and program development support.

- CADAM is the world's most popular main frame CAD system, therefore the benefits of MEHRAN software can be shared by the established CADAM user group.
- The latest release of CADAM (release 21) specialises in interactive user interface, with access to four CADAM files at one time, which would allow designer control on all four overlay files of MEHRAN composite layout.

## **CATIA**

### Merits:

- Provide the best representation of facilities.
- Application can be extended to workstation design level.
- Layout implementation can be simulated using kinematics.
- Interfaces are being improved, showing long term potential.
- New features e.g. 3-D details and increased file size (from 1 Mbyte to 1.6 Mbytes) would allow moderate industrial size problem representation.

### Limitations:

- Particularly weak geometry interface in a batch mode only.
- Best image but very poor CAFL analysis.
- Require the highest memory overheads.
- Less exploitable in the industrial sector than CADAM.

In summary, the present picture of MEHRAN on CATIA is one of restriction to "best representation without CAFL analysis" whilst MEHRAN on CADAM enjoys a "good representation with good analysis". The geometry interface ability is the most crucial point in the development of true CAFL application (i.e. graphical representation

with analytical analysis) which favours CADAM over CATIA. Therefore:

3. Use of CADAM should be continued in future development.

Future work on CATIA should be deferred until new releases of CATIA allow the development of CAFL geometry interface.

### **7.2.3 Commercial DBMS Software**

The Standard Query Language Data System (SQL/DS) has become the relational database standard (ANSI standard) with interface application support in five languages. It has proved a very powerful and efficient data handling tool.

4. The recommendation is therefore made that SQL/DS should be continued in future developments of MEHRAN software, specially in the area of direct data acquisition by specialised CAFL routines.

## **7.3 MEHRAN MODEL AND CAD-CAFL PHILOSOPHY**

The main areas of future work recommended in the MEHRAN model involve; developing and linking of analytical software, enhancing geometry interface and extending graphics database.

### **7.3.1 Specialised Analytical Software**

Two approaches for developing and linking of the specialised analytical software are identified for future development :

5. Linking of previously developed models in the analytical software module of MEHRAN.

6. Progressive development of interactive geometry interface to incorporate, the execution of more CAFL "unit tasks" from within CADAM.

### Linking Previous Software

This development approach is desired for integrating layout design with pre design and post design analysis programs.

7. Pre design software (e.g. to identify machine tool cells, calculate machine tool requirements) and post design software (e.g. layout implementation) should also be added to the analytical module.

Linking of pre design and post design software is a non trivial task. For example sizable effort would be required to remove imbedded bespoke software routines, and modify input and output statements.

Post design layout simulation work carried out at the University of Liverpool offers a potential for linking. It is envisaged that the easiest of all the work carried by the predecessors at the University, would be the work of Driscoll [11], written in FORTRAN and free from any specialised bespoke graphics routines. On the other extreme the most recent, detailed and elaborate models of Lilley [34] would require sizable work to remove GINO routines, and modify input and output statements. Therefore two recommendations are made; first for non graphics (first generation) software and second for bespoke graphics based (second generation) software :

8. Link only simple non graphics based evaluation software (e.g. Driscoll [11] and Abdul-Magid [1]) using the data extracted by geometry interface routines.

9. Bespoke graphics based CAFL evaluation models (e.g. Lilley [34]) should be considered for structured break down and reprogramming as "unit tasks" within MEHRAN geometry interface software (see recommendation 6).

### **Structuring Interactive Analytical Module**

The second approach would involve the breakdown of multiple design and analysis models into elemental tasks, programming these elemental tasks as simple routines or functions and linking within the MEHRAN menu structure, for execution as part of interactive geometry interface. This approach would have the following advantages :

- Graphics and analysis together on CADAM terminals.
- High designer involvement in selection of "unit tasks" and the sequence in which these are executed.
- High level of modularity, menu structure would allow structured dialogue between designer and MEHRAN software.
- Software will be operating similar to CADAM itself and therefore can be seen as an additional CAFL module within CADAM software.
- Previous models can be structured and added to increase analysis versatility.

### **7.3.2 Geometry Interface**

The geometry interface program in CADAM release 19 was seen as merely a means of extracting data from the layout drawing for eventual use in analytical programs functioning outside CAD. CADAM release 20, illustrates greater potential for interactive CAD-CAFL

development. Main development areas of interactive CAFL interface programs using CADAM release 20 would include; integrated analysis, program execution through interactive menu structure and designer assistance (e.g prompts, messages and screen based report layouts).

10. Future development work should be carried out using interactive (CADMACGM) part of the CADAM geometry interface.

This interactive geometry interface will enhance MEHRAN in two areas; automated data collection (from graphics and factory database), analysis and reporting of results on the CADAM screen.

#### **Messages Prompts and Menus**

11. Interactive geometry interface features i.e. prompts, menu and message generation demonstrated in MEHRAN model should be refined and extended to construct a more effective dialogue between user and CADAM system.
12. More "unit tasks" should be developed and linked as menu options to offer greater choice to the designer in interactive design and analysis.

#### **Help Screens**

The CADAM macro geometry allows definition of help screens for users. These are pre defined screen images consisting either a single or a series of drawings and can be displayed automatically or at user discretion.

13. Help screens within MEHRAN should be developed to guide and train users of MEHRAN in designing facilities layout.

## Results on CADAM Screens

14. Geometry interface analysis routines should be refined to display results on customised CADAM screens to support the CAFL designer.

## Objective Layout Design

Certain subjective factors in layout design can be converted into objective decisions by assigning attributes to the facilities and layout areas. Expanding on this point, for example, the relationship between two facilities with respect to noise will be dependent on either the distance between the two facilities or the use of partitions to reduce noise. In a first instance, a noise attribute of the two facilities can be checked against the distance between these facilities and a satisfying or non satisfying result can be recorded. In a second situation, extra cost of partitions can be recorded for overall layout evaluation.

Similarly, an attribute of the facility representing special foundation requirements can be checked against the layout area where it is being located. In case of foundation work to be carried out at that location, appropriate cost should be recorded.

A mechanism of attribute assignment, extracting and modifying is possible in CADAM geometry interface, therefore :

15. Attribute feature should be exploited for qualitative factors in the layout design to improve subjective decisions of the designer.
16. A record of designer decisions should be made for later review of the layout.



### **Automated Computerised Layout**

One of the long-term developments of MEHRAN was identified as an ability of the program to construct a new layout or modify an existing layout based on optimisation algorithm results. When the specialised analytical software development becomes established.

17. Present interactive layout generation method can be extended to allow "exchanges" or complete construction of layout based on automated algorithm results.

### **Automated Data Acquisition**

Direct data acquisition from SQL/DS and CADAM is another important area for future development.

18. Each program model in the specialised analytical module can be enhanced to obtain required data direct from the factory and CAD databases.

This will simplify the framework and allow bypassing the construction of CAFL problem database. New hardware configuration at the University opens this opportunity and pursuing this path is envisaged highly valuable in integrated CAFL analysis.

In summary, future developments in the area of interactive geometry interface offer a great potential for efficient computer and designer interface and development of well structured modular CAFL analysis routines within the MEHRAN model. Strong practical value is envisaged in this area of MEHRAN development.

### **7.3.3 Graphics Database**

#### **Additions to Graphics Database**

Pioneering work on the important structured graphics database has been completed, and procedures for inputting facilities, material handling equipment and layout area have been fully developed.

19. Extending the standard library to include additional facilities will be a useful contribution.

One area of the graphics database unutilised in the present research was representation of services and utilities.

20. Data relating to associated supporting services and utilities should be organised in a similar manner to the layout area.

### **7.3.4 Micro Application of MEHRAN**

There exists a considerable potential of developing a micro based application using microcomputer based CAD and database software. Two packages AutoCAD (from Micro desk, USA) and dBASE (from Ashton-Tate, USA) have been examined and are recommended as having future development potential for the following reasons :

1. AutoCAD allows geometry interface ability, similar to MEHRAN where data extraction i.e. attribute data can be extracted from the drawing [46].
2. AutoCAD is the world's largest used micro CAD package and dBASE is one of the widest applied industry standard micro database package.
3. AutoCAD can pass data to dBASE [46].

4. CADAM and AutoCAD can exchange graphical images via the IGES interface, therefore, standard library facilities in CADAM need not be redrawn.
  5. The new release of dBASE (i.e. dBASEIV) is SQL/DS compatible therefore, main frame data can be transferred to and from the micro version.
  6. DBASE is a relational database which is an added compatibility with MEHRAN.
  7. AutoCAD has been linked with engineering analysis software (e.g engineering mechanics software NISA II and DISPLAY). Therefore there seems a potential to develop specialised CAFL analysis programs based on AutoCAD.
- 
21. The recommendation is therefore made to start work on a microcomputer version of MEHRAN.

## **7.4 EXPLOITATION OF MEHRAN SOFTWARE**

### **7.4.1 CADAM Application**

The MEHRAN software system has been developed in a structured menu driven mode, identical to CADAM procedures.

22. Therefore, with enhancement described earlier (section 7.3), it could be exploited as an optional CAFL module offered to industrial clients of CADAM through CADAM or IBM channels.
23. The standard library of MEHRAN should be supplied as a basic set of facilities and where necessary the clients could add their own equipment shapes into the library.

#### **7.4.2 AutoCAD Application**

24. The microcomputer version of MEHRAN should be developed using AutoCAD and dBASE packages and supplied as an optional program to AutoCAD users.

### **7.5 MISCELLANEOUS DEVELOPMENTS**

#### **Drawing Management**

Based on the experience gained during the natural phasing of CAFL design, it is envisaged that when layout design and optimisation processes will be applied, there will be a number of intermediate drawings.

25. It is recommended that a well defined automated naming conventions should be incorporated in the programs to systematically identify drawings.

26. CADAM uses two part, 20 characters drawing identity which should be utilised to devise automated drawing naming scheme.

#### **Commercial Software for CAD-CAFL Approach**

The conceptual CAD-CAFL frame work can be applied to suitable commercial CAD and DBMS software. CADAM, CATIA and SQL/DS were used to develop MEHRAN model.

27. A general survey study is recommended of other commercial CAD and DBMS software with respect to CAD-CAFL potential identification.

This type of survey would result in the identification of commercial packages which can and more importantly cannot be used for CAFL.

It is envisaged that CAD based layout designs are likely to increase in future.

28. The recommendation therefore can be made to the commercial CAD suppliers to utilise MEHRAN concepts and develop modular structure of CAFL within their future CAD releases.

29. The MEHRAN development work should be extended to cover the life cycle of facilities planning.

#### **7.6 SUMMARY OF FUTURE WORK**

Five main recommendations from the 29 discussed above are :

1. MEHRAN development should be continued on CADAM and SQL/DS.
2. Development effort should be focused on interactive geometry interface part of the MEHRAN model.
3. Structured, menu driven CAFL analytical software should be developed and linked to the interactive geometry interface.
4. MEHRAN concepts should be exploited in microcomputer CAD packages.
5. MEHRAN should be developed as an identifiable module of commercial CAD systems, by the large CAD software development companies.

**CHAPTER 8**

**CONCLUSIONS**

## CHAPTER 8

### CONCLUSIONS

#### 8.1 CHAPTER OBJECTIVES

The work presented in this thesis has advanced the knowledge on four areas within the subject of Computer Aided Facilities Layout. Initially a thorough coverage of the state-of-the-art within CAFL was presented in an international perspective followed by the definition of components of an ideal CAFL package. This "ideal" specification was detailed as a conceptual CAD-based CAFL package and an initial MEHRAN model was built to examine the feasibility of this CAD-CAFL philosophy. The model was initially tested on an academic 10 facility prototype test case. An examination of MEHRAN on a full size (60 facility) real industrial test case followed (developed as the result of collaboration between the University and Lucas Automotive, Bromborough). The industrial test case led to an understanding of the potential of CAD based CAFL within the company, who now posses a database of layouts and facilities originating from this work. With the independent work of the Manufacturing Systems Task Force now also complete the company may takes up the challenge of on-line facilities management in future. At this point the main conclusions of this research are summarised. The objectives of this chapter therefore are :

1. To present general comments on the subject of CAFL.
2. To present overall conclusions on the progress of CAFL in an international scenario.

3. To draw conclusions on the role of the MEHRAN graphics database.
4. To comment on the task of developing geometry interface software.
5. To draw overall conclusions on the MEHRAN research work and CAD-CAFL approach.

## **8.2 GENERAL CONCLUSIONS**

### **Life Cycle of Facilities Planning**

1. Facilities life cycle consists of three identifiable phases; design, implementation and operation. Prime considerations at each phase are different and CAFL software development should progress in parallel to match these changing criteria.
2. The life cycle CAD-CAFL package should accommodate a three stage, multi-situation multi-criteria solution procedures.

### **Application of Design Concepts to CAFL**

3. Classical engineering design methodology can be applied to CAFL.
4. CAFL is a combination of "images" and "analysis". "Computer graphics", "quantitative analysis" and "qualitative analysis" are the three basic elements of CAFL design process.
5. The individual case study dictates the criteria, approach and information which would be required to carry out true CAFL analysis, therefore, CAFL analysis packages should incorporate multiple design and evaluation procedures.



### **Application of CAD to CAFL**

6. CAD systems can be effectively applied to CAFL applications.
7. A CAD based specialised CAFL oriented design process is most likely to form the basis of a new generation of CAFL software.
8. The main work load of CAD-CAFL approach will require effort in the designing and organisation of the graphics database within CAD, exploration of limitations and potentials of using CAD and defining mechanisms to carry out analysis through CAD and geometry interface.

### **8.3 INTERNATIONAL SURVEY**

Within the published survey report 40 conclusions were presented. Additionally conclusions are drawn at the end of each section within Chapter 3. At this point the overall summary conclusions are presented.

9. Healthy development in CAFL software is mainly a result of academic effort which lacks professional software features useful for industrial application.
10. There is a limited and incomprehensive effort of major software companies in CAFL development.
11. Industrial practitioners are less aware of the progress in CAFL and their identified interest is restricted to using either old first generation CAFL software or a CAD only approach.

12. The second generation software has failed to achieve third party use. Consequently further development should be diverted to alternative method of graphics supported software development i.e. CAD based CAFL software.
13. Two dimensional graphics has become the norm in CAFL, however, quality and effectiveness of graphics is still being criticised and improvements are sought in effective on-line graphics.
14. Increase in the application of commercial packages, with a majority being CAD packages, in CAFL is in evidence.
15. Construction and improvement methods are well established in CAFL software.
16. Most commonly used criteria are materials movement and closeness desirability. Evidence however exists of multiple model CAFL evaluation.
17. Two stages of CAFL applications were found particularly weak; preparation of test case data and conversion of software results into a practical layout. Additionally, requests were made for improvement in working mode, graphics and modelling attributes.
18. In summary, a designer controlled, industrial oriented, graphics supported, interactive approach with multiple models is the ultimate requirement of CAFL users.

#### **8.4 CAD-CAFL MODEL**

##### **CAD-CAFL as Industrial Practice**

19. Evidence indicates that sizeable industrial concerns have started CAD based graphical representation of factories.
20. The importance of CAD based CAFL need to be emphasised among industrial concerns and at the same time development of "practically useful in industrial environment" CAD-CAFL packages should be developed.
21. The need arises to reduce the gap between academic research and its application in industry by considering collaborative advances of software and hardware. This is important for two reasons; research benefits can be realised quickly and feedback will be available for the direction of future research.
22. The industrial test cases would require massive data handling therefore a need to employ a DBMS in CAD-CAFL is identified.
23. CAD based CAFL is an attractive choice for companies already employing a CAD package.

##### **CAD-CAFL Development**

24. The continuing fast rate of growth of CAD package applications makes CAD a preferable choice for developing a CAD-CAFL model.
25. Commercial CAD packages bring many powerful graphics and analytical features to assist layout designers. However, due to the specialised needs of the CAFL design process, CAD applications would require initially to search for "useful to

CAFL" functions and then to enhance application by customising CAD procedures into CAFL design process.

26. The CAD packages, with geometry interface ability e.g. CADAM can be used to develop a CAD-CAFL model as evidenced by MEHRAN.
27. Alternately commercial software houses can extend capabilities of their CAD products to provide powerful routines for CAFL design and analysis. However, specialist analytical routines will still be required to tackle unique CAFL problems.

## **8.5 THE MEHRAN MODEL**

### **MEHRAN Graphics**

28. The 3-D CATIA database provides more realistic visualisation but demands high level of storage and processing overheads and therefore its use will remain experimental at present.
29. Considering a reasonable sized industrial layout, CATIA could prove expensive and technically infeasible.
30. Good quality 3-D images can be generated economically by using solid geometry construction features of CATIA.
31. 3-D CATIA to 2-D CADAM image conversion is efficient and effective in producing high quality 2-D facility images.
32. Two dimensional graphics which is now a standard in layout graphics can be achieved by using a CADAM package which provides

an effective, efficient and cheaper method of generating 2-D layout drawings.

33. The MEHRAN 2-D graphics database effectively brings benefits to the designer in terms of; multi level representation, high quality graphical visualisation, low level ambiguity of images, designer controlled graphics, economy of storage and processing, efficient use of CAD file limitations and expansion flexibility.
34. Graphical image data can be transferred between two CAD systems through IGES interface. However, reliability of transferred data is dependant on the CAD systems involved and may vary with releases and versions of the packages in question.
35. In summary, the structured MEHRAN database approach within this thesis has three main advantages; modular flexibility, storage and processing efficiency, reduced ambiguity in constructing layout visualisation.

#### **MEHRAN Factory and CAFL Databases**

36. The use of DBMS is highly desirable for two reasons. Firstly the future layout analysis will require sound basis of design, which directly depends upon the accuracy and amount of data needed to satisfy multi criteria design evaluation. Secondly, the data collection and preparing has been found a difficult task by CAFL users.
37. Standard format of operating system can support data being transferred between CAD systems, CAD systems and analysis software, analysis software and database.

## **MEHRAN Geometry Interface**

38. Two types of interfaces are possible; between CAD systems and between CAD system and analysis package. In the first instance image data can be transferred between two CAD systems through built-in IGES interface. In the second case, specialised analytical programs can access image database. These programs could function both within CAD (e.g. "DESIGN" and "ANALYS" within CADMACGM part of CADAM) or outside CAD (e.g. "ATTRES" and "IMPROV" using CADET and CADCD parts of CADAM).
39. Geometry interface capability of the CAD packages is sensitive of individual CAD package and may vary with updates and release changes, thereby affecting previously developed geometry interface based CAFL programs. A consideration to testing and possible updating of CAFL interface should be included in selection and/or updating decision of individual CAD package.
40. MEHRAN geometry interface programs can make use of graphics database in three ways; generate layout, extract data and manipulate data for analysis.
41. Use of ditto method of representation of a facility within MEHRAN has proved efficient, effective and economical in processing and storage.
42. Use of ditto representation and symbols and attributes in facility image reduce processing requirements of extraction programs by allowing filtering of data through the geometry interface programs.

### **MEHRAN Commercial Software**

43. Use of commercial software for CAFL is a progressive step forward, and the MEHRAN system has demonstrated high quality graphics, efficient data handling and multiple analysis are possible with use of commercial software packages CATIA, CADAM and SQL/DS enhanced with interface software.
44. The MEHRAN model has demonstrated CAD can be linked with analysis software and powerful geometry interface (e.g. CADAM GI) can be used to develop modular design and evaluation routines within CAD itself.
45. One noted drawback of commercial software application is that the CAFL programs are limited to specific package capabilities and advances in commercial software can influence the operation of a CAFL package.

### **MEHRAN Based Industrial Layout Design**

46. The MEHRAN graphics database has been successfully applied to an actual industrial layout problem. The MEHRAN approach has demonstrated an ability to represent even bigger size or more detailed industrial test case. Therefore the conclusion is drawn that MEHRAN is well capable of handling actual industrial problems.
47. No significant problem was evidenced in geometry interface programs for handling industrial test case, suggesting MEHRAN application of CAFL analytical software, have a sound basis for handling industrial test case.

48. Use of proprietary DBMS e.g. SQL/DS is useful and convenient in handling CAFL and manufacturing data while examining industrial test cases within MEHRAN.

## 8.6 SUMMARY CONCLUSIONS

49. Computer Aided Facilities Layout will progress with the quality of computer hardware and commercial software.

50. The user interest has shifted to commercial software with majority of CAD package applications since more advanced commercial software offers many functional advantages and is comparatively cheaper to buy than to develop an in house application.

51. CAD packages offer full graphics capability, in a form most suitable to the CAFL design process and additionally can be used to develop customised CAFL package within CAD packages having good geometry interface capability.

52. The content and manner in which the required data is stored, acquired and organised are important for effective CAFL software development, a high degree of structured organisation is therefore important for both graphics and manufacturing data.

53. A new merger of both CAD and CAFL within this thesis has demonstrated wide scope and potential of merged application of CAFL design concepts and Computer Aided Design (CAD) technology.



**APPENDIX A**

**MEHRAN FACILITIES DATABASE**

- A1        THE PROTOTYPE TEST CASE**
- A2        THE INDUSTRIAL TEST CASE**

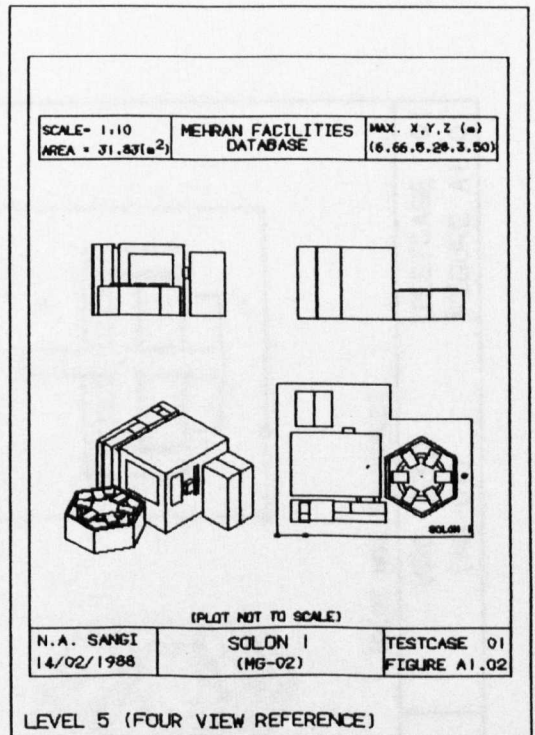
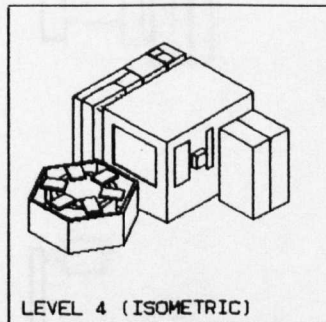
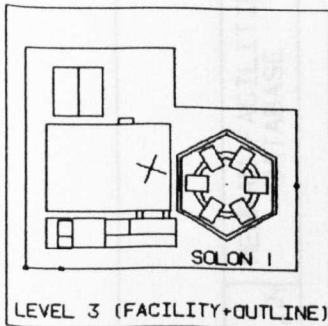
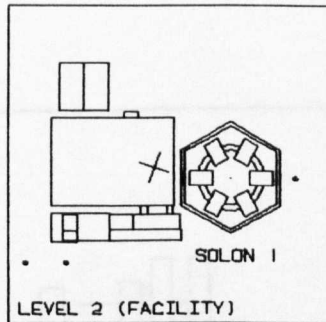
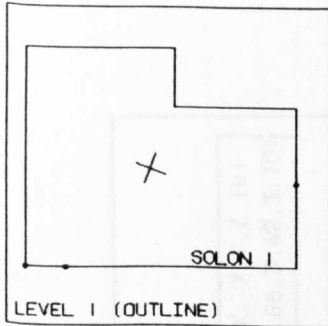
**A1**

**A1 THE PROTOTYPE TEST CASE  
(10 FACILITIES)**

## Prototype Test Case Facilities

Serial Number	Figure Number	Facility Name	Facility Identity
1.	A1.01	BPC 630	MG-01
2.	A1.02	Solon 1	MG-02
3.	A1.03	Solon 2	MG-03
4.	A1.04	Cubotic D400	MG-04
5.	A1.05	Easiturn 3	MG-05
6.	A1.06	Lathe	MG-06
7.	A1.07	Mitsubishi RM-501	MG-07
8.	A1.08	Adept One	MG-08
9.	A1.09	Fork Lift	MG-09
10.	A1.10	Hazmac L3	MG-10

### Illustration of Facilities Database Levels 1 to 5 Prototype Test Case Facilities



SOLON 1 (MG-02)

SOLID MODELS ARE HELD IN CATIA.

N.A. SANGI  
14/02/1988

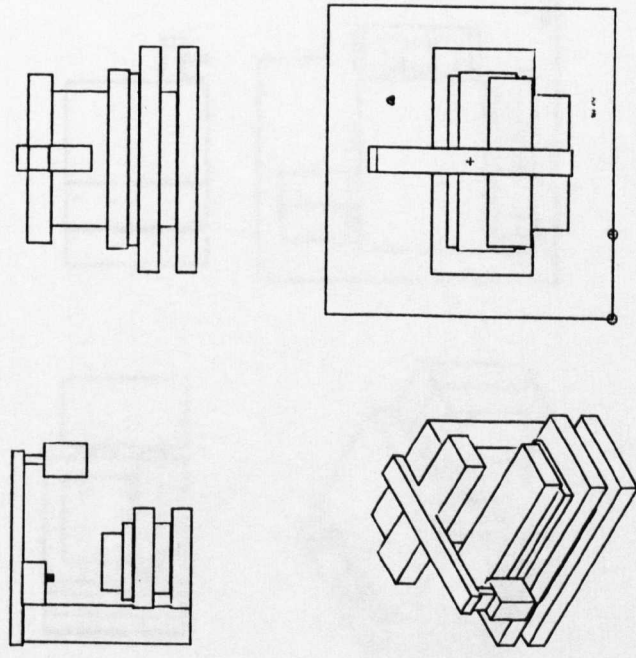
FIVE LEVELS OF FACILITY REPRESENTATION IN CADAM

TEST CASE 01  
FIGURE A1.00

SCALE= 1:10  
 AREA = 12.59(m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (3.68,3.42,3.15)



(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

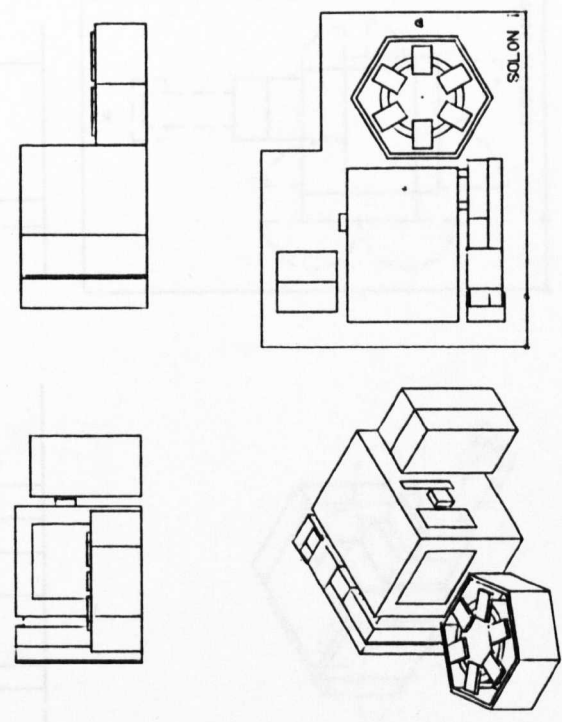
VPC 630  
 (MG-01)

TESTCASE 01  
 FIGURE A1.01

SCALE= 1:10  
 AREA = 31.83(m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (6.66,5.28,3.50)



(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

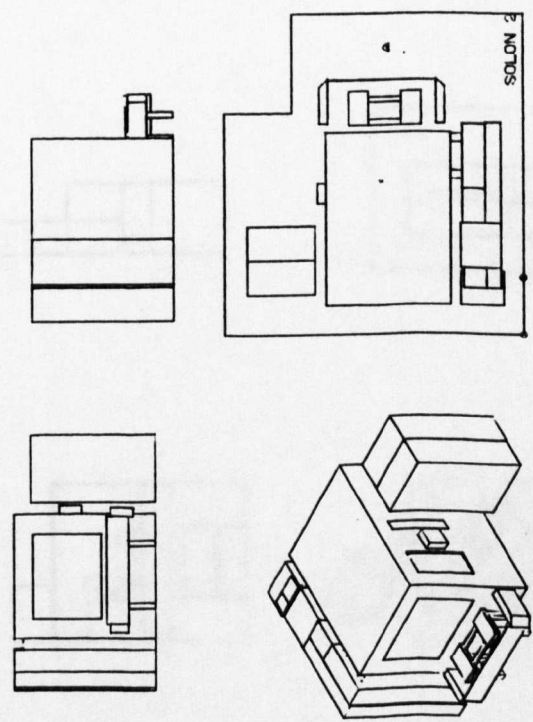
SOLON 1  
 (MG-02)

TESTCASE 01  
 FIGURE A1.02

SCALE= 1:10  
 AREA = 27.75(m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (5.66,5.28,3.50)



(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

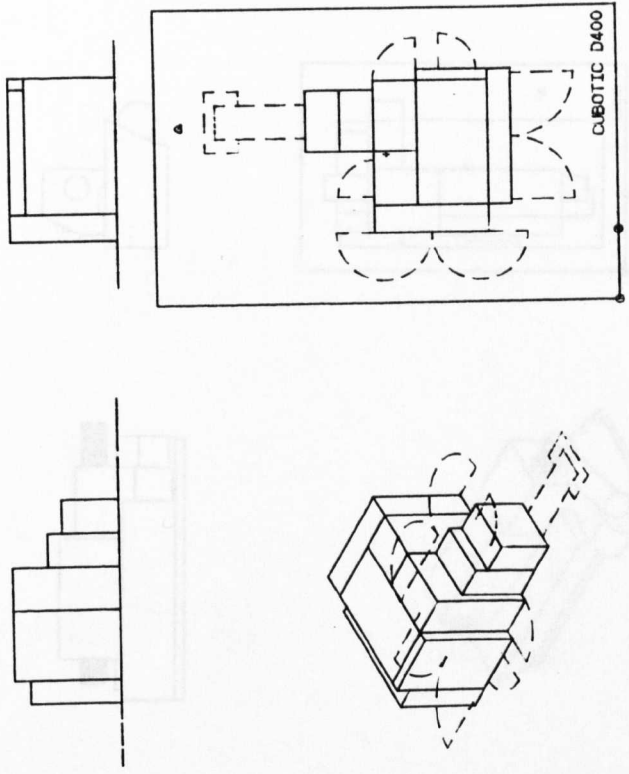
SOLON 2  
 (MG-03)

TESTCASE 01  
 FIGURE A1.03

SCALE= 1:10  
 AREA = 27.87(m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (4.22,6.60,2.52)



(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

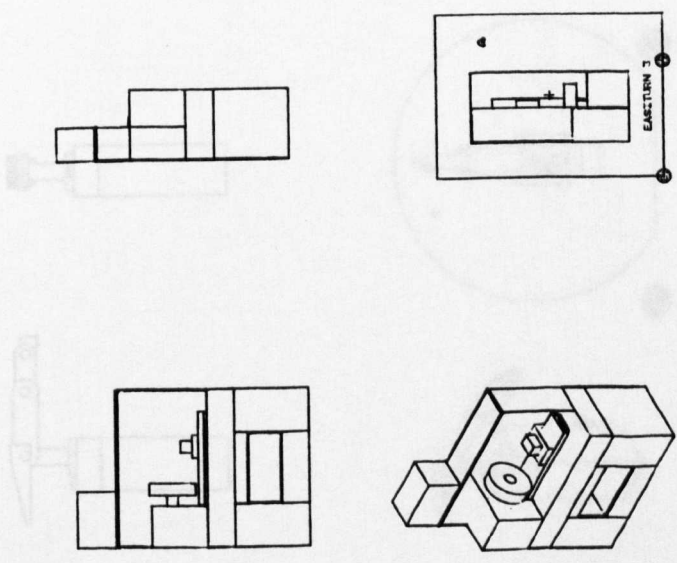
CUBOTIC D400  
 (MG-04)

TESTCASE 01  
 FIGURE A1.04

SCALE= 1:10  
 AREA = 2.78 (m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (1.41, 1.97, 3.02)



(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

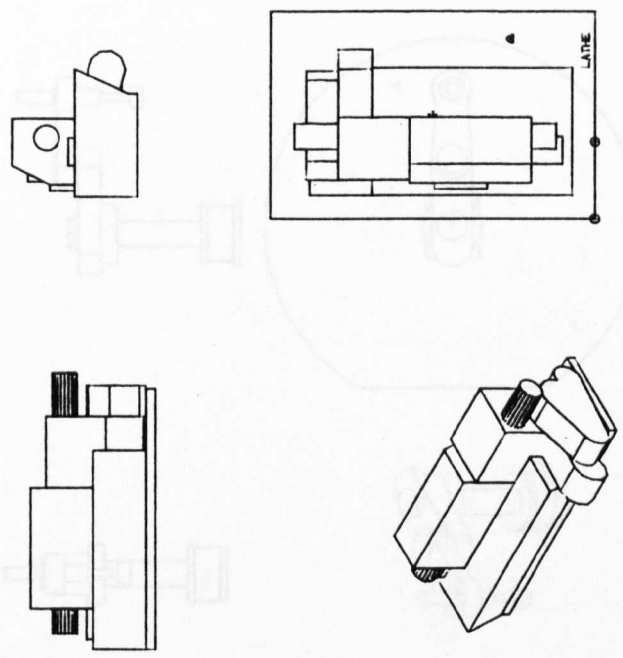
EASITURN 3  
 (MG-05)

TESTCASE 01  
 FIGURE A1.05

SCALE= 1:10  
 AREA = 5.86 (m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (1.93, 3.27, 2.17)



(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

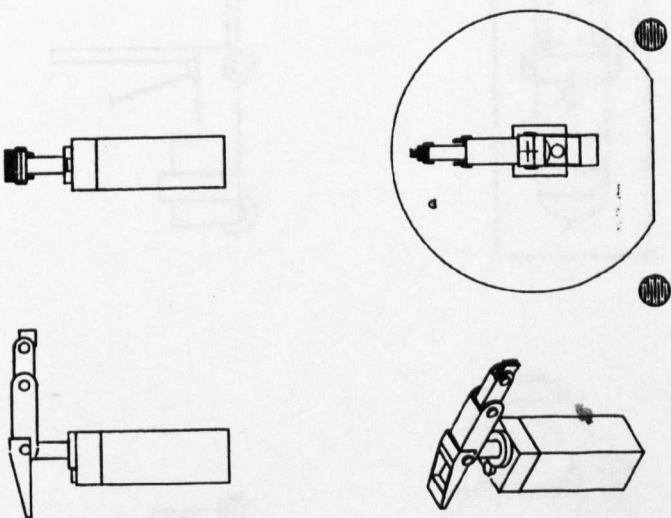
LATH  
 (MG-06)

TESTCASE 01  
 FIGURE A1.06

SCALE= 1:10  
 AREA = 0.92 (m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (1.98, 1.02, 1.86)



(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

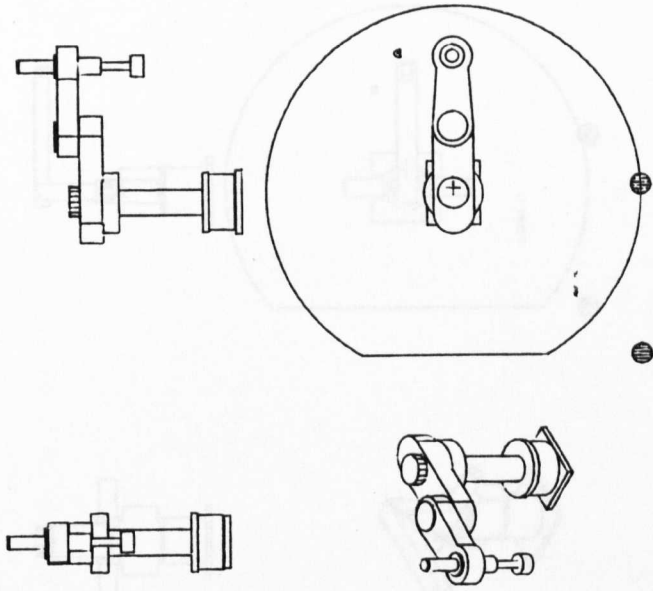
MITSUBISHI RM-501  
 (MG-07)

TESTCASE 01  
 FIGURE A1.07

SCALE= 1:10  
 AREA = 3.69 (m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (2.06, 2.20, 2.30)



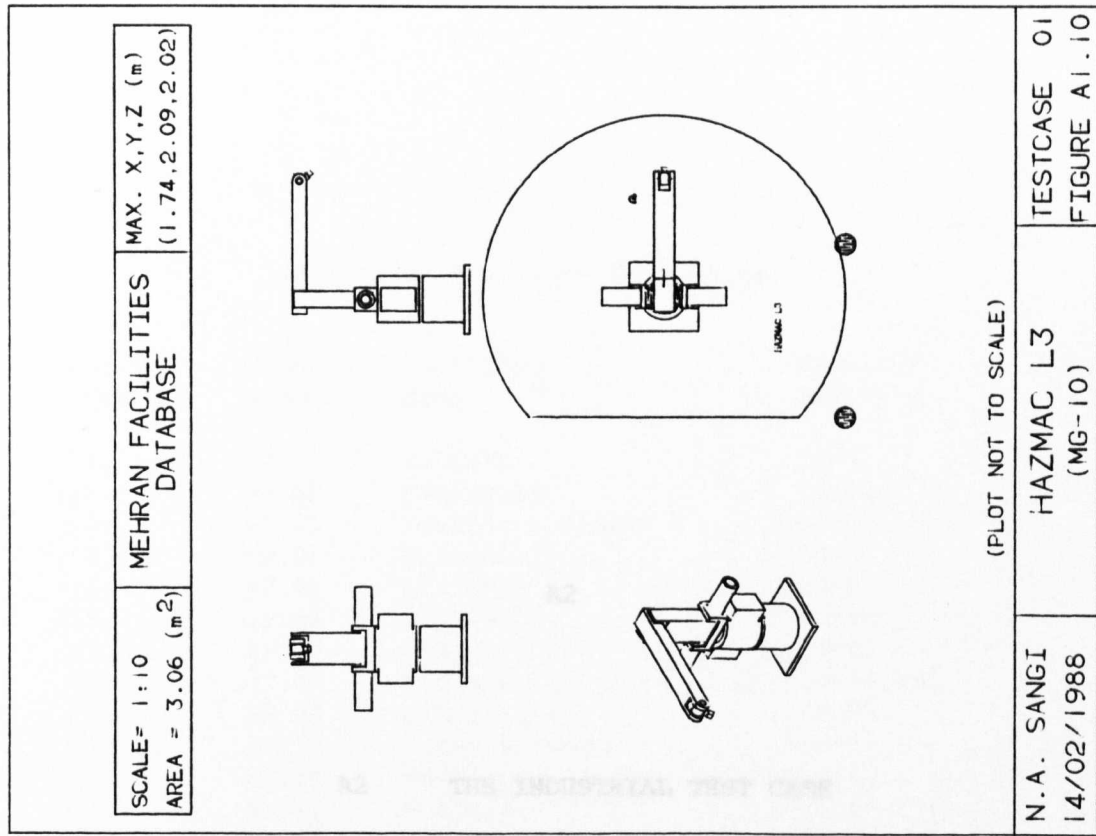
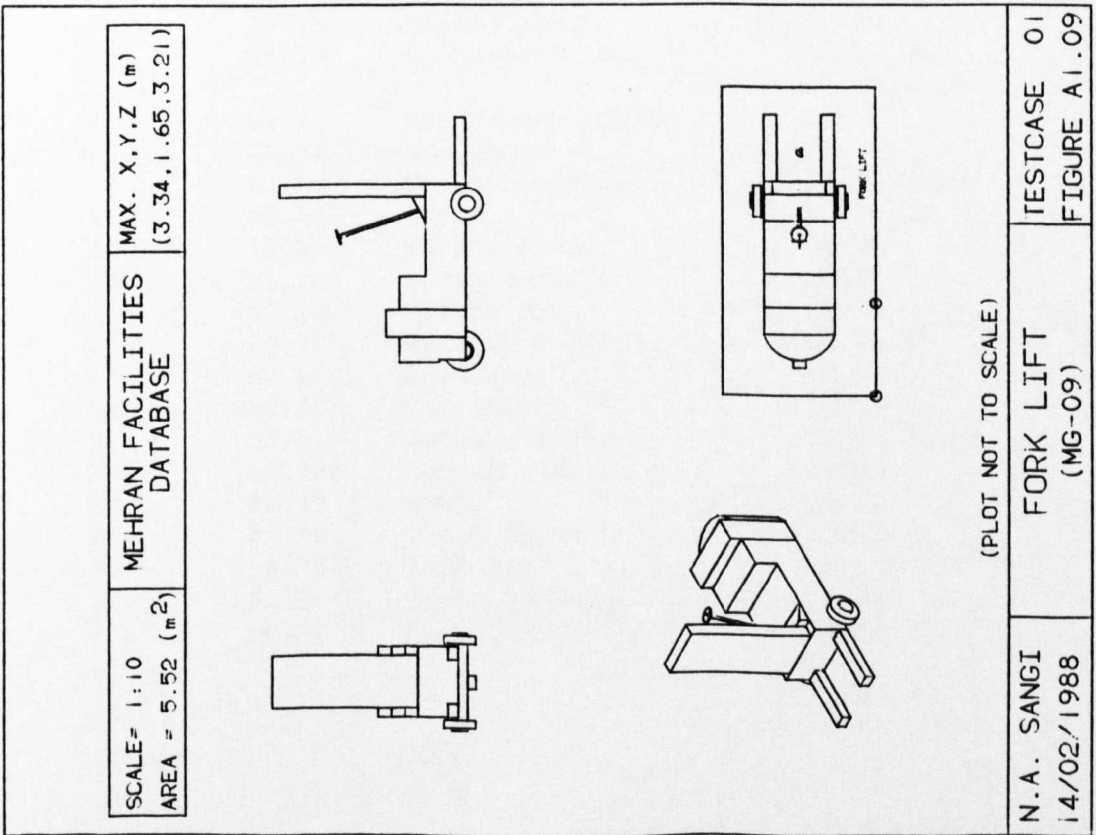
(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

ADEPT ONE  
 (MG-08)

TESTCASE 02  
 FIGURE A1.08







**A2**

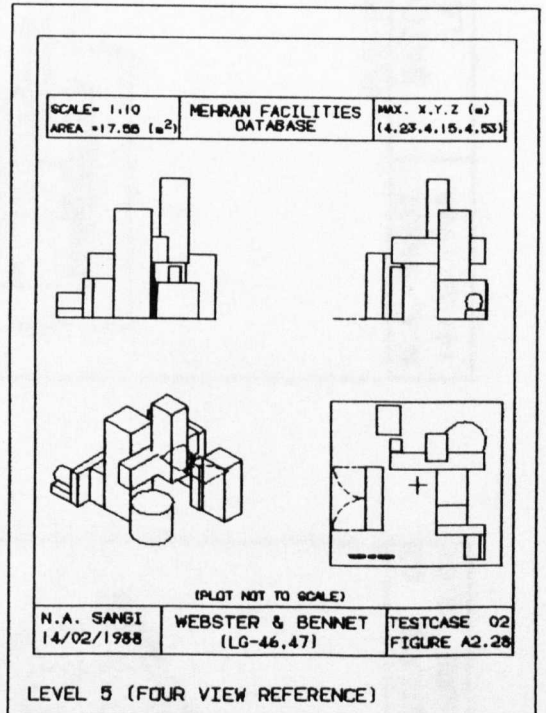
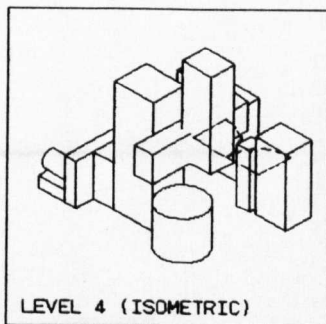
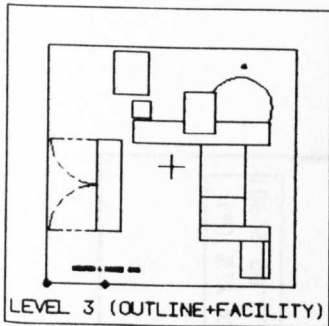
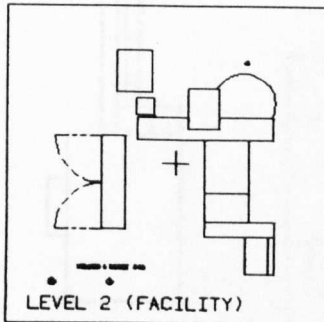
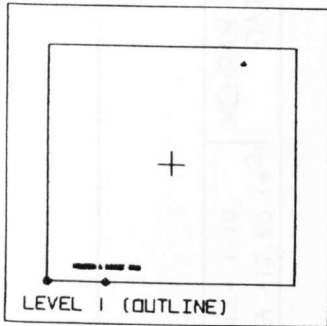
**A2      THE INDUSTRIAL TEST CASE  
(37 FACILITIES)**

### Industrial Test Case Facilities

Serial Number	Figure Number	Facility Name	Facility Identity
1.	A2.01	Mollart	LG-01
2.	A2.02	Batchmatic	LG-02
3.	A2.03	Webster & Bennet	LG-03,64-68
4.	A2.04	Morando	LG-04
5.	A2.05	Linisher	LG-05
6.	A2.06	Eisele	LG-06
7.	A2.07	AMT	LG-07
8.	A2.08	Pollard	LG-08,26
9.	A2.09	Cincinnati	LG-09
10.	A2.10	Jones Shipman	LG-12
11.	A2.11	Oerlikon	LG-13
12.	A2.12	Pollard	LG-14, 16
13.	A2.13	BSA Taper	LG-15
14.	A2.14	Vero	LG-19
15.	A2.15	Cincinnati IOV	LG-20
16.	A2.16	Pollard	LG-22,45,75
17.	A2.17	Funditor	LG-23
18.	A2.18	Archdale R/Arm	LG-24,31,56
19.	A2.19	Hosan Drill	LG-25
20.	A2.20	Cincinnati 400	LG-27,59, 60,63,69,70
21.	A2.21	Hey Face & Center	LG-30
22.	A2.22	Bar Ender	LG-33
23.	A2.23	Warner & Swasey	LG-34,52,53
24.	A2.24	CTC 4	LG-35,37
25.	A2.25	Hi-Ton Press	LG-36
26.	A2.26	Spray Booth	LG-39
27.	A2.27	Matrix V50	LG-40,41
28.	A2.28	Webster & Bennet	LG-46,47
29.	A2.29	Dorries	LG-48
30.	A2.30	Cintimatic	LG-50
31.	A2.31	Kitchen R/Arm	LG-55,71,72
32.	A2.32	Spin Rivetter	LG-57
33.	A2.33	Wavis	LG-58
34.	A2.34	Fritz Werner	LG-61,62
35.	A2.35	Lapointe	LG-73
36.	A2.36	Ideal hardener	LG-76
37.	A2.37	Snow Grinder	LG-77

# Illustration of Facilities Database Levels 1 to 5

## Industrial Test Case Facilities



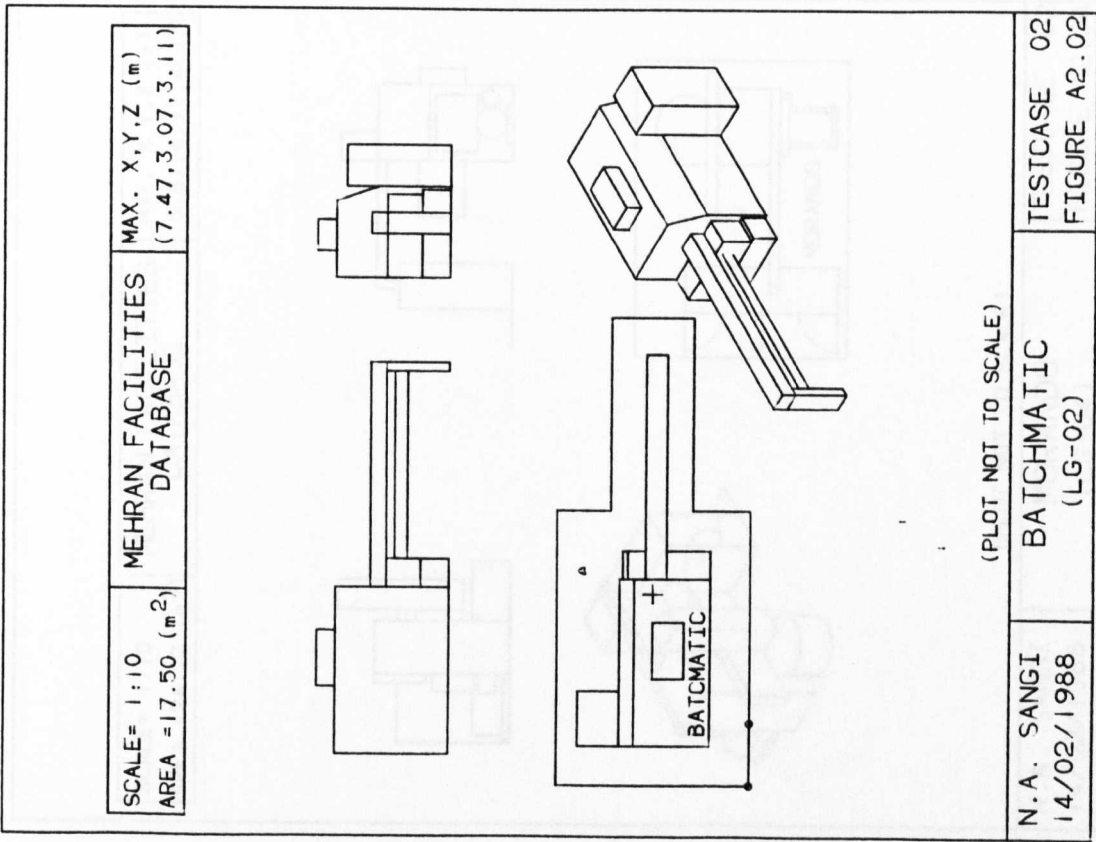
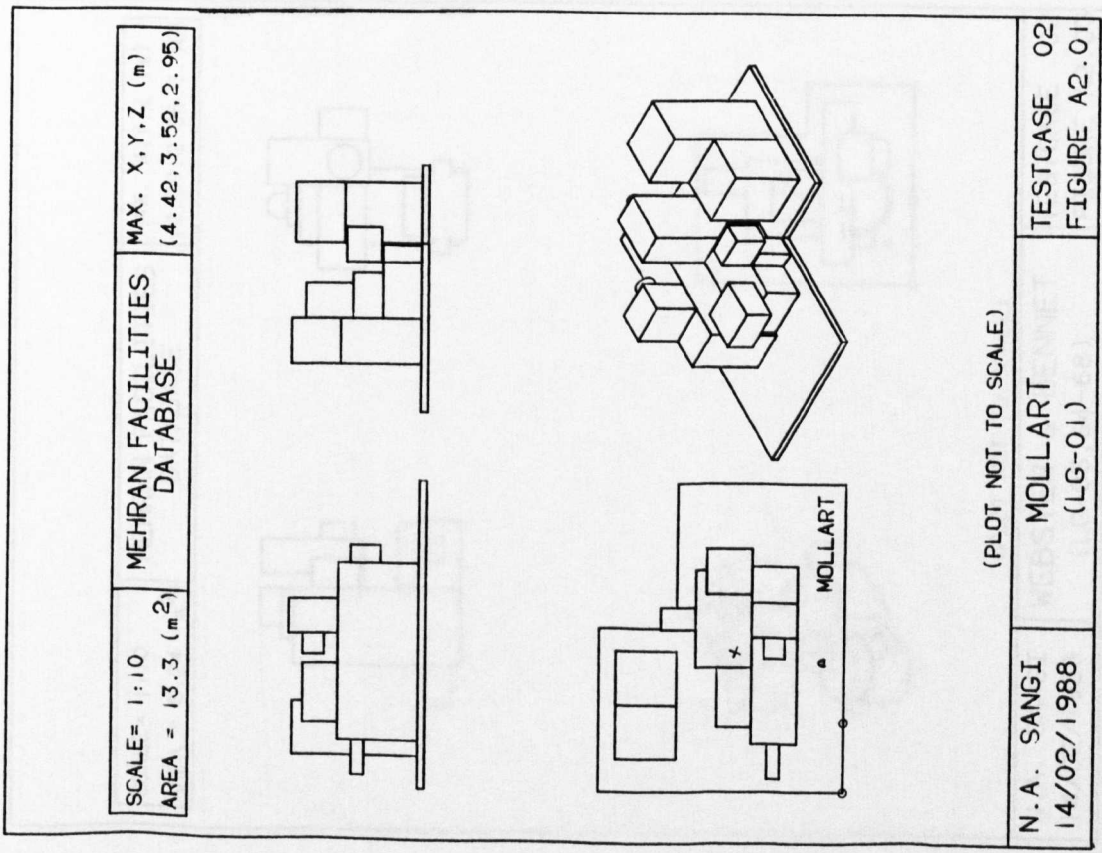
WEBSTER AND BENNET NC (LG-46,47)

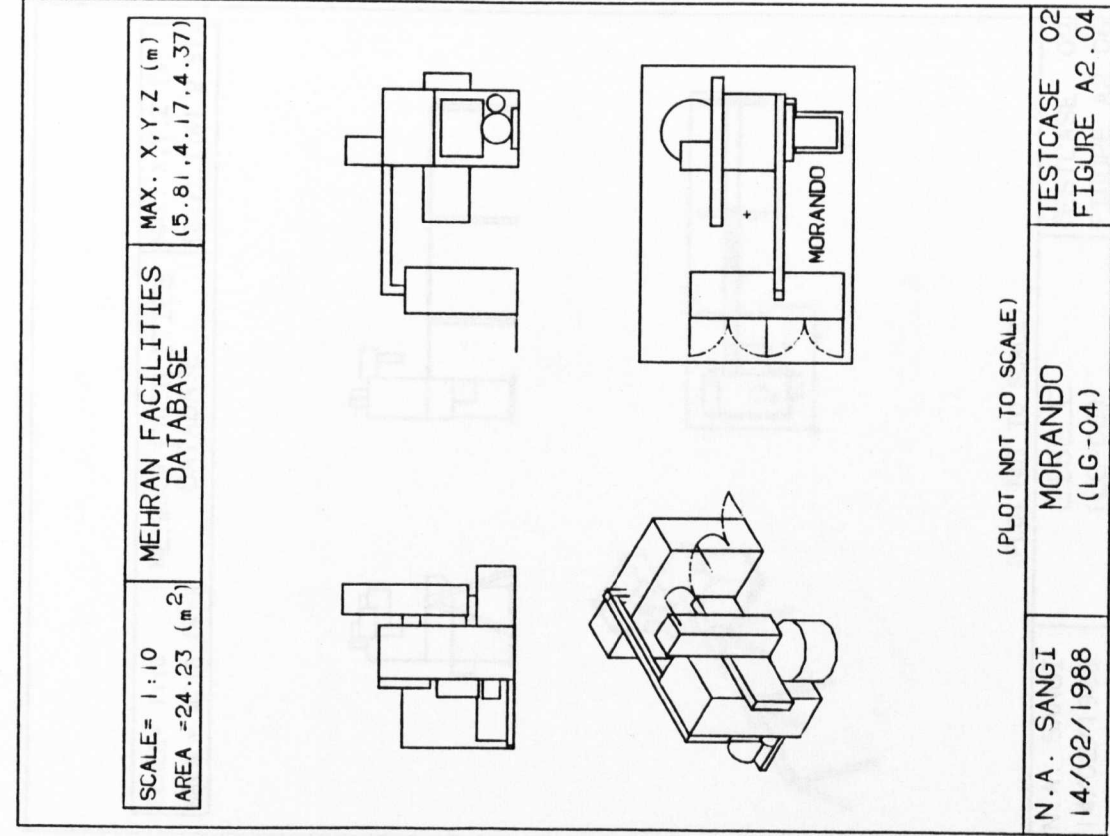
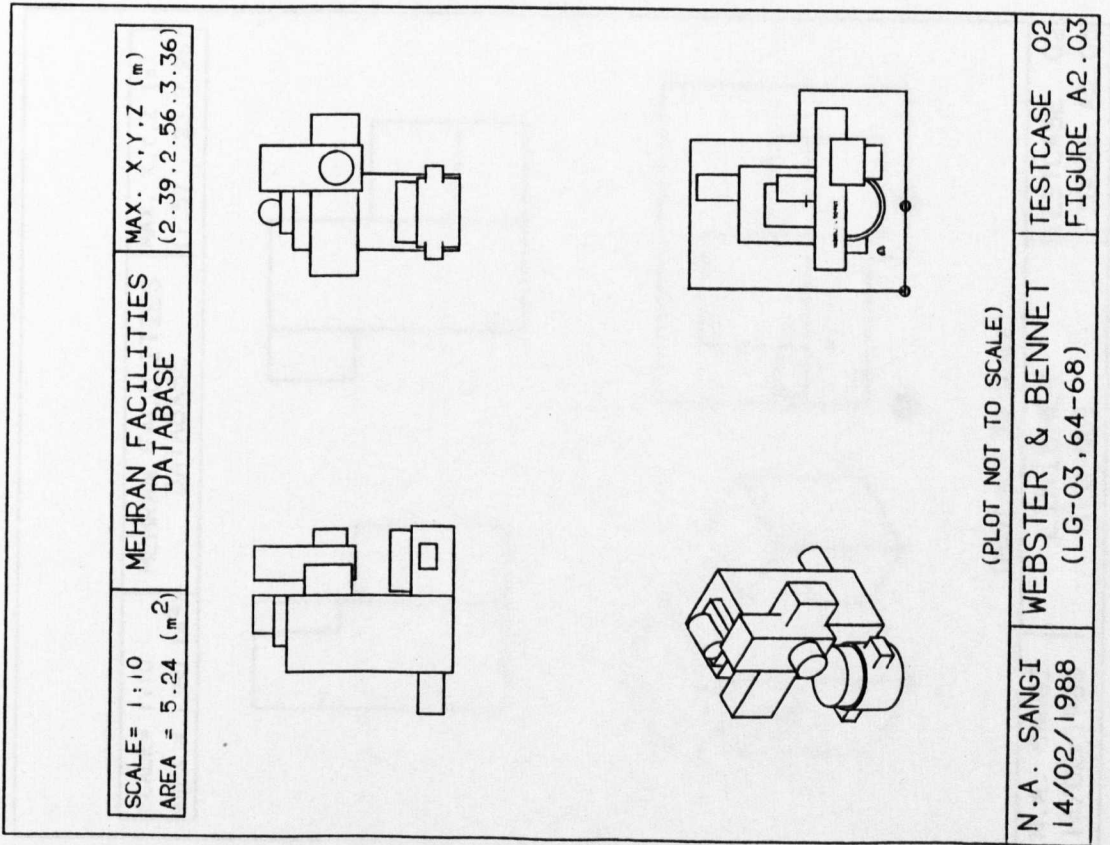
SOLID MODELS ARE HELD IN CATIA.

N.A. SANGI  
14/02/1988

FIVE LEVELS OF FACILITY REPRESENTATION IN CADAM

TESTCASE 02  
FIGURE A1.00

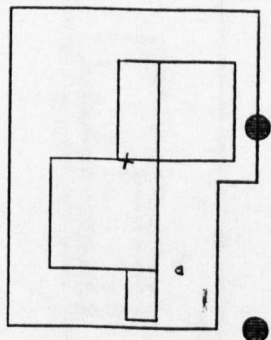
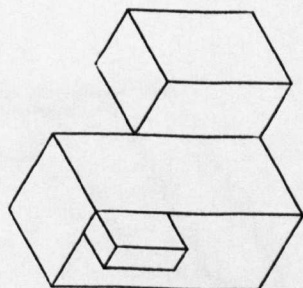
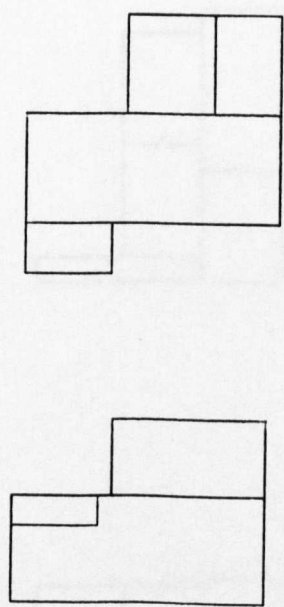




SCALE = 1:10  
 AREA = 1.80 (m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (1.57, 1.23, 2.26)



(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

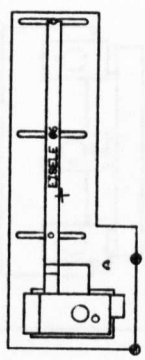
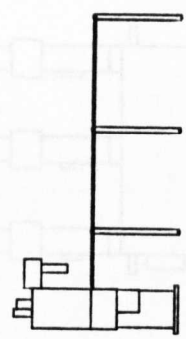
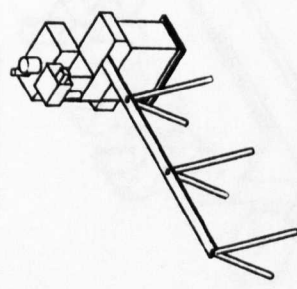
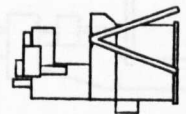
LINISHER  
 (LG-05)

TESTCASE 02  
 FIGURE A2.05

SCALE = 1:10  
 AREA = 4.18 (m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (3.71, 1.41, 2.81)

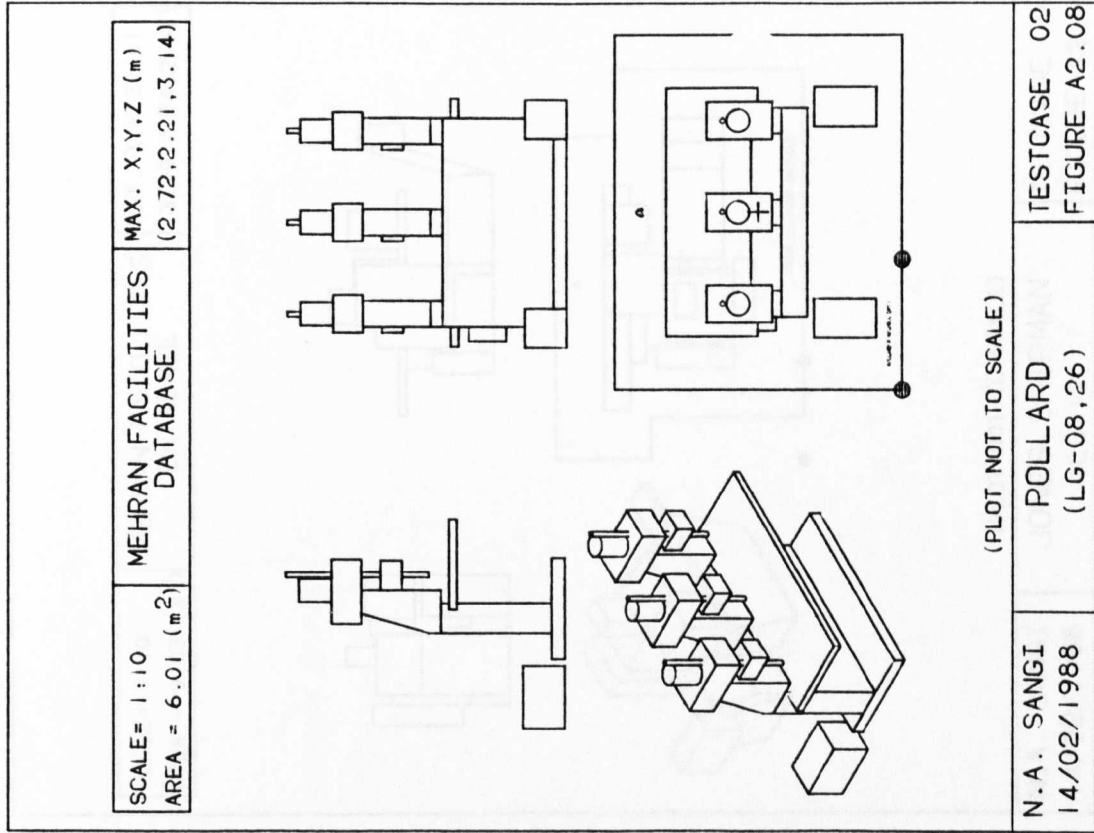
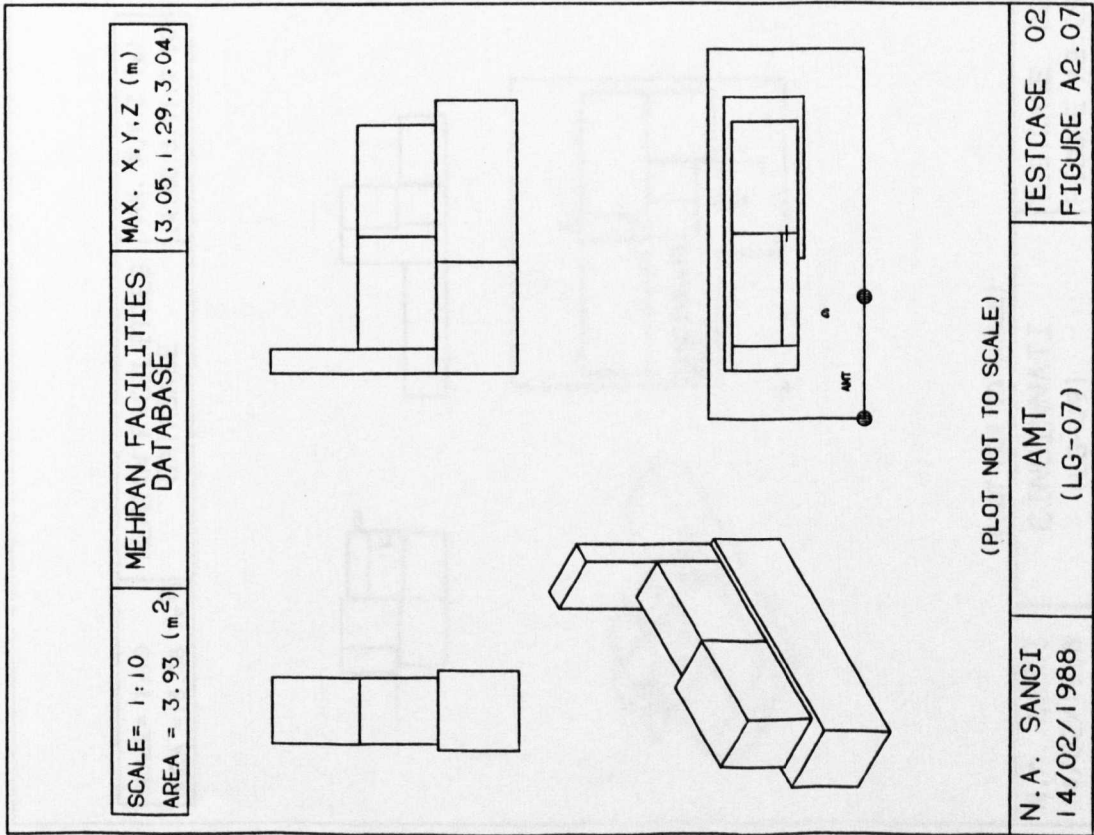


(PLOT NOT TO SCALE)

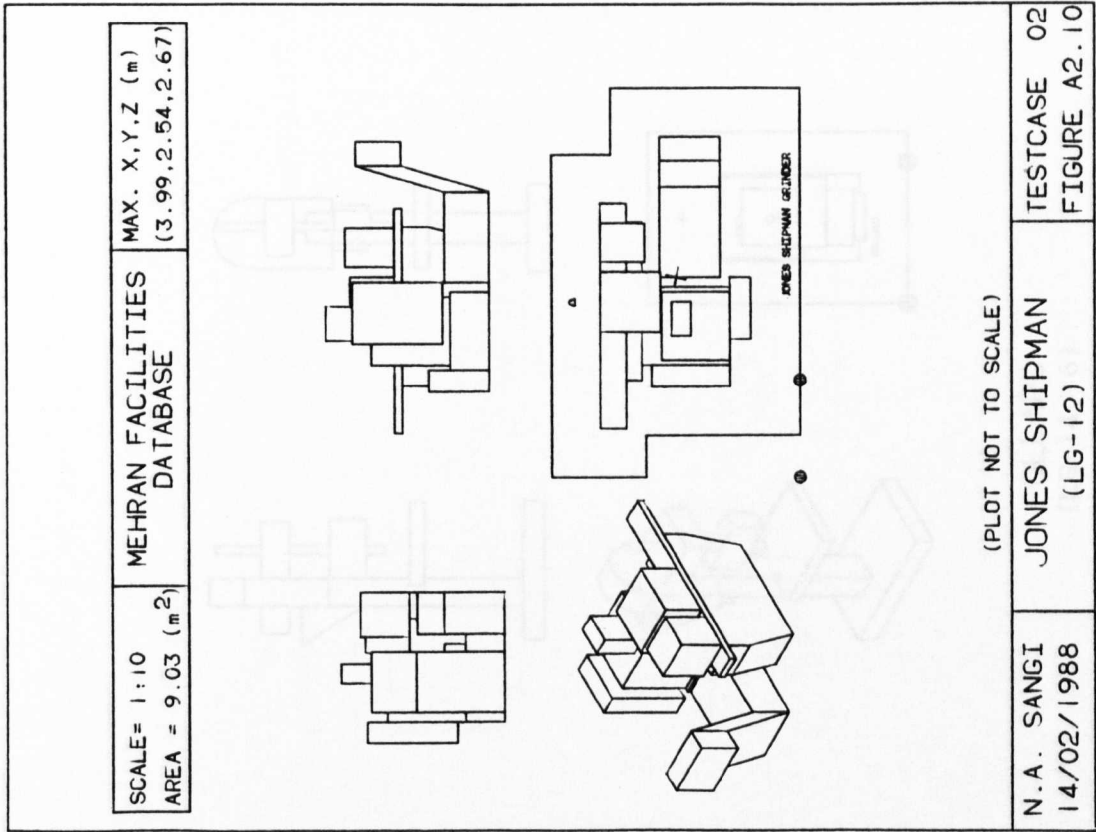
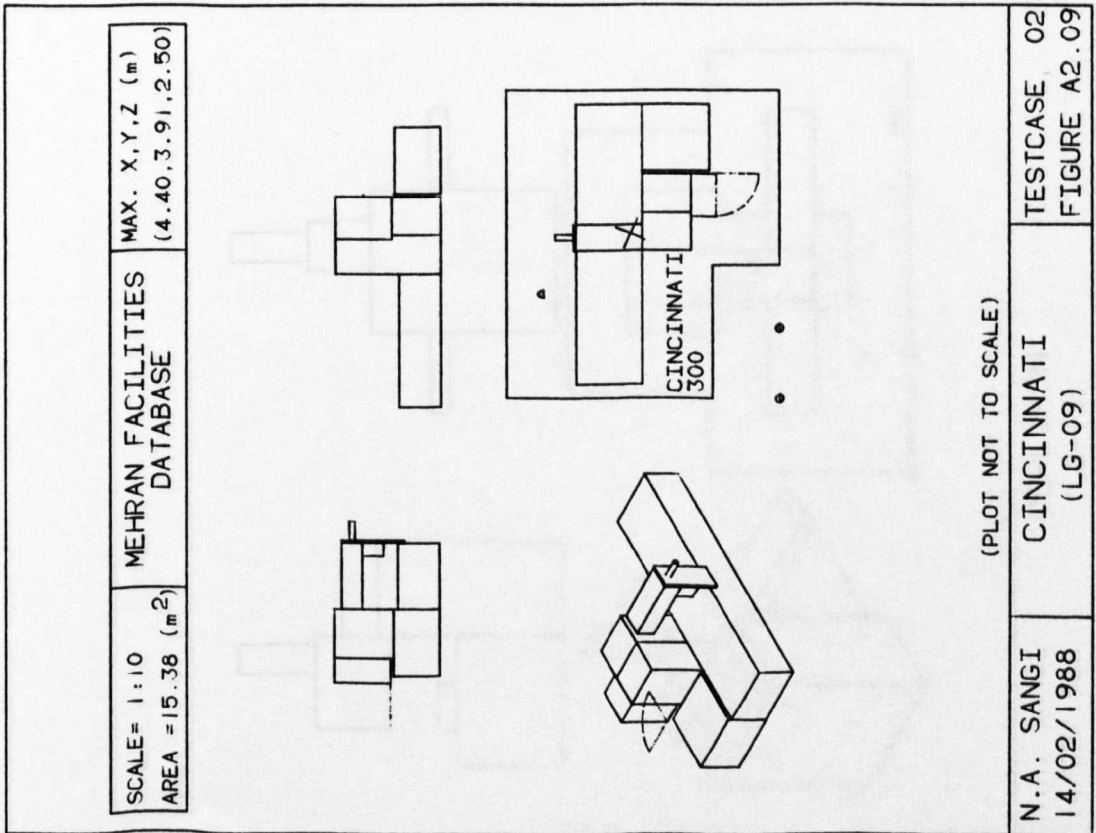
N.A. SANGI  
 14/02/1988

EISELE  
 (LG-06)

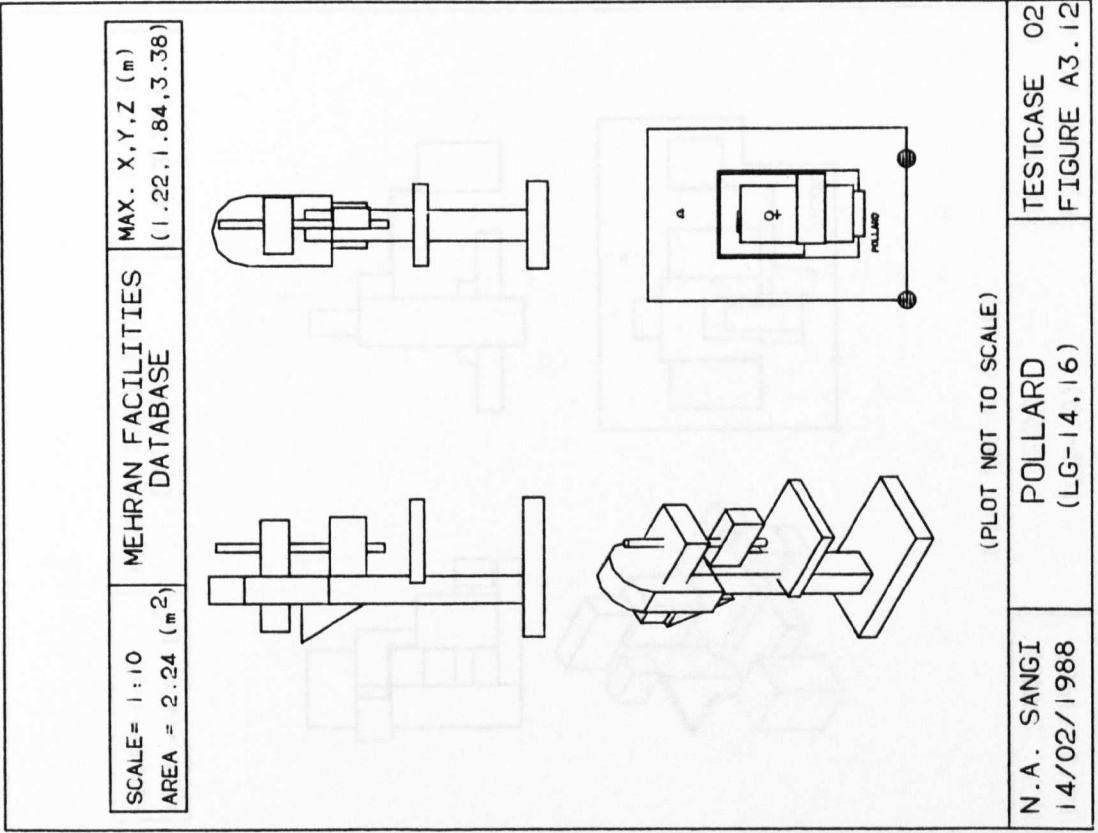
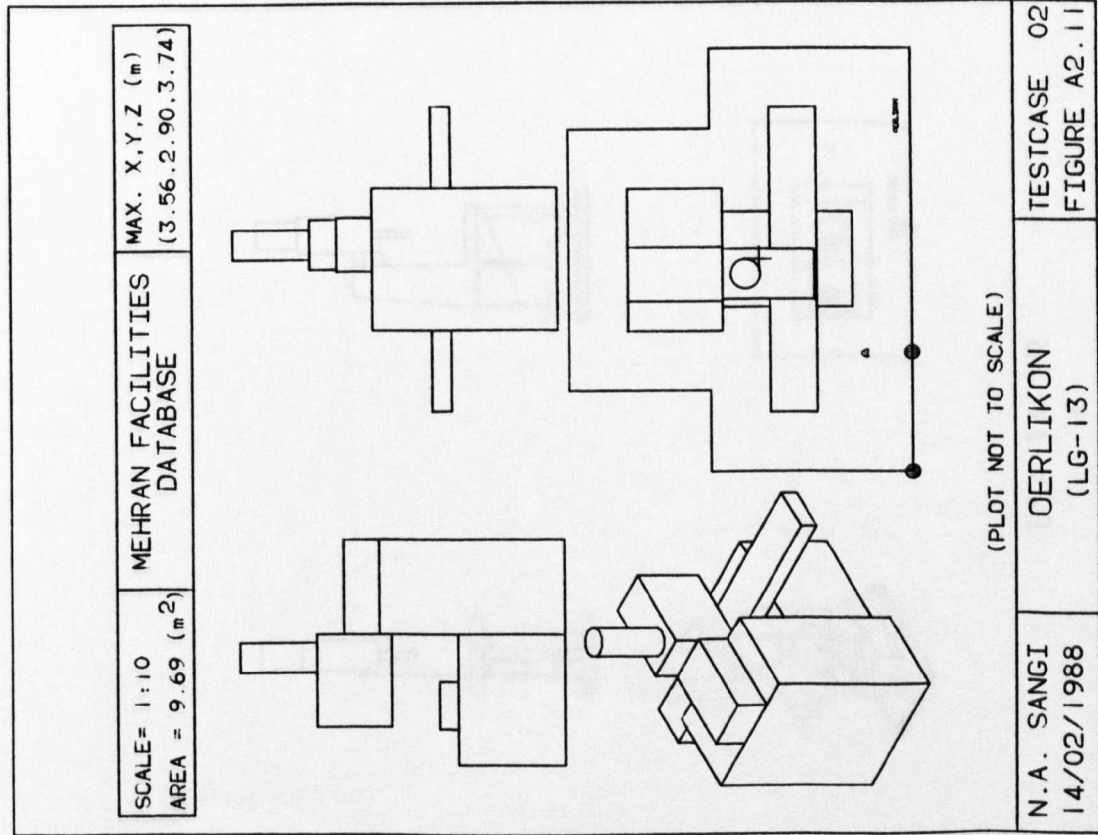
TESTCASE 02  
 FIGURE A2.06

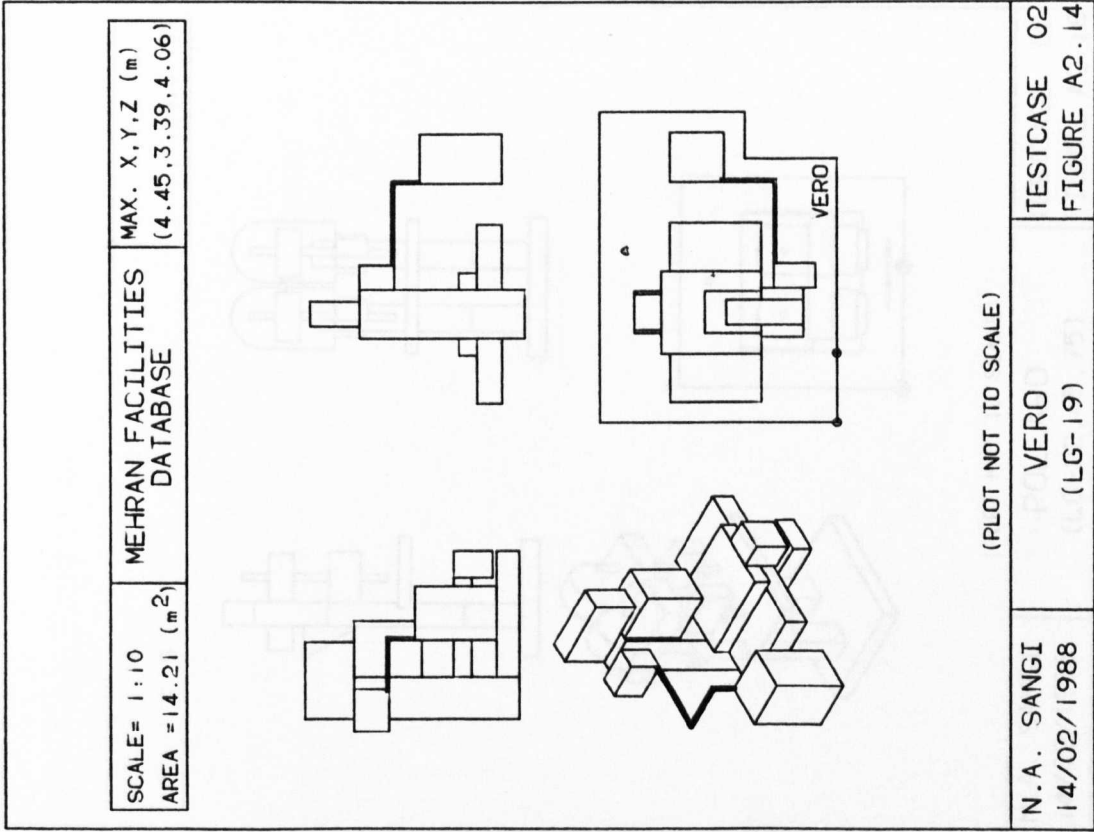
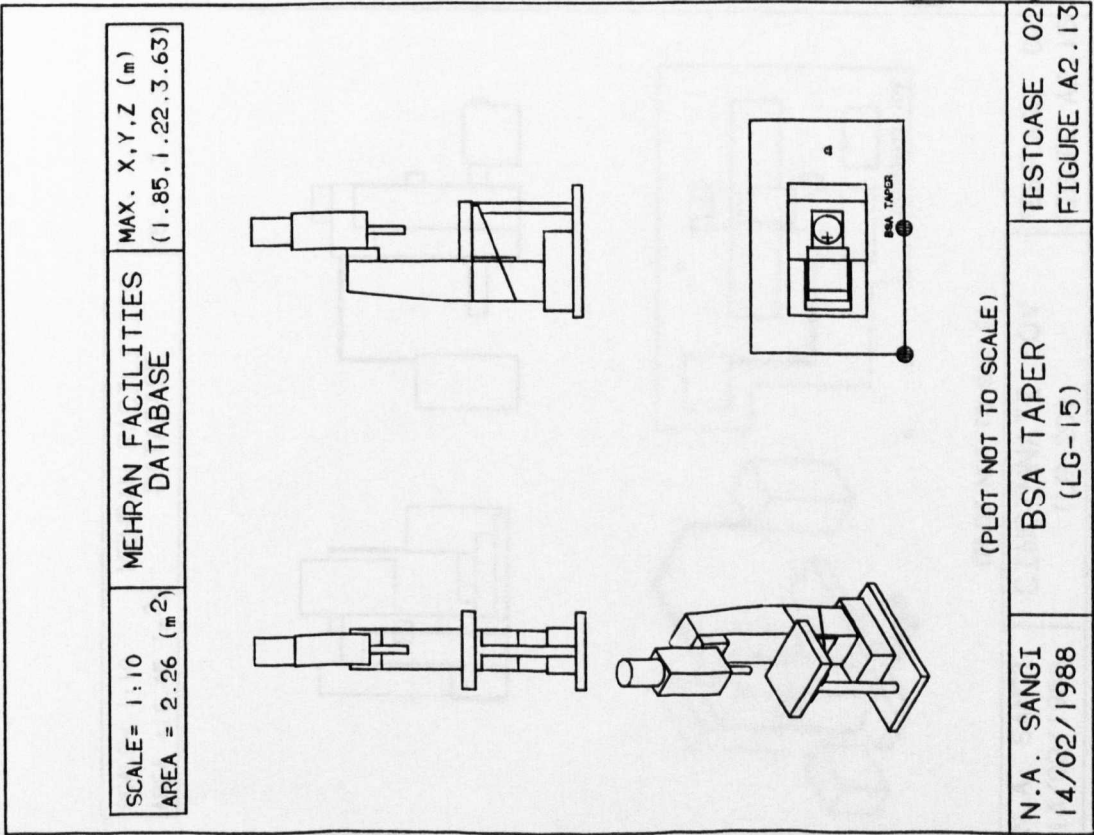








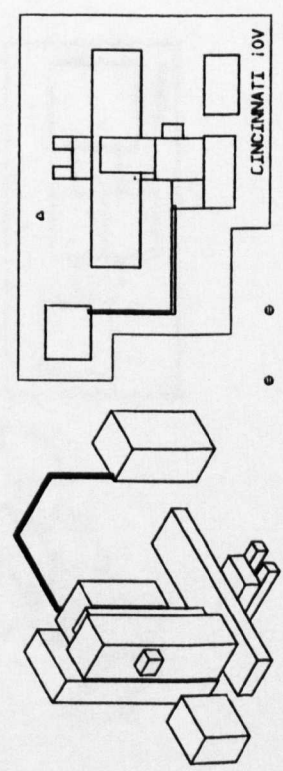
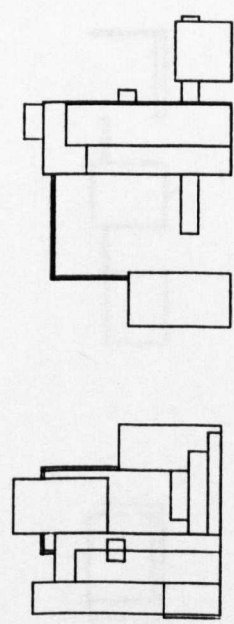




SCALE= 1:10  
 AREA = 16.45 (m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (5.21, 3.60, 3.96)



(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

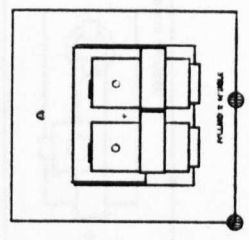
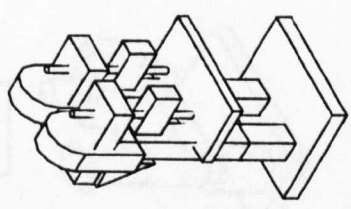
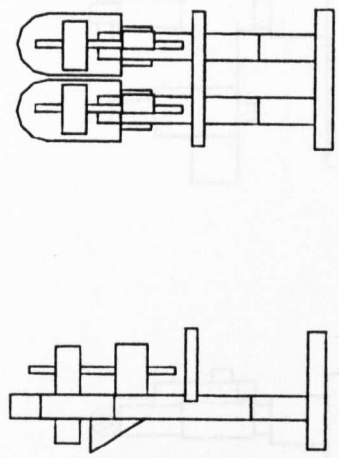
CINCINNATI 10V  
 (LG-20)

TESTCASE 02  
 FIGURE A2.15

SCALE= 1:10  
 AREA = 3.15 (m<sup>2</sup>)

MEHRAN FACILITIES  
 DATABASE

MAX. X,Y,Z (m)  
 (1.72, 1.83, 3.15)

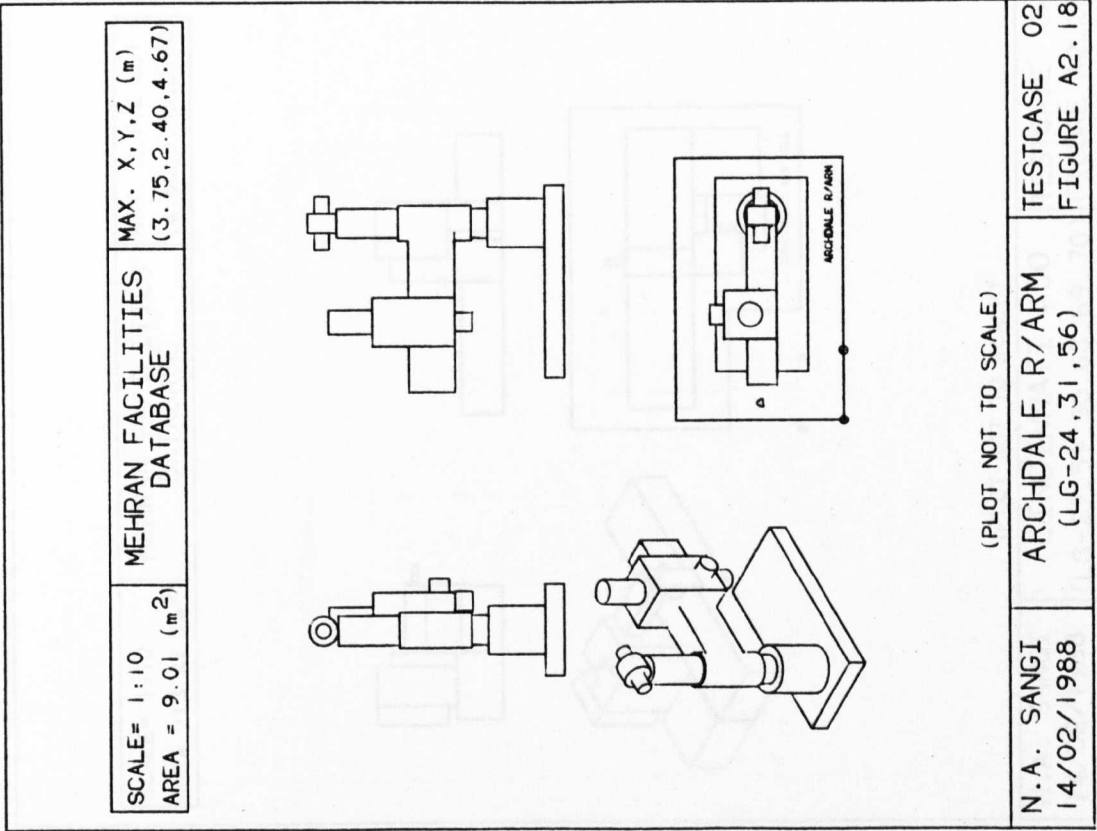
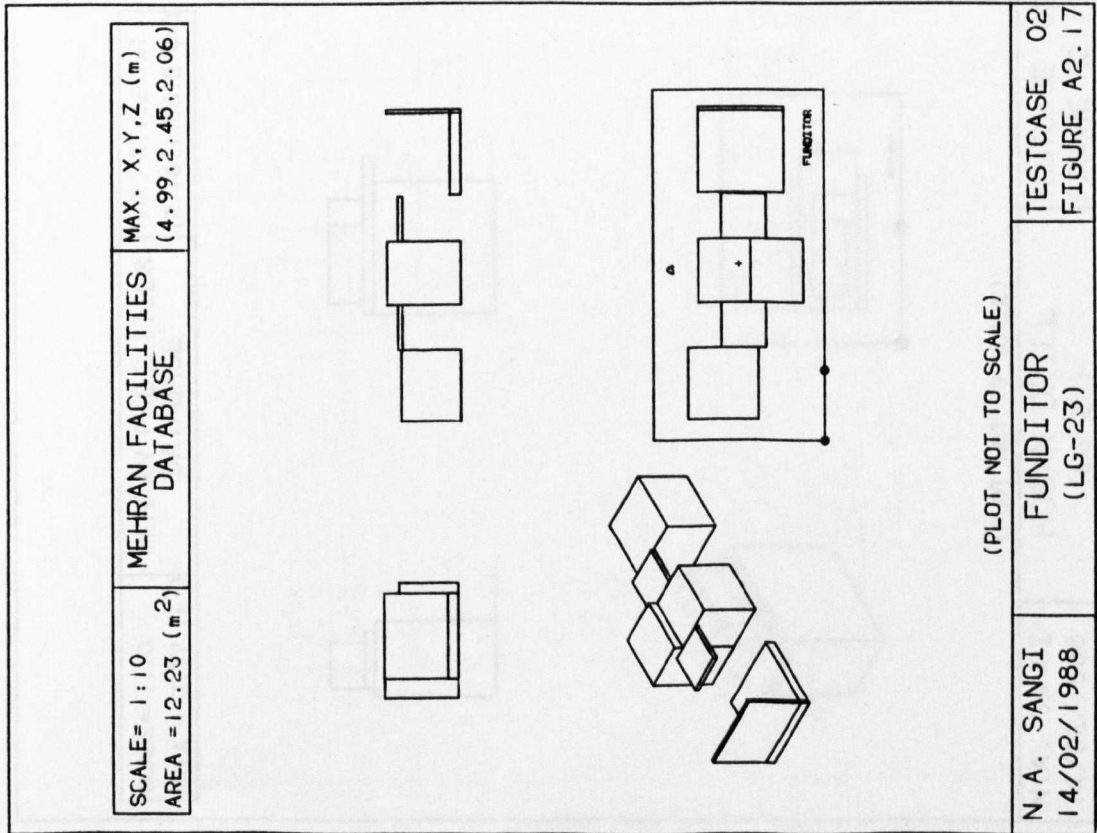


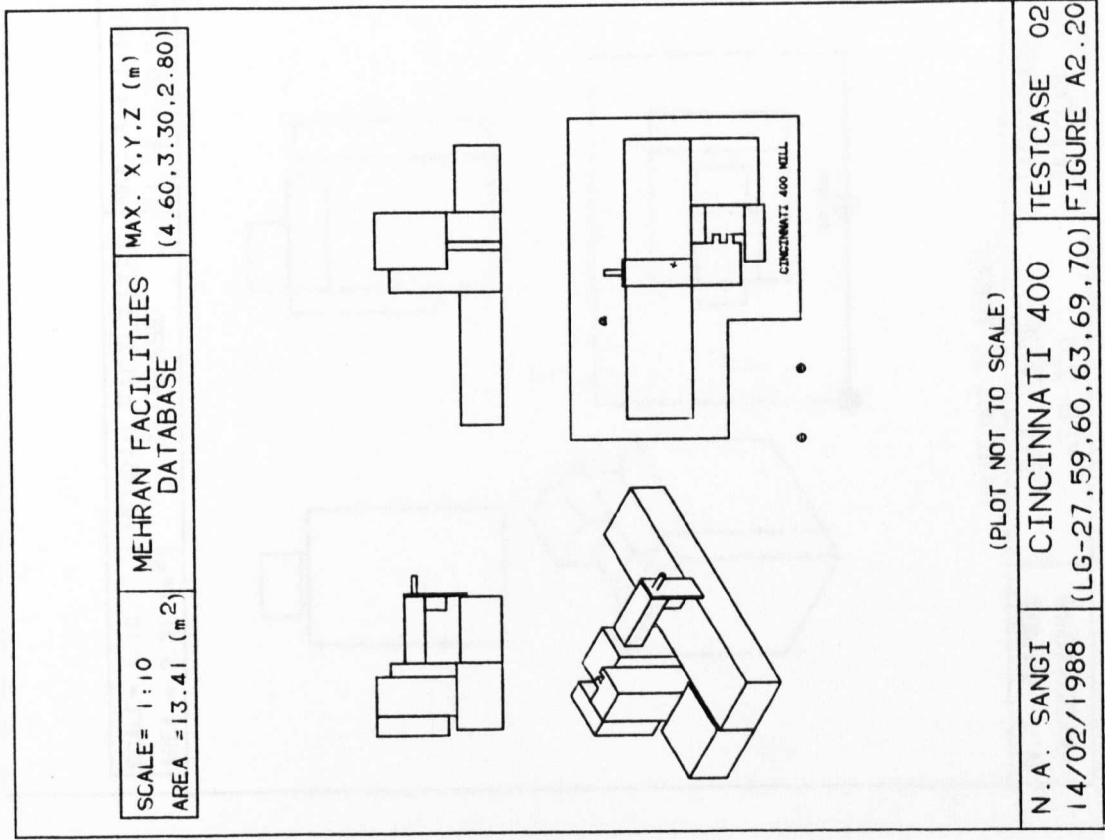
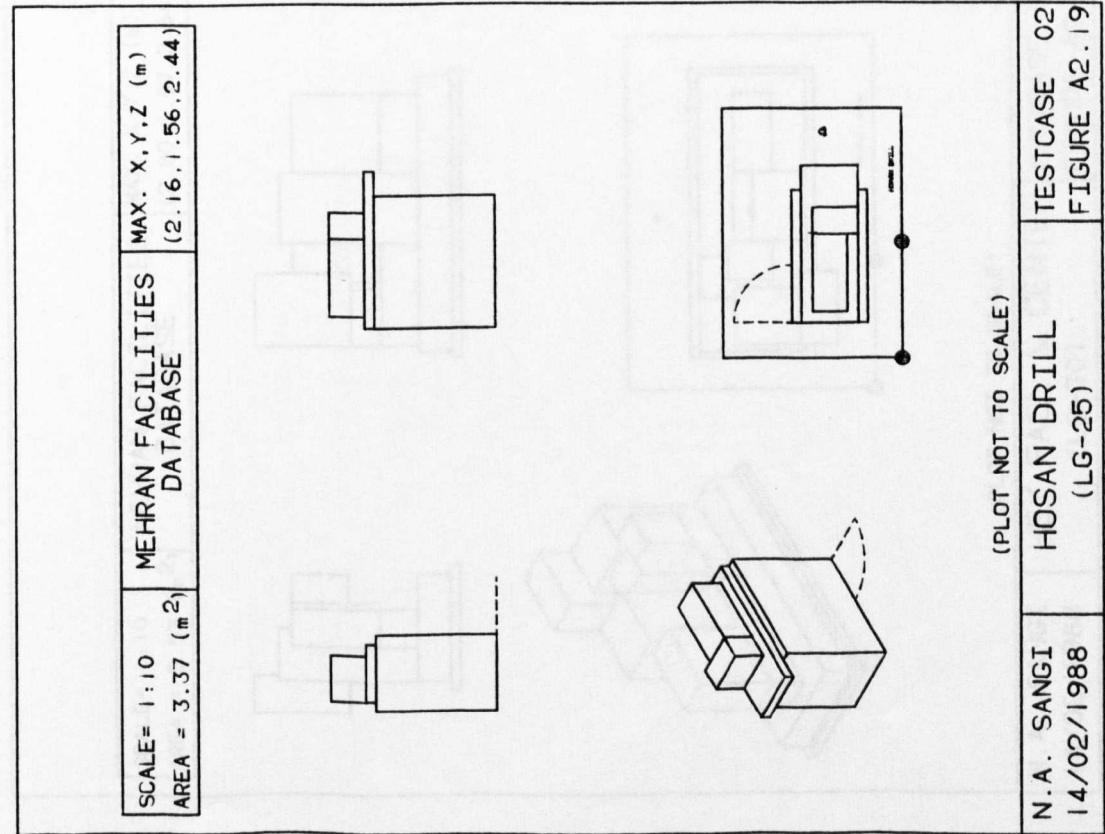
(PLOT NOT TO SCALE)

N.A. SANGI  
 14/02/1988

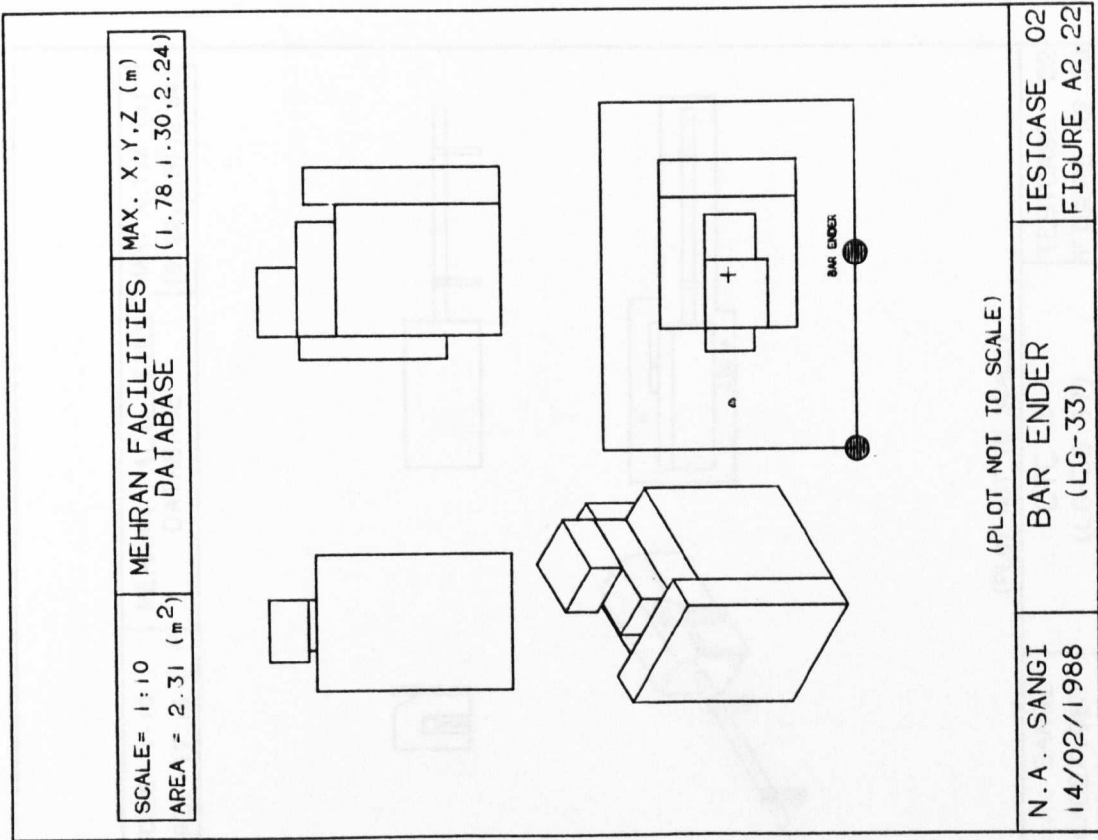
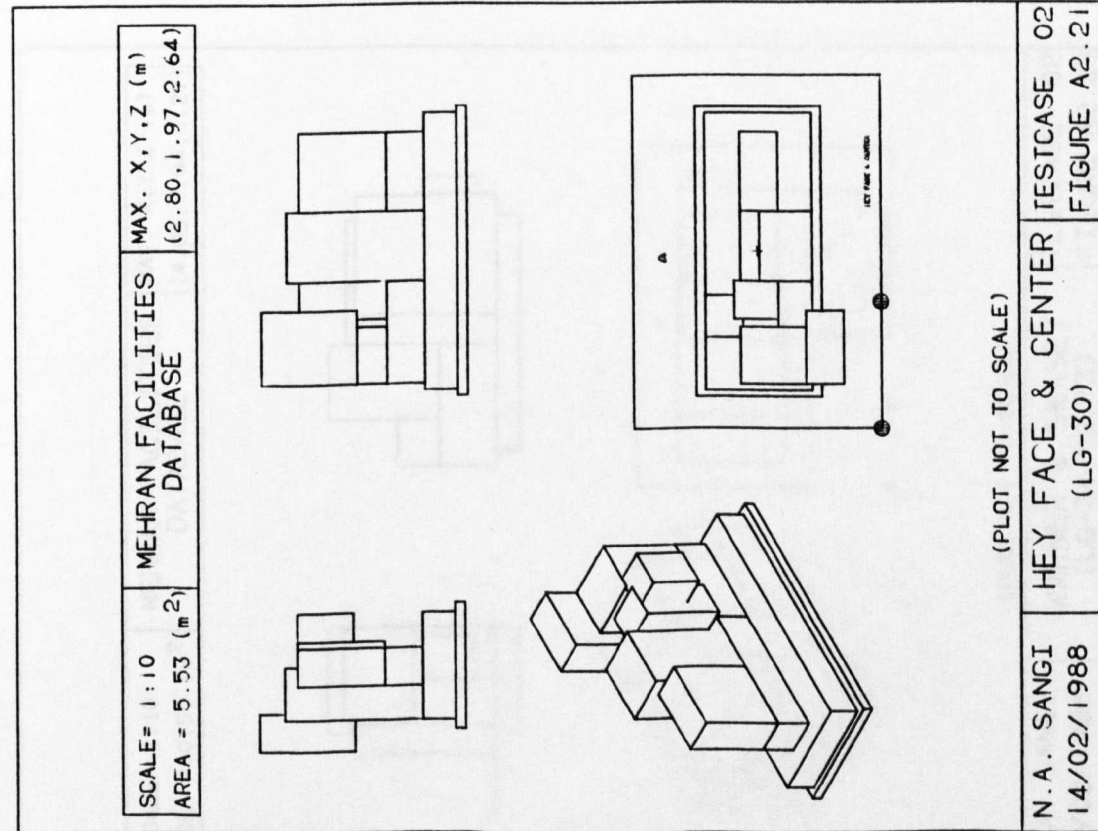
POLLARD  
 (LG-22, 45, 75)

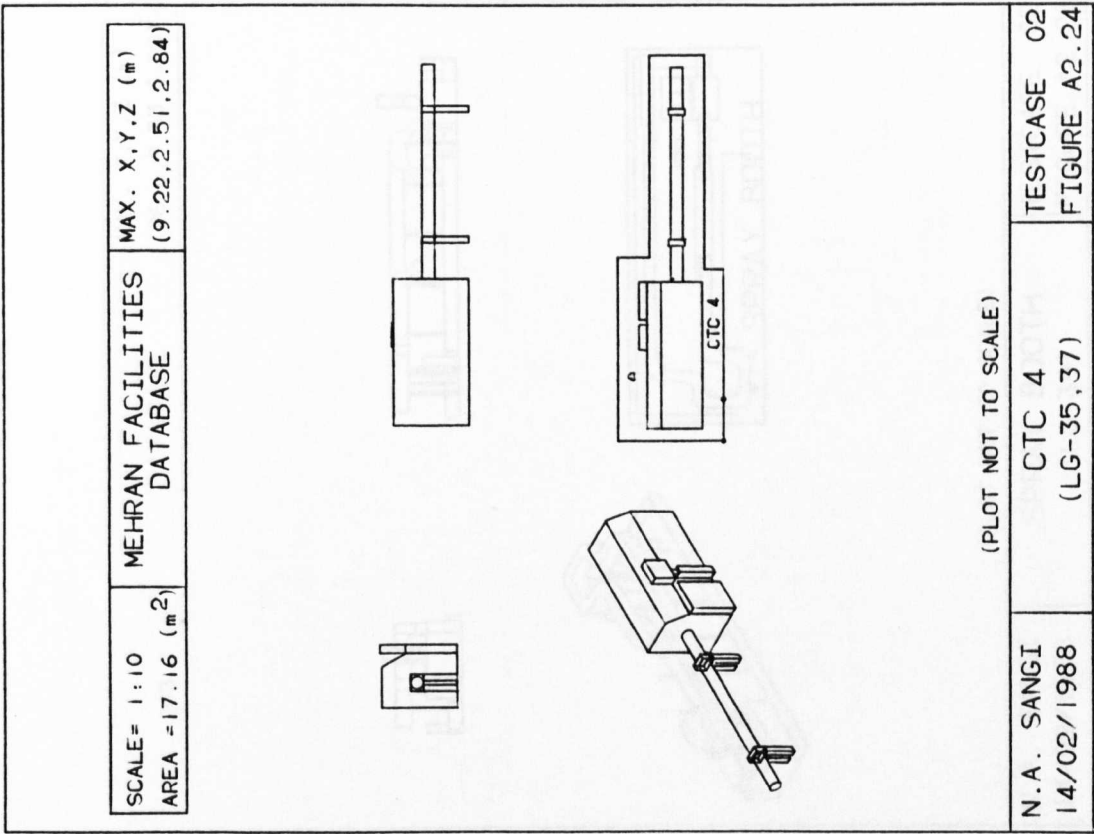
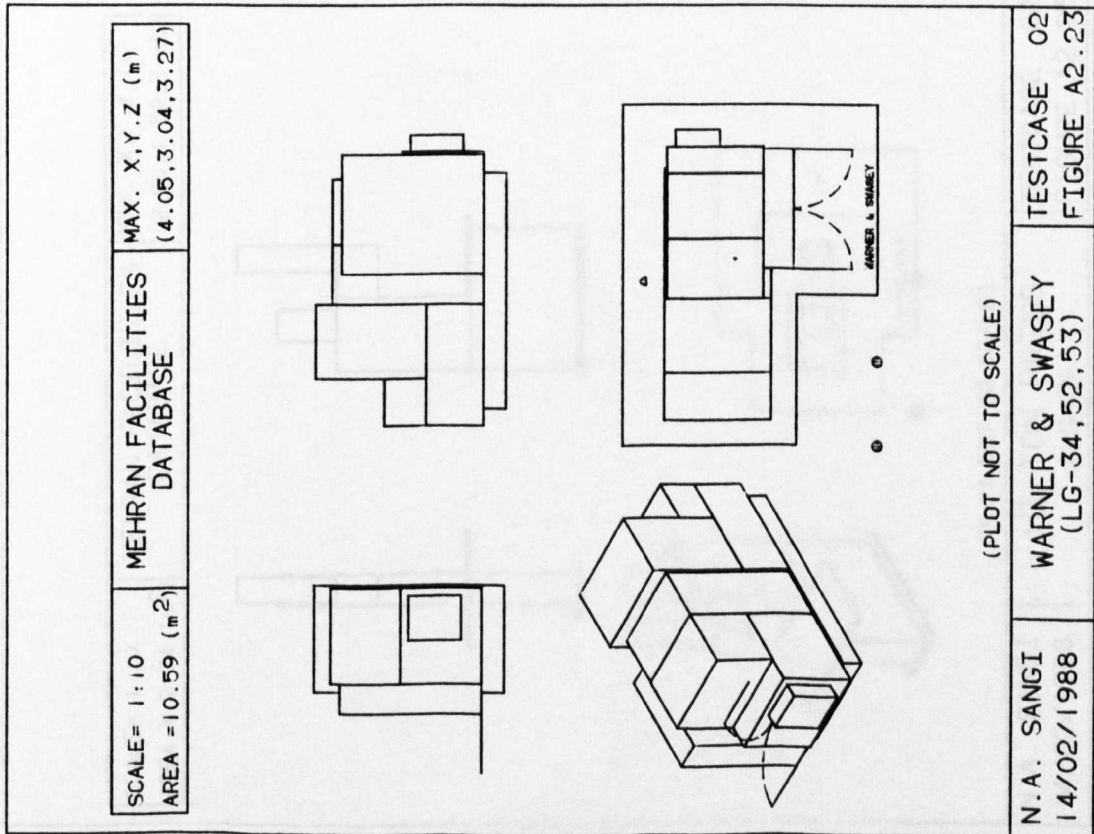
TESTCASE 02  
 FIGURE A2.16







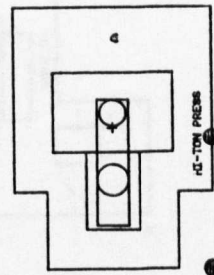
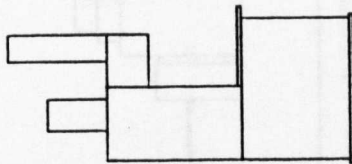
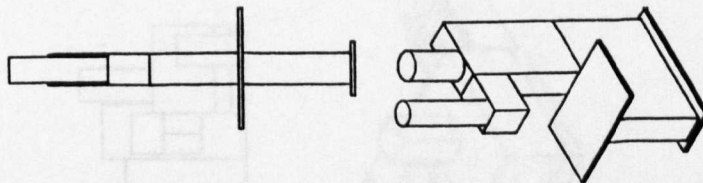




SCALE= 1:10  
AREA = 2.74 (m<sup>2</sup>)

MEHRAN FACILITIES  
DATABASE

MAX. X,Y,Z (m)  
(2.00, 1.52, 3.65)



(PLOT NOT TO SCALE)

N.A. SANGI  
14/02/1988

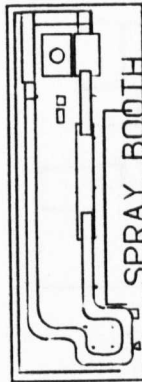
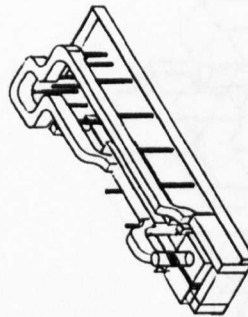
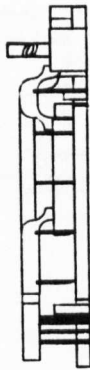
HI-TON PRESS  
(LG-36)

TESTCASE 02  
FIGURE A2.25

SCALE= 1:10  
AREA = 253.3 (m<sup>2</sup>)

MEHRAN FACILITIES  
DATABASE

MAX. X,Y,Z (m)  
(26.6, 9.53, 5.00)



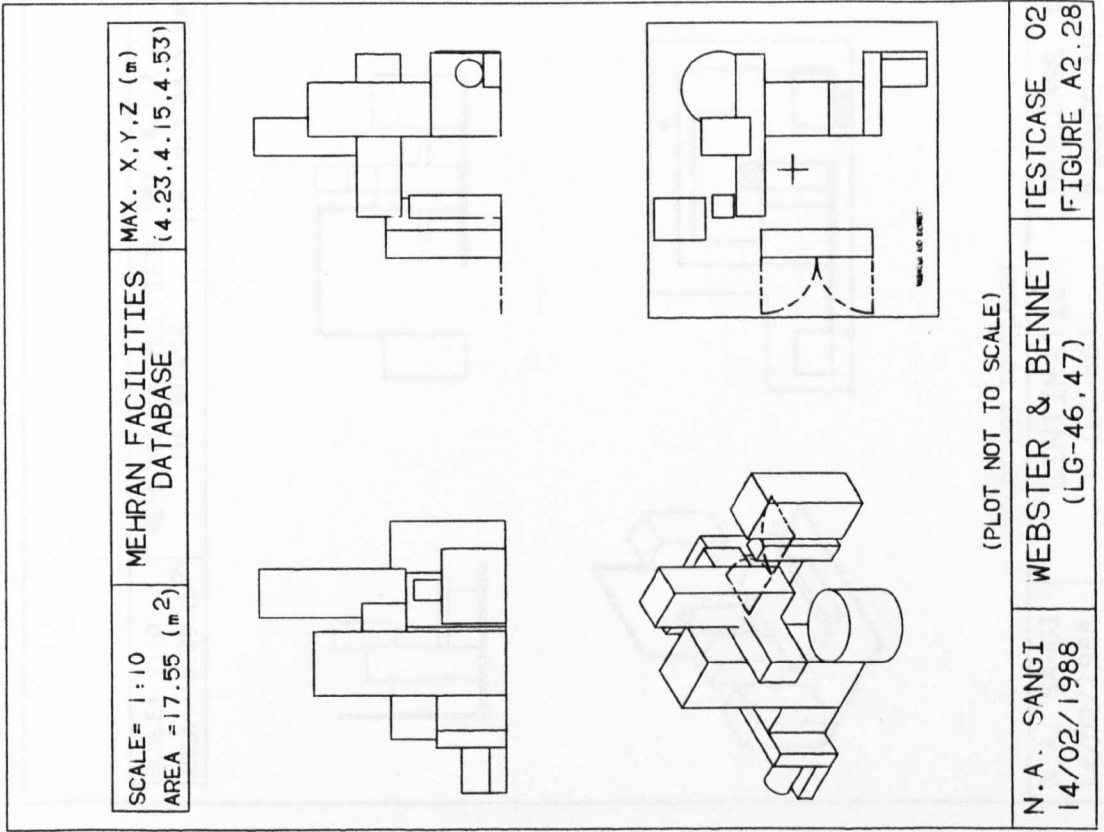
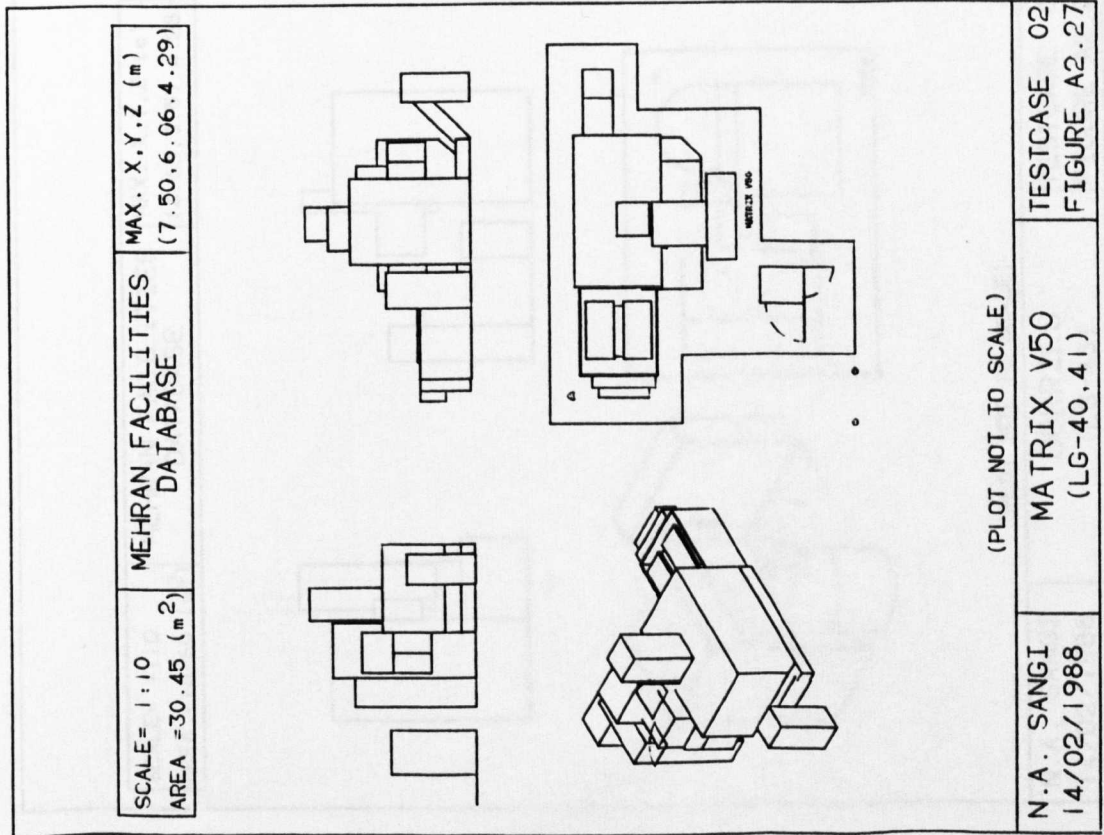
(PLOT NOT TO SCALE)

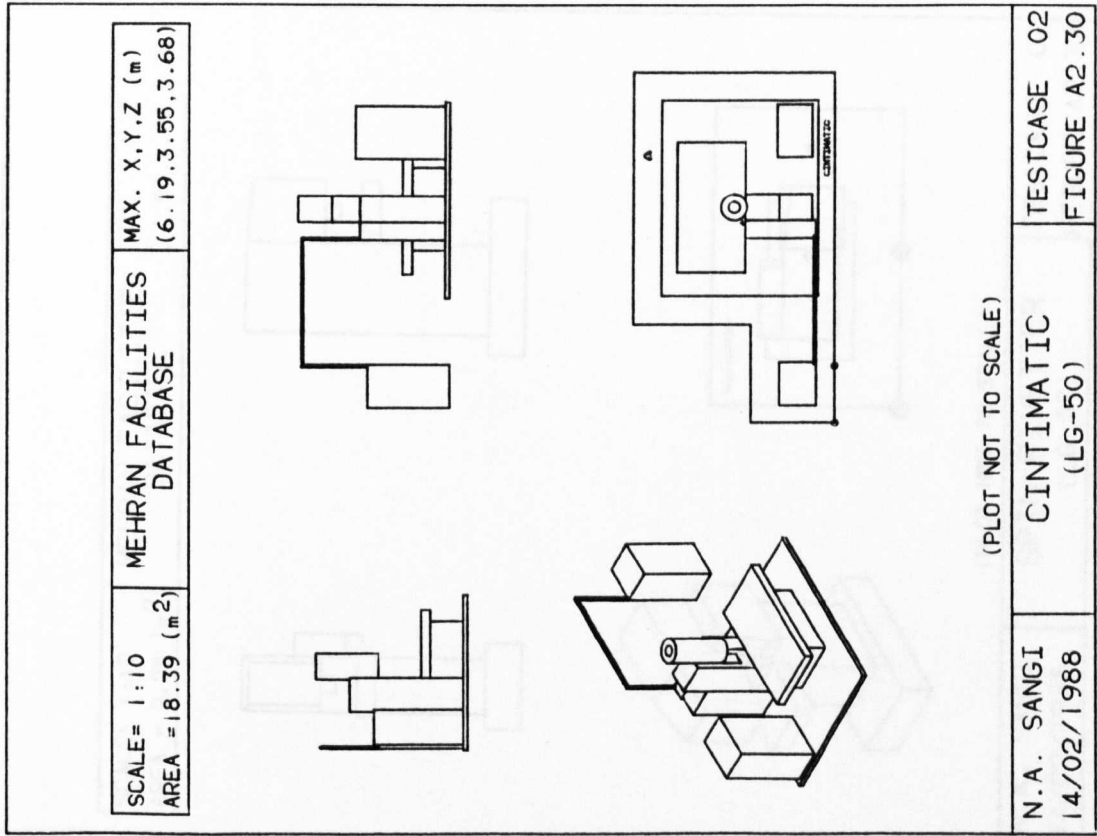
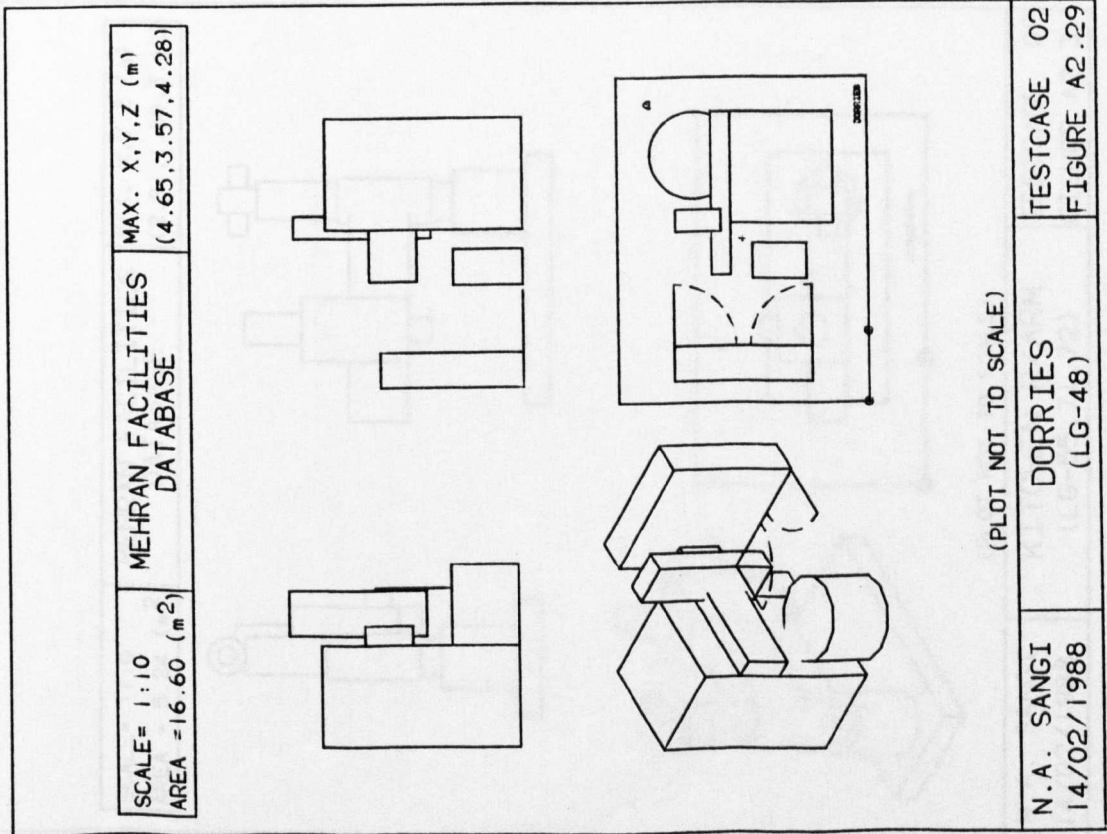
N.A. SANGI  
14/02/1988

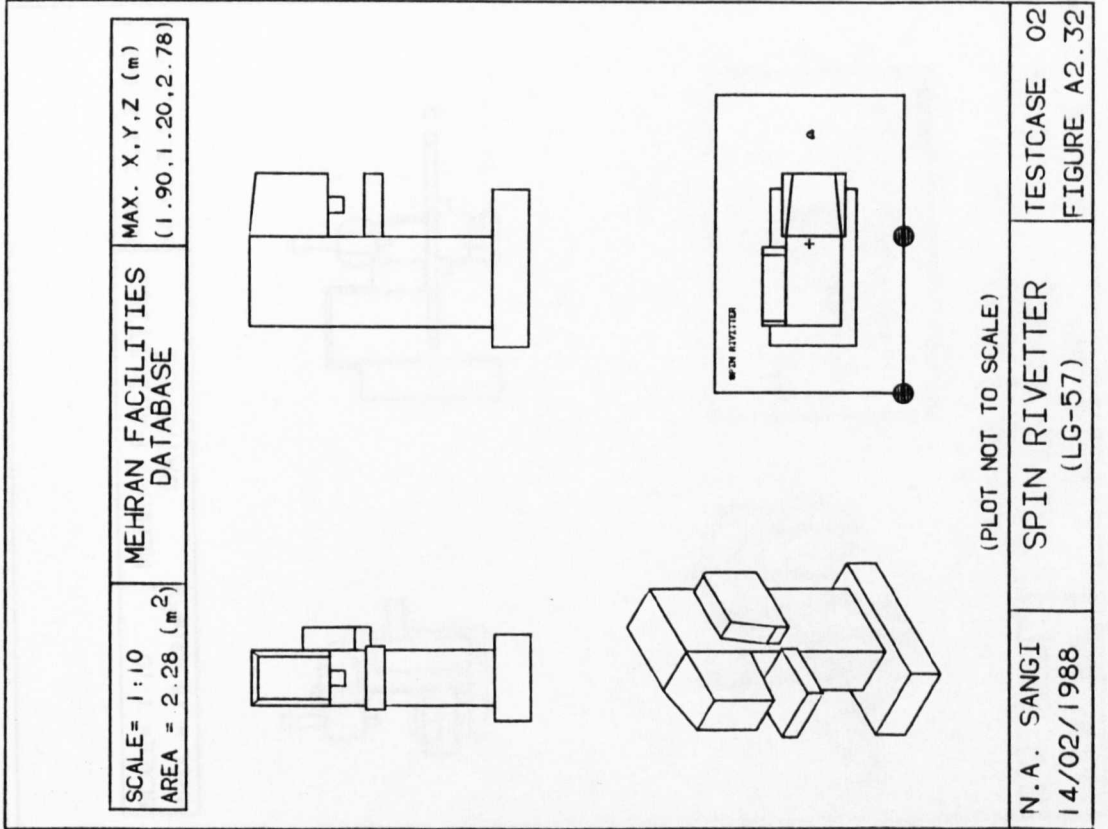
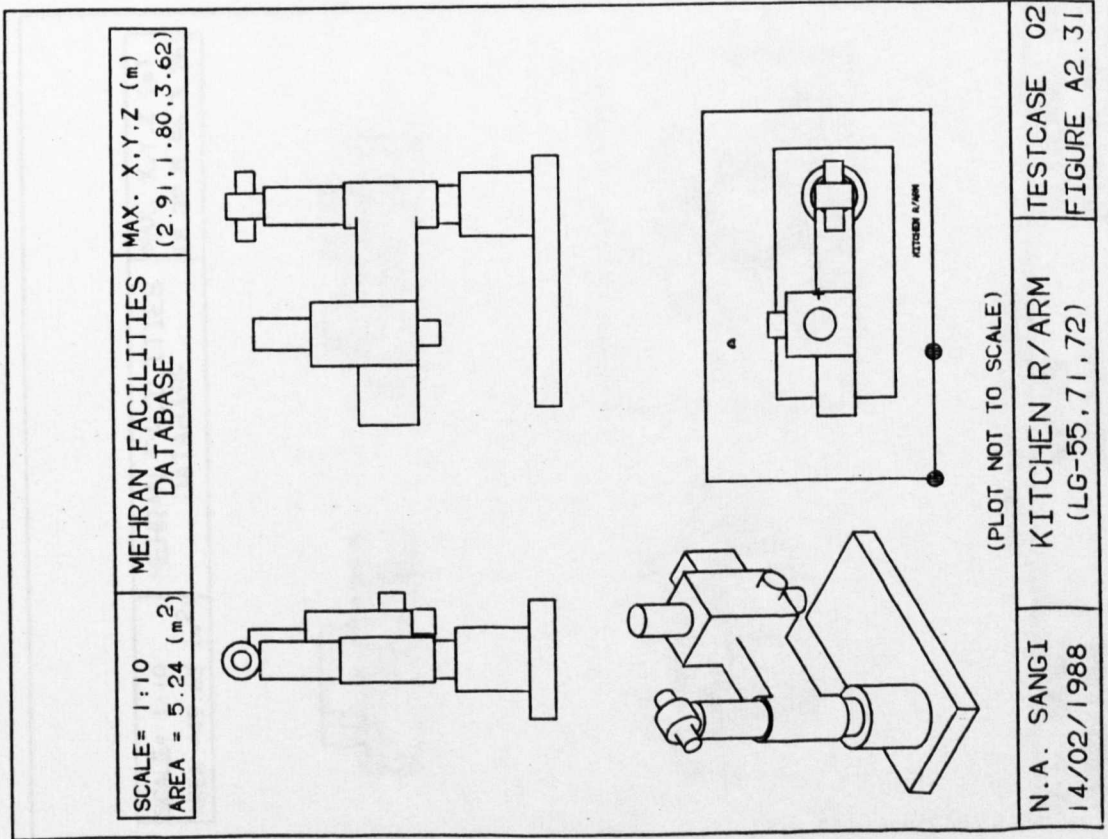
SPRAY BOOTH  
(LG-39)

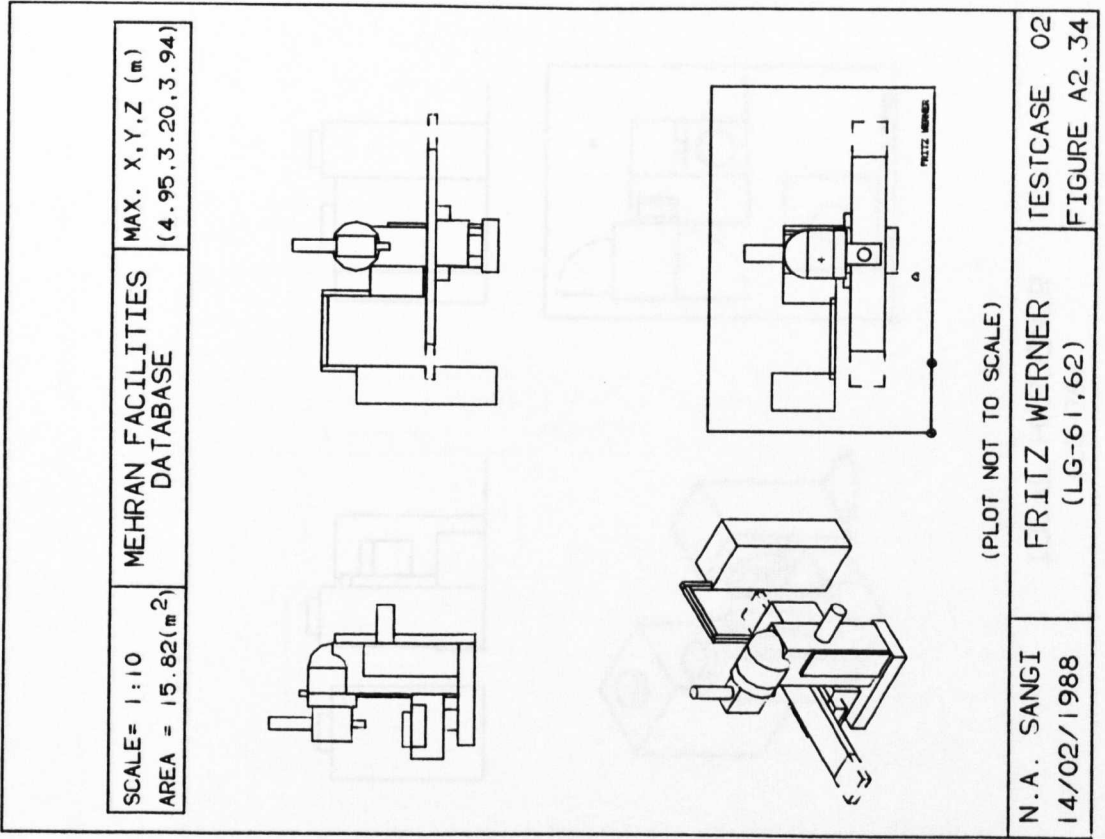
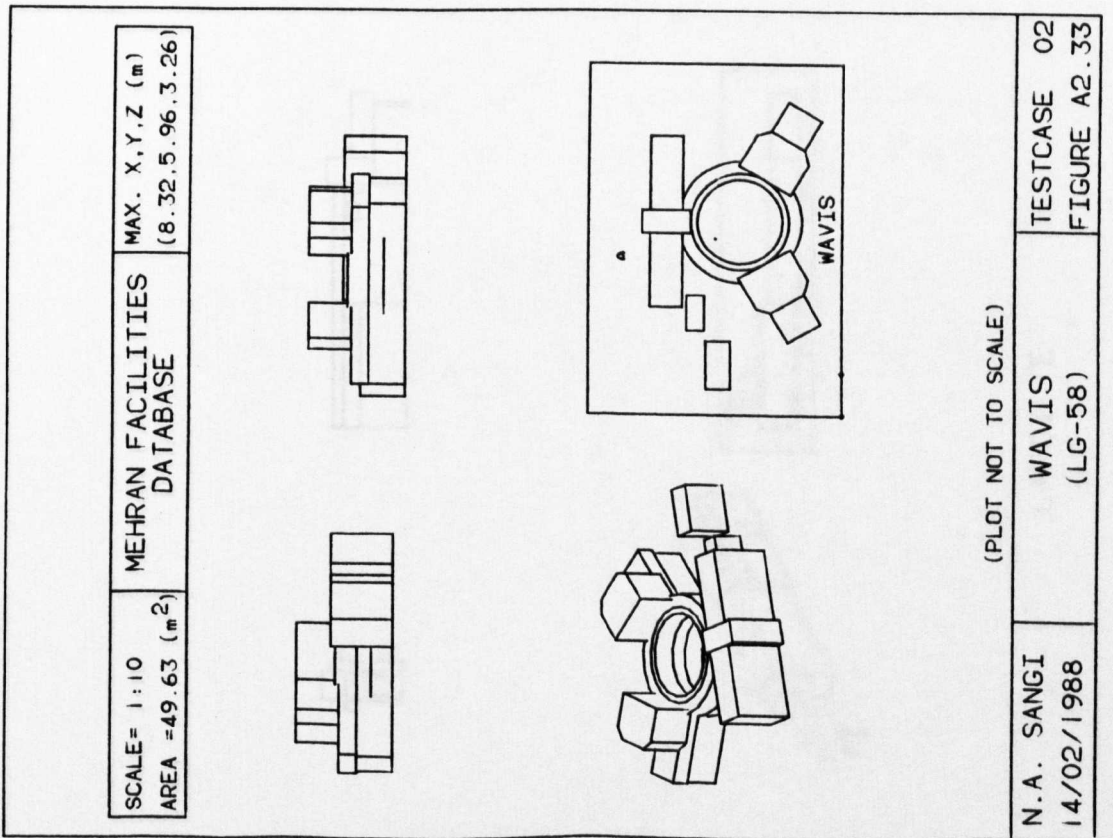
TESTCASE 02  
FIGURE A2.26

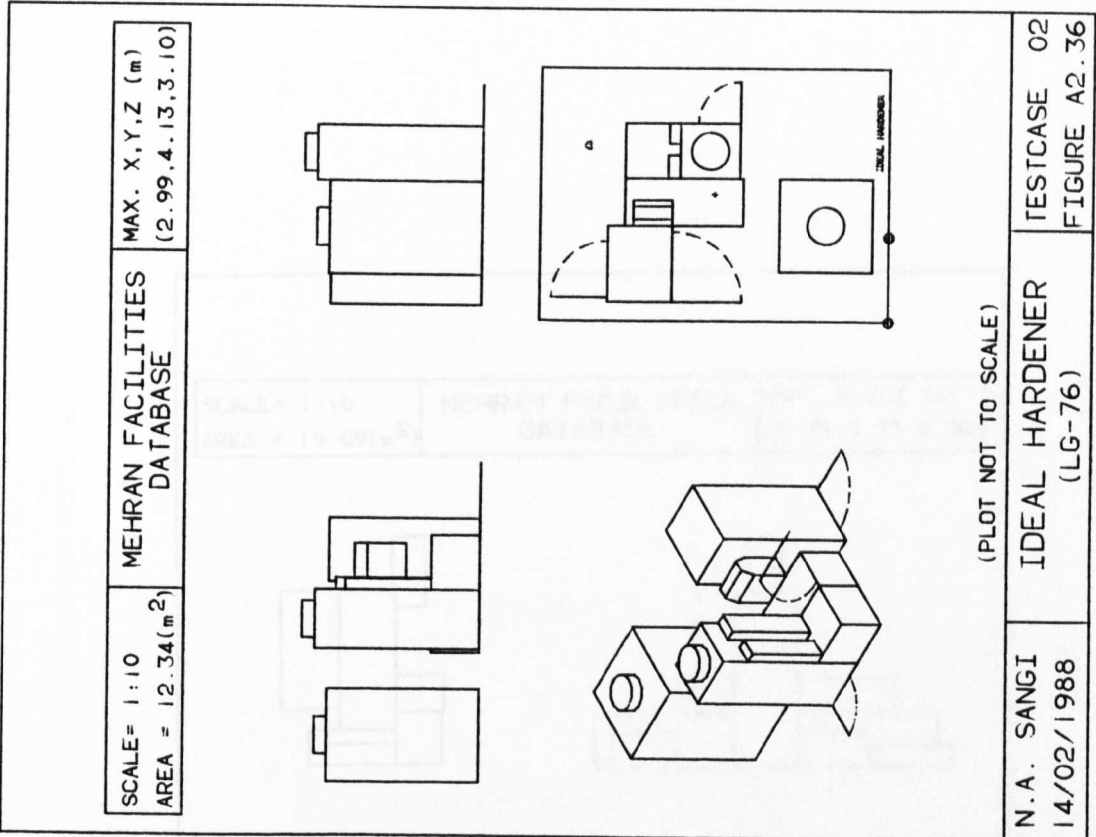
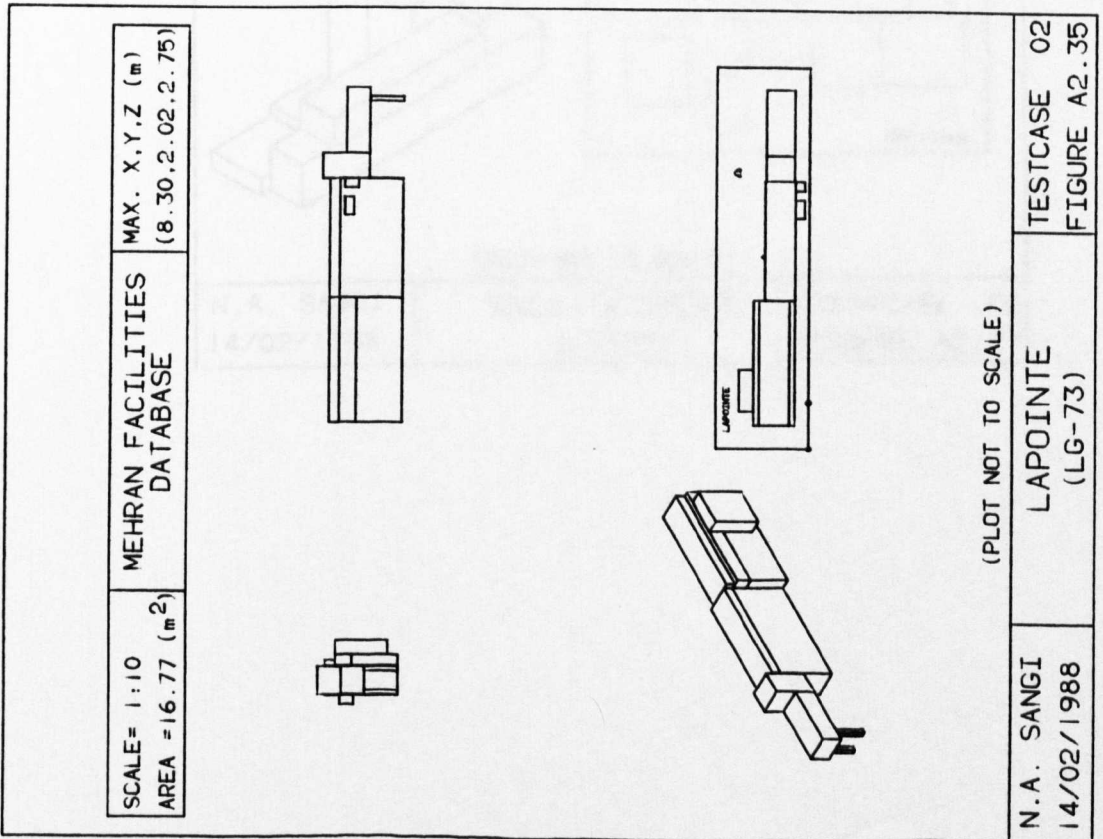






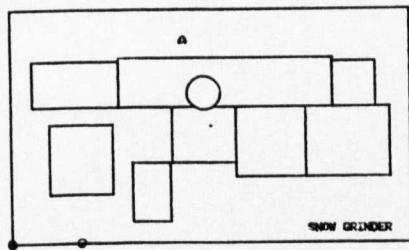
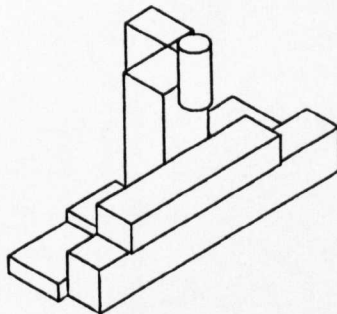
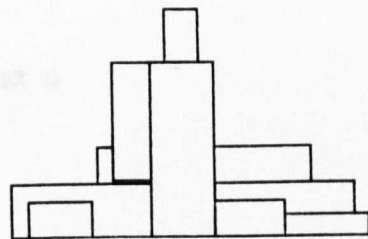
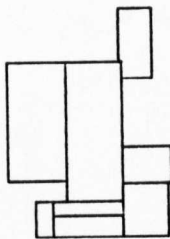








SCALE = 1:10 AREA = 19.09(m <sup>2</sup> )	MEHRAN FACILITIES DATABASE	MAX. X,Y,Z (m) (5.70,3.35,4.26)
---	-------------------------------	------------------------------------



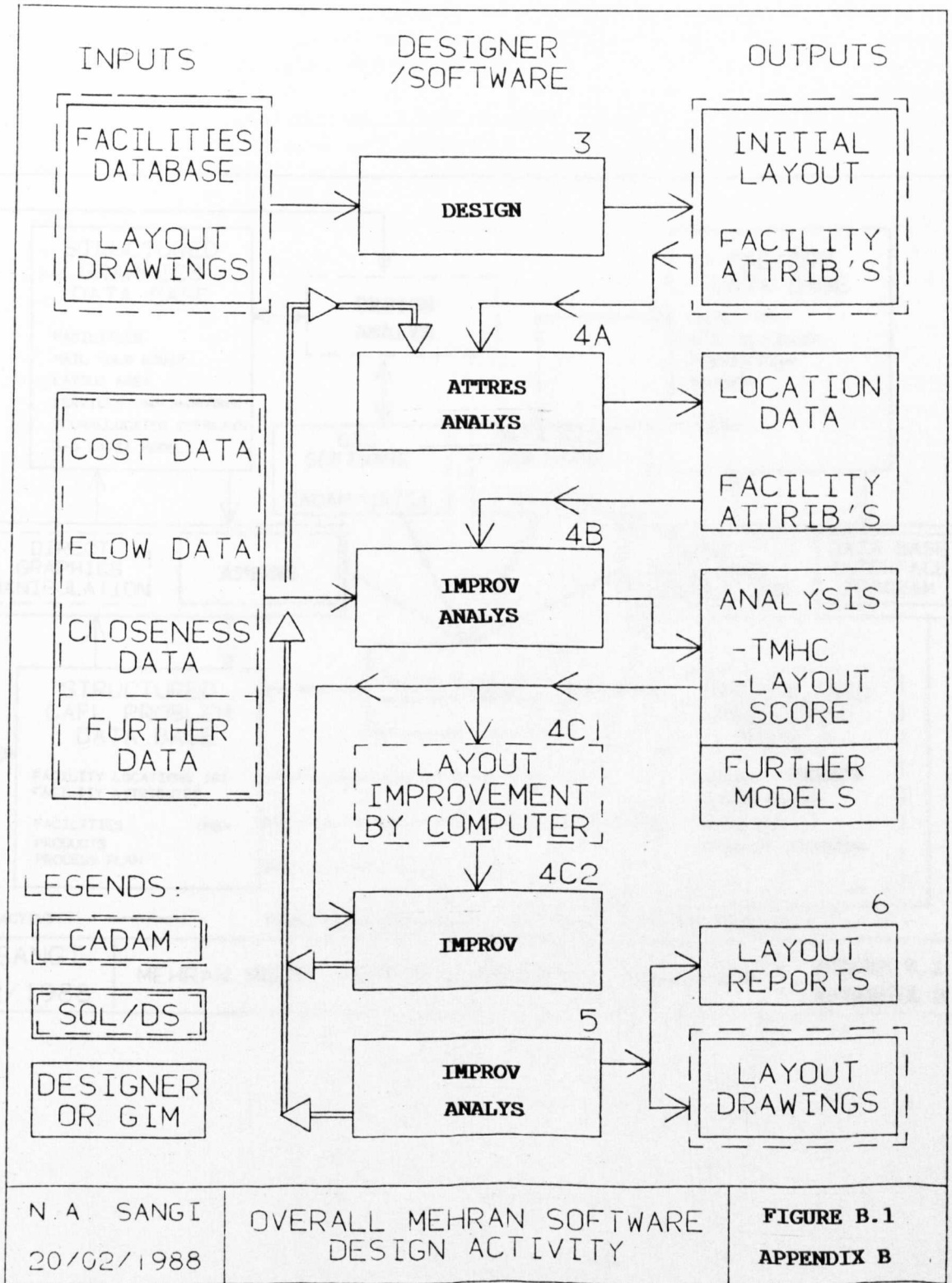
(PLOT NOT TO SCALE)

N.A. SANGI 14/02/1988	SNOW GRINDER (LG-77)	TESTCASE 02 FIGURE A2.37
--------------------------	-------------------------	-----------------------------

**APPENDIX B**

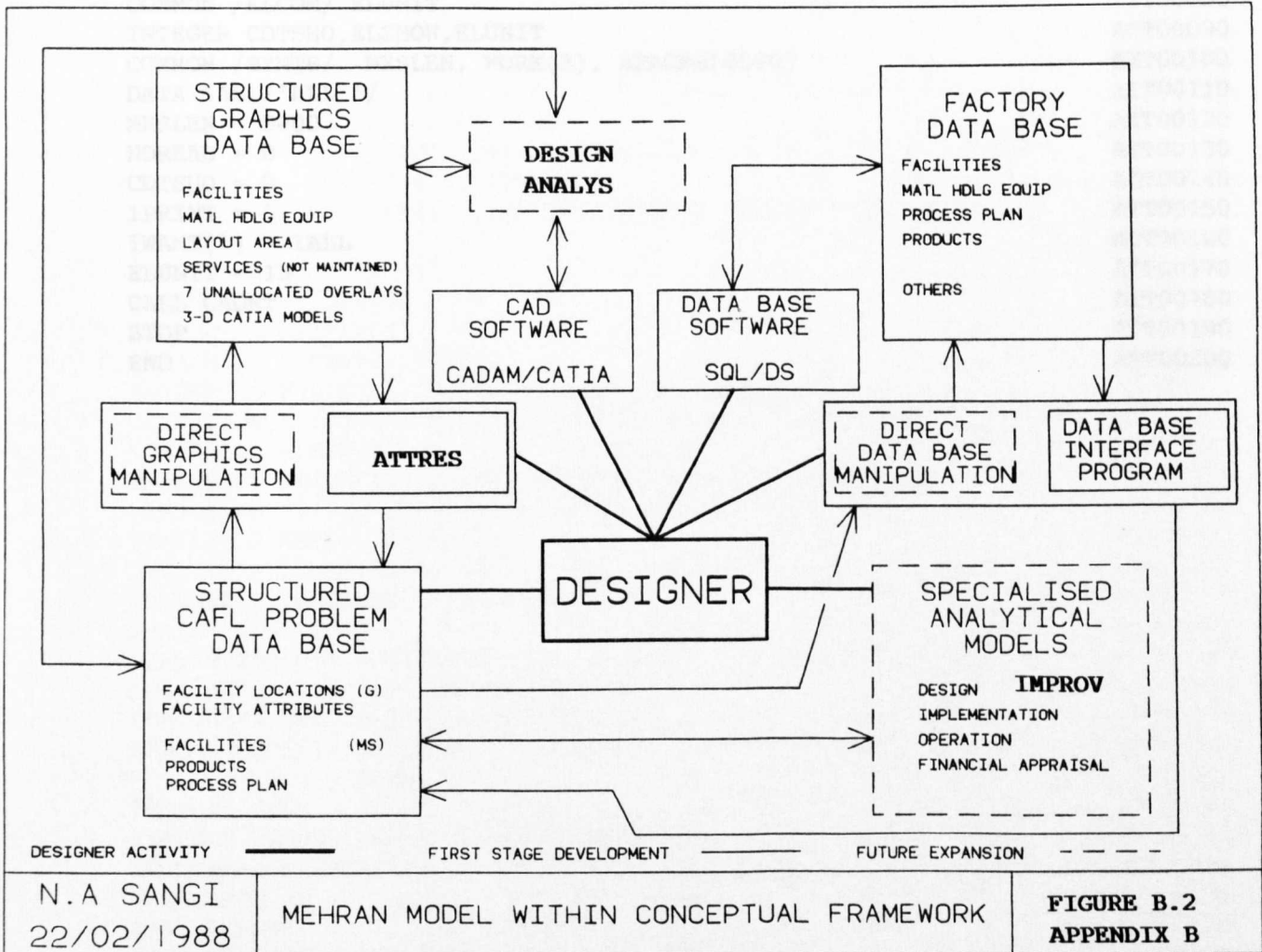
**THE MEHRAN SOFTWARE LISTING**

OVERALL MEHRAN SOFTWARE - DESIGN ACTIVITY





MEHRAN SOFTWARE WITHIN CONCEPTUAL FRAMEWORK



N.A SANGI  
 22/02/1988

MEHRAN MODEL WITHIN CONCEPTUAL FRAMEWORK

FIGURE B.2  
 APPENDIX B

Program ATTRES (Main Program)

```
C          ATTRES MAIN PROGRAM                                ATTO00010
C          THIS PROGRAM CALLS CADET AFTER INITIALISING CADET  ATTO00020
C          PARAMETERS . LATER CADET PASSES EXTRACTED DATA TO ATTO00030
C          ATTRES SUBROUTINE NAMED RESOLV.                    ATTO00040
C                                                            ATTO00050
COMMON /CDTCOM/ LETGO,NOREAD,CDTSHO,ELSHOW,IPRINT,          ATTO00060
*          MDLSIZ,MDLLFT,FILDAT(2),MDLTX(17),IWANT(9)       ATTO00070
COMMON /ELCOM/ ELUNIT                                       ATTO00080
INTEGER CDTSHO,ELSHOW,ELUNIT                                ATTO00090
COMMON /SYMTB/  MXSLEN, WORK(3), SPACES(8000)               ATTO0100
DATA IALL/'ALL '/                                          ATTO0110
MXSLEN = 8000                                               ATTO0120
NOREAD = 0                                                  ATTO0130
CDTSHO = 0                                                  ATTO0140
IPRINT = 6                                                  ATTO0150
IWANT(1) = IALL                                             ATTO0160
ELUNIT = 13                                                 ATTO0170
CALL CADET                                                  ATTO0180
STOP                                                         ATTO0190
END                                                         ATTO0200
```

Program ATTRES (Subroutine RESLOW)

```

COMMENT      THIS ROUTINE STRIPS OUT ATTRIBUTE INFORMATION FROM CADAM  ATT00010
C            MODEL(S). THE OUTPUT IS IN THE FORM OF A TABLE WHICH MAY  ATT00020
C            THEN LOADED TO THE SQL/DS FOR MANUFACTURING SYSTEM DATA  ATT00030
C            BASE TABLE "ATTRIBUTES"                                  ATT00040
C                                                                ATT00050
C            FOR FURTHER INFORMATION CONTACT N. A. SANGI,              ATT00060
C            DEPARTMENT OF INDUSTRIAL STUDIES, LIVERPOOL UNIVERSITY.  ATT00070
CC                                                  ATT00080

SUBROUTINE RESOLV                                                  ATT00090
DIMENSION A(2),B(2),C(3),ARRAY(100 ),ARRAE(100),D(3),E(3)          ATT00100
DIMENSION APLNAM(2),SDATA(50)                                       ATT00110
COMMON /CDTCOM/ LETGO,NOREAD,CDTSHO,ELSHOW,IPRIN,MODSIZ,MDLLFT,    ATT00120
* FILDAT(2), MDLTX(17), IWANT(9)                                     ATT00130
DIMENSION PT1(3),PT2(3),TEXT(64),DIR(3),START(3),TXT(19)          ATT00140
INTEGER ELUNIT                                                       ATT00150
COMMON /ELCOM/ ELUNIT                                               ATT00160
DIMENSION TXT2(129)                                                  ATT00170
INTEGER*2 I2TXT2(1)                                                 ATT00180
DIMENSION EMPNO(2),PART(5)                                          ATT00190
DIMENSION FULL(18),IWORD(18),NSTDTO(10),NOFF(400)                  ATT00200
DIMENSION XYZ(3,NOPTS),ABC(3,NOPTS),FANGLE(NOPTS),FDERIV(NOPTS)   ATT00210
DIMENSION S(NOPTS)                                                  ATT00220
DIMENSION HOMOG(4,1),UVEC(3,4),WVEC(3,4),TWIST(3,4)                ATT00230
DIMENSION SL(6),CIR(15),E1(15),E2(15),DLTRAD(5),ABC2(3,1)         ATT00240
DIMENSION HBP(4,16),FN(2)                                           ATT00250
INTEGER*2 LOOKB(200), LOOKR(200), NUMB(200)                         ATT00260
INTEGER*2 ISEQ(200), KINDEL(200)                                    ATT00270
REAL*8 DOUBLE(9)                                                    ATT00280
REAL*8 IPTNO(4,400)/1600*'      '/                                  ATT00290
LOGICAL*1 BYTE(72), SETNME(20)                                       ATT00300
LOGICAL*1 SPACTB(776),ALPHA(36)                                     ATT00310
REAL*8 BET(5)/'ABCDEFGH','IJKLMNOP','QRSTUVWXYZ','YZ012345',      ATT00320
*      '6789      '/                                               ATT00330
LOGICAL CLC                                                         ATT00340
INTEGER REDUNT, SPAN, ELSHOW, CURPLN                                  ATT00350
INTEGER*4 NUMBER                                                    ATT00360
INTEGER*2 ID                                                         ATT00370
REAL LINEWT                                                         ATT00380
INTEGER TURN,SCALE,VERT,HORIZ,JUST,FONT,IFSUPR                     ATT00390
INTEGER SHOFLG,TCLCKN,DSPLMT,XYMNSR(2),XYMXSR(2)                   ATT00400
DIMENSION XYORIG(2),XSTEP(20),YSTEP(20)                             ATT00410
INTEGER*2 IHALF(36)                                                 ATT00420
EQUIVALENCE (DOUBLE(1),FULL(1),IWORD(1),BYTE(1),IHAF(1))          ATT00430
EQUIVALENCE (BET(1),ALPHA(1))                                       ATT00440
EQUIVALENCE (I2TXT2(1),TXT2(1))                                     ATT00450
DATA IOTYP / 1 /                                                  ATT00460
C                                                                ATT00470
C            START OF CADET PROGRAM                                  ATT00480
C                                                                ATT00490
1 ENTRY CDTST (EMPNO,PART,IPRINT,IEOF)                               ATT00500
  FORMAT (1H ,A4,A2,2X,5A4,2X,I2,2X,I1,2X,F7.4,2X,F7.4,2X,          ATT00510
  * F7.4,2X,I1,4X,I2)                                               ATT00520
  READ (5,1,END=3) EMPNO,PART,IPRINT,IOTYP,CH,CW,UPI,CDTSHO,ELUNIT  ATT00530

```

```

IEOF = 0
GO TO 4
IEOF = 1
RETURN
CONTINUE

SET UPI TO CENTIMETERS

CALL SETUPI(CH,CW,UPI,IFOK)
UPI =2.5400
***** INITIALISE ATTRIBUTE FILES
I=1
IFILE=20+I
WRITE (IFILE,19997) I
19997 FORMAT (' POSITIONAL FILE FOR ATTRIBUTE ',I4)
WRITE (IFILE,19999)
19999 FORMAT (' DETNO          FACILITY IDENTITY          PIVOT POINT
+          LEVER POINT')
DO 20000 I=1,5
  IF (I.EQ.3) GOTO 20000
  IFILE=I+20
  WRITE (IFILE,19996)I
  19996 FORMAT (' THIS FILE IS   FOR ATTRIBUTE',I4)
20000 CONTINUE
RETURN
ENTRY CDTDTO(C,D,IDET,SCAL,IFMIRR,IFXPND,LT)
IFXPND = 1
GO TO 10005

***** START OF EXTRACTED DATA RECEPTION

ENTRY CDTPLT (ABC2,ANG,SCL,UPI,CHI,FN,DH,DW,IOVRPL,IFN,FU1,IFU2)
RETURN
ENTRY CDTPT (C,LT)
GO TO 10000
ENTRY CDTBGD (IVU,IDTXPD)
IDTXPD = 1
GO TO 10000
ENTRY CDTEDT ( P,Q,R,T,IDTNUM)
GO TO 10000
ENTRY CDTBVU (IVU,ID,I,J,ARRAY,C,A,B,SCAL)
I=IOTYP
J=0
GO TO 11500
ENTRY CDTEVU(I)
GO TO 11500
ENTRY CDTLN (C,D,LT)
GO TO 10000
ENTRY CDTARC (C,D,E,LT)
GO TO 10000
ENTRY CDTEPS (C,D,E,AMAJ,AMIN,A,LT)
GO TO 10000
ENTRY CDTDOT (C,R,LT)
GO TO 10000
ENTRY CDTTRI (C,D,E,LT)
GO TO 10000
ENTRY CDTREC (C,HH,HW,LT,DIR)
GO TO 10000

```

```

ATT00540
ATT00550
ATT00560
ATT00570
ATT00580
ATT00590
ATT00600
ATT00610
ATT00620
ATT00630
ATT00640
ATT00650
ATT00660
ATT00670
ATT00680
ATT00690
ATT00700
ATT00710
ATT00720
ATT00730
ATT00740
ATT00750
ATT00760
ATT00770
ATT00780
ATT00790
ATT00800
ATT00810
ATT00820
ATT00830
ATT00840
ATT00850
ATT00860
ATT00870
ATT00880
ATT00890
ATT00900
ATT00910
ATT00920
ATT00930
ATT00940
ATT00950
ATT00960
ATT00970
ATT00980
ATT00990
ATT01000
ATT01010
ATT01020
ATT01030
ATT01040
ATT01050
ATT01060
ATT01070
ATT01080
ATT01090
ATT01100
ATT01110

```

ENTRY CDTRVT (C,D,DIST)	ATT01120
GO TO 10000	ATT01130
ENTRY CDTREV (C,D,DIST)	ATT01140
GO TO 10000	ATT01150
ENTRY CDTTCIR (C,RAD,LT)	ATT01160
GO TO 10000	ATT01170
ENTRY CDTEND (EMPNO,PART)	ATT01180
GO TO 11500	ATT01190
ENTRY CDTSP5 (NOPTS,KIND,XYZ,ABC,S,FANGLE,FDERIV,OFFSET, * JMIN,JMAX,LT,IPARNT,UMIN,UMAX)	ATT01200
GO TO 10000	ATT01210
ENTRY CDTSP5 (NOPTS,KIND,XYZ,ABC,S,FANGLE,FDERIV,OFFSET, * JMIN,JMAX,LT,IPARNT,UMIN,UMAX)	ATT01220
GO TO 10000	ATT01230
ENTRY CDTDIM (ISW,IRET,LT,IFSPEC)	ATT01240
GO TO 11500	ATT01250
ENTRY CDTBRK (PT1,PT2,DIST,WGLHI,WGLWID,NBRKS)	ATT01260
GO TO 10000	ATT01270
ENTRY CDTARO (PT1,PT2,NCHAR,TEXT,START,C,TXTHI,TXTWID)	ATT01280
GO TO 10000	ATT01290
ENTRY CDTSCCT (PT1,PT2,C,D,E)	ATT01300
GO TO 10000	ATT01310
ENTRY CDTNTE (PT1,NCHAR,TEXT,NTHT,TXTHI,TXTWID)	ATT01320
GO TO 10000	ATT01330
ENTRY CDTNTE (PT1,NCHAR,TEXT,NTHT,TXTHI,TXTWID)	ATT01340
GO TO 10000	ATT01350
ENTRY CDTTCUT (PT1,DIR,TLRAD,CRNRAD)	ATT01360
GO TO 10000	ATT01370
ENTRY CDTDLT (PT1,NCHAR,TEXT,PT2,TXTHI,TXTWID,SL,CIR,DLTRAD,E1,E2)	ATT01380
GO TO 10000	ATT01390
ENTRY CDTBLN (PT1,NCHAR,TEXT,RAD,PT2,TXTHI,TXTWID)	ATT01400
GO TO 10000	ATT01410
ENTRY CDTTXT (START,ANG,NCHAR,CHHIGH,CHWIDE,TEXT)	ATT01420
GO TO 10000	ATT01430
ENTRY CDTTXL (PT1,START,PT2,NCHAR,ISVERT,TEXT,TXTHI,TXTWID,C,D)	ATT01440
GO TO 10000	ATT01450
ENTRY CDTSUP (START,ANG,NCHAR,CHHIGH,CHWIDE,TEXT, 1 FONT,SCALE,TURN,JUST,HORIZ,VERT, 1 SLANT,SPAN,HSPACE,VSPACE,LINWTT,IFSUPR)	ATT01460
GO TO 10000	ATT01470
10000 CONTINUE	ATT01480
C	ATT01490
COMMENT - ANALYZE ELEMENTS FOR ATTRIBUTES	ATT01500
C	ATT01510
IFXPND = 0	ATT01520
10005 CALL ELNAME (NAMELE,IGROUP,NSTDTO,LEVEL)	ATT01530
C	ATT01540
C CALL 'ATTRIB' TO ACTUALLY GET ATTRIBUTE INFORMATION	ATT01550
C	ATT01560
7500 CALL ATTRIB (NAMELE,NXTNME,NUMATT,ITYPE,LENGTH,FULL,IHALF,BYTE 1 ,IWORD,DOUBLE,LEVEL)	ATT01570
C	ATT01580
C ***** IATNO IS ATTRIBUTE NUMBER	ATT01590
IATNO = 1	ATT01600
IF (NUMATT.EQ.0) GOTO 7550	ATT01610
IFILE=20+NUMATT	ATT01620
IF (NUMATT.EQ.1) GOTO 7525	ATT01630
WRITE (IFILE,75505) (DOUBLE(I),I=1,4)	ATT01640
75505 FORMAT (' ',4A8)	ATT01650
GOTO 7550	ATT01660
	ATT01670
	ATT01680
	ATT01690

7525	WRITE (IFILE,75500) IDET,(DOUBLE(I),I=1,4),C,D	ATT01700
75500	FORMAT (3H,I2,1X,2A8,3F9.3,2X,3F9.3)	ATT01710
7550	IF (NUMATT.EQ. IATNO) GOTO 7700	ATT01720
	IATNO =IATNO +1	ATT01730
	IF (IATNO.EQ.6) GOTO 7600	ATT01740
	GOTO 7550	ATT01750
C		ATT01760
C	START OF ATTRIBUTE STRIPPING	ATT01770
7700	DO 7750 I=1,ICOUNT	ATT01780
	IF (IPTNO(1,I).EQ.DOUBLE(1).AND.IPTNO(2,I).EQ.DOUBLE(2).AND.	ATT01790
	1 IPTNO(3,I).EQ.DOUBLE(3).AND.IPTNO(4,I).EQ.DOUBLE(4)) GOTO 7752	ATT01800
7750	CONTINUE	ATT01810
	ICOUNT=ICOUNT+1	ATT01820
C	WRITE (6,71) ICOUNT	ATT01830
C71	FORMAT (10X,' ICOUNT ',I12)	ATT01840
	IPTNO(1,ICOUNT)=DOUBLE(1)	ATT01850
	IPTNO(2,ICOUNT)=DOUBLE(2)	ATT01860
	IPTNO(3,ICOUNT)=DOUBLE(3)	ATT01870
	IPTNO(4,ICOUNT)=DOUBLE(4)	ATT01880
	I=ICOUNT	ATT01890
7752	NOFF(I)=NOFF(I)+1	ATT01900
C	WRITE (6,72) I,NOFF(I)	ATT01910
C72	FORMAT (5X,' I= ',I12,5X,' NOFF= ',I12)	ATT01920
7600	CONTINUE	ATT01930
	IF (NXTNME.EQ.0) RETURN	ATT01940
	NAMELE=NXTNME	ATT01950
	GO TO 7500	ATT01960
11500	RETURN	ATT01970
C		ATT01980
	ENTRY CDTSYM (PT1,DIR,SCAL,MIRR,ISTN,ISN,IFFILL,IFXPND)	ATT01990
	IFXPND = 0	ATT02000
	WRITE (6,8001)	ATT02010
8001	FORMAT (' INSIDE SYMBOL')	ATT02020
	GOTO 10000	ATT02030
	ENTRY CDTGSN(SYMTB,ISYMNO,IR)	ATT02040
	RETURN	ATT02050
	ENTRY CDTESE (SYMTB,ISYMNO,IR)	ATT02060
	RETURN	ATT02070
	ENTRY CDTGFN (SYMTB,ISYMNO,IR,SPACTB)	ATT02080
	RETURN	ATT02090
	ENTRY CDTEFE (SYMTB,ISYMNO,IR)	ATT02100
	RETURN	ATT02110
	ENTRY CDTMPL (XYZ,NOPTS,OFFSET,LT,IPARNT,ITYP)	ATT02120
	GO TO 10000	ATT02130
	ENTRY CDT3DS (NOPTS,NPS,NC,NCALLS,XYZ,ABC,ABC2,HOMOG,LT,NPT)	ATT02140
	RETURN	ATT02150
	ENTRY CDTBCB (XYZ,UVEC,WVEC,TWIST,BCBID,LT)	ATT02160
	RETURN	ATT02170
	ENTRY CDTRUL(NOPTS,NPS,NC,NCALLS,XYZ,ABC,ABC2,HOMOG,LT,N2PTS,NP2,	ATT02180
*	NPT,N2T)	ATT02190
	RETURN	ATT02200
	ENTRY CDT3DC (C,D,E,P,Q,LT,IFCIR,PT1,PT2,AMAJ,AMIN)	ATT02210
	GO TO 10000	ATT02220
	ENTRY CDTPLN (E1)	ATT02230
	GO TO 10000	ATT02240
	ENTRY CDT3DP (PT1,J)	ATT02250
	GO TO 10000	ATT02260
	ENTRY CDT3DD (PT1,RAD,LT)	ATT02270

GO TO 10000	ATT02280
ENTRY CDT3DL (PT1,PT2,LT)	ATT02290
GO TO 10000	ATT02300
ENTRY CDT3DA (PT1,PT2,LT)	ATT02310
GO TO 10000	ATT02320
ENTRY CDTHBP (J,HBP)	ATT02330
GO TO 10000	ATT02340
ENTRY CDTGRD( SHOFLG, TCLCKN, DSPLMT, XYORIG, XYMNSR, XYMXSR,	ATT02350
& NXSTEP, NYSTEP, XSTEP, YSTEP )	ATT02360
GOTO 10000	ATT02370
999 STOP	ATT02380
END	ATT02390

Program IMPROV

C		IMP00010
C	IMPROV PROGRAM	IMP00020
C		IMP00030
	COMMON /ROOM1/ MACHID,COST,FLOW,DIST,PIVOTX,PIVOTY,ICON(12),NUM	IMP00040
	REAL*8 PIVOTX(60),PIVOTY(60),DIST(60,60)	IMP00050
	REAL*8 MACHID(60),COST(60,60),FLOW(60,60)	IMP00060
	INTEGER IDENTO(60)	IMP00070
	EXTERNAL SUMA	IMP00080
	DX=0.0	IMP00090
	READ(5,9001)(ICON(I),I=1,12)	IMP00100
9001	FORMAT(12I1)	IMP00110
	WRITE(1,8001)	IMP00120
8001	FORMAT(5X,'INPUT INTEGER NUMBERS, NSET,NUM,IDD')	IMP00130
	NUM=60	IMP00140
	READ(1,9002)NSET,NUM, IDD	IMP00150
9002	FORMAT(3(I2,1X))	IMP00160
	DO 1000 I=1,NUM	IMP00170
	READ(5,9000)IDENTO(I),MACHID(I),PIVOTX(I),PIVOTY(I)	IMP00180
1000	CONTINUE	IMP00190
9000	FORMAT(I5,A8,2F10.3)	IMP00200
	DO 1019 I=1,NUM	IMP00210
	WRITE(6,9000)IDENTO(I),MACHID(I),PIVOTX(I),PIVOTY(I)	IMP00220
1019	CONTINUE	IMP00230
	CALL DISTA	IMP00240
	CALL FLOW1(NSET)	IMP00250
	CALL MINIMA(DX,IDD)	IMP00260
	IF(ICON(2).EQ.1) TSUM = SUMA(DIST,FLOW,NUM)	IMP00270
	IF(ICON(2).EQ.2) TSUM = SUMA(DIST,COST,NUM)	IMP00280
	DO 2000 I=1,10	IMP00290
	WRITE(6,8000)I,(COST(I,L),L=1,10)	IMP00300
2000	CONTINUE	IMP00310
8000	FORMAT(I2,2X,10F9.1)	IMP00320
	DO 2001 I=1,10	IMP00330
	WRITE(6,8002)I,(FLOW(I,L),L=1,10)	IMP00340
2001	CONTINUE	IMP00350
8002	FORMAT(I2,2X,10F5.1)	IMP00360
	DO 2002 I=1,10	IMP00370
	WRITE(6,8003)I,(DIST(I,L),L=1,10)	IMP00380
2002	CONTINUE	IMP00390
8003	FORMAT(I2,2X,10F9.3)	IMP00400
8004	WRITE(1,8100) IDD,PIVOTX(IDD),PIVOTY(IDD)	IMP00410
8100	FORMAT(5X,'LG-',I2,5X,'LOCATION X =',F19.8,'Y =',F19.8)	IMP00420
	DO 1009 I=1,NUM	IMP00430
	WRITE(6,9000)IDENTO(I),MACHID(I),PIVOTX(I),PIVOTY(I)	IMP00440
1009	CONTINUE	IMP00450
	STOP	IMP00460
	END	IMP00470
C		IMP00480
C		IMP00490
	SUBROUTINE DISTA	IMP00500
	COMMON /ROOM1/ MACHID,COST,FLOW,DIST,PIVOTX,PIVOTY,ICON(12),NUM	IMP00510
	REAL*8 PIVOTX(60),PIVOTY(60),DIST(60,60)	IMP00520
	REAL*8 MACHID(60),COST(60,60),FLOW(60,60)	IMP00530
C--IPT	=1 .....	IMP00540
C	=2 .....	IMP00550



```

DO 1001 I=1,NUM
DO 1001 J=1,NUM
  A1=(PIVOTX(I)-PIVOTX(J))**2
  A2=(PIVOTY(I)-PIVOTY(J))**2
  DIST(I,J)=SQRT(A1+A2)
1001 CONTINUE
RETURN
END
C
SUBROUTINE FLOW1(NSET)
COMMON /ROOM1/ MACHID,COST,FLOW,DIST,PIVOTX,PIVOTY,ICON(12),NUM
REAL*8 PIVOTX(60),PIVOTY(60),DIST(60,60)
REAL*8 MACHID(60),COST(60,60),FLOW(60,60)
REAL*8 A1,NAME1,NAME2
DO 1000 I=1,NUM
  DO 1000 J=1,NUM
    COST(I,J)=0.0
    FLOW(I,J)=0
1000 CONTINUE
C-----NSET IS THE NUMBER OF PRODUCTS
  READ(4,9000)A1,NUM1,NAME1,NK1,COST1
9000 FORMAT(1X,A8,I3,A6,I2,F8.1)
  DO 1001 I=1,NSET
5000 CONTINUE
  READ(4,9000)A1,NUM2,NAME2,NK2,COST1
  IF(NUM2.LT.NUM1) GOTO 5001
  IF(NK2.EQ.NK1) COST1=0.0
  COST(NK1,NK2)= COST(NK1,NK2)+COST1
  AFLOW=1.0
  IF(NK2.EQ.NK1) AFLOW=0.0
  FLOW(NK1,NK2)=FLOW(NK1,NK2)+AFLOW
  NK1=NK2
  NUM1=NUM2
  GOTO 5000
5001 NK1=NK2
  NUM1=NUM2
1001 CONTINUE
RETURN
END
C
FUNCTION SUMA(D,P,NUM)
REAL*8 D(60,60),P(60,60)
SUMA=0.0
DO 1000 I=1,NUM
  DO 1000 J=1,NUM
    SUMA=SUMA+D(I,J)*P(I,J)
1000 CONTINUE
RETURN
END
C
SUBROUTINE MINIMA(DX,IDD)
COMMON /ROOM1/ MACHID,COST,FLOW,DIST,PIVOTX,PIVOTY,ICON(12),NUM
REAL*8 PIVOTX(60),PIVOTY(60),DIST(60,60)
REAL*8 MACHID(60),COST(60,60),FLOW(60,60)
REAL*8 CDX(8),CDY(8),T(8)
C---TO CALCULATE DELTA X IF IT IS ZERO -----CMAX===NUMBER OF ITERATIONS

```

	GMAX=DIST(1,1)	IMP01140
	CMAX=100.0	IMP01150
	DO 1003 I=1,NUM	IMP01160
	DO 1003 J=1,NUM	IMP01170
	IF(DIST(I,J).GT.GMAX) GMAX= DIST(I,J)	IMP01180
1003	CONTINUE	IMP01190
	IF(DX.LE.0.0) DX=GMAX/CMAX	IMP01200
	WRITE (6,800) DX,IDD	IMP01210
800	FORMAT (1X,'DX=',F8.2,'MACHINE= LG-',I2)	IMP01220
	CDX(1)=DX	IMP01230
	CDX(2)=-DX	IMP01240
	CDX(3)=0.0	IMP01250
	CDX(4)=0.0	IMP01260
	CDX(5)=DX	IMP01270
	CDX(6)=-DX	IMP01280
	CDX(7)=DX	IMP01290
	CDX(8)=-DX	IMP01300
	CDY(1)=0.0	IMP01310
	CDY(2)=0.0	IMP01320
	CDY(3)=DX	IMP01330
	CDY(4)=-DX	IMP01340
	CDY(5)=DX	IMP01350
	CDY(6)=-DX	IMP01360
	CDY(7)=-DX	IMP01370
	CDY(8)=DX	IMP01380
C-----	IDD FROM MECHINE IDENTIFIER	IMP01390
	X=PIVOTX(IDD)	IMP01400
	Y=PIVOTY(IDD)	IMP01410
	DO 1000 I=1,8	IMP01420
	PIVOTX(IDD)=X+CDX(I)	IMP01430
	PIVOTY(IDD)=Y+CDY(I)	IMP01440
	CALL DISTA	IMP01450
	IF(ICON(2).EQ.1) T(I) = SUMA(DIST,FLOW,NUM)	IMP01460
	IF(ICON(2).EQ.2) T(I) = SUMA(DIST,COST,NUM)	IMP01470
1000	CONTINUE	IMP01480
	SSUM=T(1)	IMP01490
	ISS=1	IMP01500
	DO 1001 I=2,8	IMP01510
	IF(T(I).LE.SSUM) SSUM=T(I)	IMP01520
	IF(T(I).LE.SSUM) ISS=I	IMP01530
1001	CONTINUE	IMP01540
	DELX=CDX(ISS)	IMP01550
	DELY=CDY(ISS)	IMP01560
	SUM1=SSUM	IMP01570
	PIVOTX(IDD)=X+2.*DELX	IMP01580
	PIVOTY(IDD)=Y+2.*DELY	IMP01590
	JTIMES=1	IMP01600
8000	CALL DISTA	IMP01610
	IF(ICON(2).EQ.1) SSUM = SUMA(DIST,FLOW,NUM)	IMP01620
	IF(ICON(2).EQ.2) SSUM = SUMA(DIST,COST,NUM)	IMP01630
	SUM2=SSUM	IMP01640
	JTIMES=JTIMES+1	IMP01650
	IF(JTIMES.GT.INT(CMAX)) GOTO 8002	IMP01660
	IF(SUM2.GT.SUM1) GOTO 8001	IMP01670
	PIVOTX(IDD)=DELX +PIVOTX(IDD)	IMP01680
	PIVOTY(IDD)=DELY +PIVOTY(IDD)	IMP01690
	GOTO 8000	IMP01700
C	SUM2 IS LARGER THAN SUM1 ----NEWTON'S ITERATIONS	IMP01710

8001	PIVOTX(IDD)=PIVOTX(IDD) -DELX	IMP01720
	PIVOTY(IDD)=PIVOTY(IDD) -DELY	IMP01730
	PH=1.0	IMP01740
	SUMLAR=SUM2	IMP01750
	SUMSMA=SUM1	IMP01760
8003	DELX=DELX/2.0	IMP01770
	DELY=DELY/2.0	IMP01780
	PIVOTX(IDD)=DELX*PH +PIVOTX(IDD)	IMP01790
	PIVOTY(IDD)=DELY*PH +PIVOTY(IDD)	IMP01800
	CALL DISTA	IMP01810
	IF(ICON(2).EQ.1) SSUM = SUMA(DIST,FLOW,NUM)	IMP01820
	IF(ICON(2).EQ.2) SSUM = SUMA(DIST,COST,NUM)	IMP01830
	IF(SSUM.LE.SUMSMA) PH=1.0	IMP01840
	IF(SSUM.GT.SUMSMA) PH=-1.0	IMP01850
	IF(SSUM.GT.SUMSMA) SUMLAR=SSUM	IMP01860
	IF(SSUM.LE.SUMSMA) SUMSMA=SSUM	IMP01870
	WRITE (6,802) SUMSMA,SUMLAR,PIVOTX(IDD),PIVOTY(IDD)	IMP01880
802	FORMAT (1X,4(2X,F12.4))	IMP01890
	IF (ABS(SUMSMA-SUMLAR).LE.1.0E-1) GOTO 8002	IMP01900
	GOTO 8003	IMP01910
8002	RETURN	IMP01920
	END	IMP01930

**Program ANALYS**

<pre> SUBROUTINE USRPGM(RDATA,*) COMMON /CDTCOM/ LETGO,NOREAD,CDTSHO,ELSHOW,IPRIN,MODSIZ,MDLLFT, * FILDAT(2),MDLTXT(17),IWANT(9) COMMON /SYMTB/ MXSLEN,WORK(3),SPACES(8000) COMMON /ELCOM/ ELUNIT DIMENSION RDATA(500),POINT1(2),POINT2(2),IDATA(500),POINTT(2) DIMENSION PPIVOT(3),PLEVER(3) INTEGER CDTSHO,ELSHOW,ELUNIT DATA PPIVOT/0.0,0.0,0.0/ DATA PLEVER/0.0,0.0,0.0/ COMMON /MCOM1/ IDETNO REAL*8 TODAY,CURTIM DATA POINTT /-9.0,10.25/ </pre>	<pre> ANA00010 ANA00020 ANA00030 ANA00040 ANA00050 ANA00060 ANA00070 ANA00080 ANA00090 ANA00100 ANA00110 ANA00120 ANA00130 ANA00140 ANA00150 ANA00160 ANA00170 ANA00180 ANA00190 ANA00200 ANA00210 ANA00220 ANA00230 ANA00240 ANA00250 ANA00260 ANA00270 ANA00280 ANA00290 ANA00300 ANA00310 ANA00320 ANA00330 ANA00340 ANA00350 ANA00360 ANA00370 ANA00380 ANA00390 ANA00400 ANA00410 ANA00420 ANA00430 ANA00440 ANA00450 ANA00460 ANA00470 ANA00480 ANA00490 ANA00500 ANA00510 ANA00520 ANA00530 ANA00540 ANA00550 </pre>
<pre> C C THE CADET DEFINITIONS OF PARAMETERS STARTS C MXSLEN = 8000 LETGO = 0 NOREAD = 1 CDTSHO = 1 IPRIN = 06 ELUNIT = 13 </pre>	
<pre> C C THE CADET DEFINITIONS OF PARAMETERS ENDS C LENTXT= 4 LENDTE= 8 POINT1(1) =-10.4 SCAL= 1.0 POINT1(2) = 4.0 CALL CADST (PART,EMPNO,GPNAME) CALL CADFIL (1,NOGOOD,IDUMMY) IF ( RDATA(1) .EQ.1.) GOTO 100 IF ( RDATA(1) .EQ.2.) GOTO 200 IF ( RDATA(1) .EQ.3.) GOTO 300 IF ( RDATA(1) .EQ.4.) GOTO 400 IF ( RDATA(1) .EQ.5.) GOTO 500 IF ( RDATA(1) .EQ.6.) GOTO 600 100 WRITE (20,110) RDATA(1) 110 FORMAT (' INSIDE USRPGM',2X,' MACRO PROG',F4.1,' SELECTED') RETURN 200 WRITE (20,210) RDATA(1) 210 FORMAT (' INSIDE USRPGM',2X,' MACRO PROG',F4.1,' SELECTED') RETURN 300 WRITE (20,310) RDATA(1) 310 FORMAT (' INSIDE USRPGM',2X,' MACRO PROG',F4.1,' SELECTED') RETURN 400 WRITE (20,410) RDATA(1) 410 FORMAT (' INSIDE USRPGM',2X,' MACRO PROG',F4.1,' SELECTED') RETURN 500 WRITE (20,510) RDATA(1) 510 FORMAT (' INSIDE USRPGM',2X,' MACRO PROG',F4.1,' SELECTED') I = RDATA(2) GOTO (550,560,570), I 550 WRITE (20,555) RDATA(2) </pre>	

```

555 FORMAT (' MACRO ANALYS ',2X,'          MENU ',F4.1,'  SELECTED')      ANA00560
      GOTO 599                                                                ANA00570
560 WRITE (20,565) RDATA(2)                                                ANA00580
565 FORMAT (' MACRO ANALYS ',2X,'          MENU ',F4.1,'  SELECTED')      ANA00590
      GOTO 599                                                                ANA00600
570 WRITE (20,575) RDATA(2)                                                ANA00610
575 FORMAT (' MACRO ANALYS ',2X,'          MENU ',F4.1,'  SELECTED')      ANA00620
599 RETURN                                                                    ANA00630
600 WRITE (20,610) RDATA(1),RDATA(2)                                       ANA00640
610 FORMAT (' INSIDE USRPGM',2X,' MACRO PROG',F4.1,F4.1, 'MENU')        ANA00650
      I = RDATA(2)                                                            ANA00660
      GOTO (650,660,670), I                                                  ANA00670
650 CALL BEGDET(&999)                                                       ANA00680
      DO 20 I =1,56                                                           ANA00690
      READ (5,10) IDATA (I)                                                 ANA00700
C   WRITE (20,10) IDATA(I)                                                 ANA00710
      10 FORMAT (A4)                                                         ANA00720
      CALL CADNS (POINT1,LENTXT,IDATA(I),&999)                             ANA00730
C
      IF (MOD(I,8).EQ.0) GOTO 30                                             ANA00740
      POINT1(1)=POINT1(1)+3.0                                               ANA00750
      GOTO 20                                                                  ANA00760
30  POINT1(2)=POINT1(2)-2.0                                                 ANA00770
      POINT1(1)=POINT1(1)-21.0                                             ANA00780
20  CONTINUE                                                                ANA00790
      PIVOTX =0.0                                                            ANA00800
      PIVOTY =0.0                                                            ANA00810
      XLEVER =0.0                                                            ANA00820
      YLEVER =0.0                                                            ANA00830
C
      CALL ENDDT(PIVOTX,PIVOTY,XLEVER,YLEVER,IDETNO,&999)                 ANA00840
C   CALL CADET                                                                ANA00850
C   CALL DITTO(PPIVOT,PLEVER,IDETNO,SCAL,&999)                             ANA00860
      WRITE (20,611)PIVOTX,PIVOTY,XLEVER,YLEVER,IDETNO                    ANA00870
611  FORMAT ('DETAIL  ',4(F6.2,2X),I2)                                       ANA00880
      RETURN                                                                    ANA00890
660  CALL CADET                                                                ANA00900
C   CALL DITTO(PPIVOT,PLEVER,IDETNO,SCAL,&999)                             ANA00910
C   RETURN                                                                    ANA00920
662  WRITE (20,661)                                                         ANA00930
661  FORMAT ('OUTSIDE CADET ')                                             ANA00940
      RETURN                                                                    ANA00950
670  CALL DATE(TODAY)                                                       ANA00960
      POINTT(2) =POINTT(2)-1.0                                             ANA00970
      CALL CADNS (POINTT,LENDTE,TODAY,&999)                                ANA00980
      CALL TIME(CURTIM)                                                     ANA00990
      POINTT(2) =POINTT(2)-1.0                                             ANA01000
      CALL CADNS (POINTT,LENDTE,CURTIM,&999)                               ANA01010
C
C   CALL CADFIL (2,NOGOOD,IDUMMY)                                           ANA01020
      RETURN                                                                    ANA01030
999  STOP                                                                    ANA01040
      END                                                                      ANA01050
COMMENT THIS ROUTINE IS ORIGINATED FROM ATTRES PROGRAM AND IS           ANA01060
C   DEVELOPED TO EXTRACT AND ANALYSE EXTRACTED DATA ON                 ANA01070
C   FACILITIES.                                                           ANA01080
C
C   FOR FURTHER INFORMATION CONTACT N. A. SANGI,                          ANA01090
C
C   (329)

```

C	DEPARTMENT OF INDUSTRIAL STUDIES, LIVERPOOL UNIVERSITY.	ANA01140
CC		ANA01150
	SUBROUTINE RESOLV	ANA01160
	DIMENSION A(2),B(2),C(3),ARRAY(100 ),ARRAE(100),D(3),E(3)	ANA01170
	DIMENSION PT1(3),PT2(3),TEXT(64),DIR(3),START(3),TXT(19)	ANA01180
	DIMENSION APLNAM(2),SDATA(50), TXT2(129)	ANA01190
	COMMON /CDTCOM/ LETGO,NOREAD,CDTSHO,ELSHOW,IPRIN,MODSIZ,MDLLFT,	ANA01200
	* FILDAT(2), MDLTXT(17), IWANT(9)	ANA01210
	INTEGER ELUNIT,IDET,IFXPND,IFMIRR,IFL	ANA01220
	REAL SCAL	ANA01230
	COMMON /ELCOM/ ELUNIT	ANA01240
	INTEGER*2 I2TXT2(1)	ANA01250
	DIMENSION EMPNO(2),PART(5)	ANA01260
	DIMENSION FULL(18),IWORD(18),NSTDTO(10),NOFF(400)	ANA01270
	DIMENSION XYZ(3,NOPTS),ABC(3,NOPTS),FANGLE(NOPTS),FDERIV(NOPTS)	ANA01280
	DIMENSION S(NOPTS), HBP(4,16),FN(2)	ANA01290
	DIMENSION HOMOG(4,1),UVEC(3,4),WVEC(3,4),TWIST(3,4)	ANA01300
	DIMENSION SL(6),CIR(15),E1(15),E2(15),DLTRAD(5),ABC2(3,1)	ANA01310
	INTEGER*2 LOOKB(200), LOOKR(200), NUMB(200)	ANA01320
	INTEGER*2 ISEQ(200), KINDEL(200)	ANA01330
	REAL*8 DOUBLE(9)	ANA01340
C	REAL*8 IPTNO(4,400)/1600* ' /	ANA01350
	LOGICAL*1 BYTE(72), SETNME(20)	ANA01360
	LOGICAL*1 SPACTB(776),ALPHA(36)	ANA01370
	REAL*8 BET(5)/'ABCDEFGH','IJKLMNOP','QRSTUVWXYZ','YZ012345',	ANA01380
	* '6789 ' /	ANA01390
	LOGICAL CLC	ANA01400
	INTEGER REDUNT, SPAN, ELSHOW, CURPLN,CDTSHO	ANA01410
	INTEGER*4 NUMBER	ANA01420
	INTEGER*2 ID	ANA01430
	REAL LINEWT	ANA01440
	INTEGER TURN,SCALE,VERT,HORIZ,JUST,FONT,IFSUPR	ANA01450
	INTEGER SHOFLG,TCLCKN,DSPLMT,XYMNSR(2),XYMXSR(2)	ANA01460
	DIMENSION XYORIG(2),XSTEP(20),YSTEP(20)	ANA01470
	INTEGER*2 IHALF(36)	ANA01480
	EQUIVALENCE (DOUBLE(1),FULL(1),IWORD(1),BYTE(1),IHALF(1))	ANA01490
	EQUIVALENCE (BET(1),ALPHA(1))	ANA01500
	EQUIVALENCE (I2TXT2(1),TXT2(1))	ANA01510
	NOREAD =1	ANA01520
	RETURN	ANA01530
C*****		ANA01540
	ENTRY CDTST (EMPNO,PART,IPRINT,IEOF)	ANA01550
	WRITE (20,15) NOREAD, LETGO	ANA01560
15	FORMAT ('INSIDE RESOLV ', 2(2X,I2))	ANA01570
	WRITE (20,16) EMPNO,PART	ANA01580
16	FORMAT ('ENTRY CDTST ', 2A4, 2X, 5A4)	ANA01590
	RETURN	ANA01600
10000	RETURN	ANA01610
	ENTRY CDTPLT (ABC2,ANG,SCL,UPI,CHI,FN,DH,DW,IOVRPL,IFN,FU1,IFU2)	ANA01620
	WRITE (20,17) LETGO,NOREAD	ANA01630
17	FORMAT ('ENTRY CDTPLT',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA01640
	RETURN	ANA01650
	ENTRY CDTPT (C,LT)	ANA01660
	WRITE (20,18) LETGO,NOREAD	ANA01670
18	FORMAT ('ENTRY CDTPT ',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA01680
	GO TO 10000	ANA01690
	ENTRY CDTBGD (IVU,IDTXPD)	ANA01700
	WRITE (20,19) IVU,IDTXPD	ANA01710

19	FORMAT ('IVU = ',I2,' EXPAND FLAG = ',I2)	ANA01720
	WRITE (20,20) LETGO,NOREAD	ANA01730
20	FORMAT ('ENTRY CDTBGD',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA01740
	GO TO 10000	ANA01750
	ENTRY CDTEDT ( P,Q,R,T,IDTNUM)	ANA01760
	RETURN	ANA01770
	ENTRY CDTBVU (IVU,ID,I,J,ARRAY,C,A,B,SCAL)	ANA01780
	WRITE (20,22) LETGO,NOREAD	ANA01790
22	FORMAT ('ENTRY CDTBVU',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA01800
	I=1	ANA01810
	J=0	ANA01820
	GO TO 11500	ANA01830
	ENTRY CDTEVU(I)	ANA01840
	WRITE (20,23) LETGO,NOREAD	ANA01850
23	FORMAT ('ENTRY CDTEVU',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA01860
	CALL DRAW (EMPNO,PART)	ANA01870
	GO TO 11500	ANA01880
	ENTRY CDTLN (C,D,LT)	ANA01890
	WRITE (20,24) LETGO,NOREAD	ANA01900
24	FORMAT ('ENTRY CDTLN ',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA01910
	GO TO 10000	ANA01920
	ENTRY CDTARC (C,D,E,LT)	ANA01930
	WRITE (20,25) LETGO,NOREAD	ANA01940
25	FORMAT ('ENTRY CDTARC',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA01950
	GO TO 10000	ANA01960
	ENTRY CDTEPS (C,D,E,AMAJ,AMIN,A,LT)	ANA01970
	WRITE (20,26) LETGO,NOREAD	ANA01980
26	FORMAT ('ENTRY CDTEPS',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA01990
	GO TO 10000	ANA02000
	ENTRY CDTDOT (C,R,LT)	ANA02010
	GO TO 10000	ANA02020
	ENTRY CDTRI (C,D,E,LT)	ANA02030
	GO TO 10000	ANA02040
	ENTRY CDTREC (C,HH,HW,LT,DIR)	ANA02050
	GO TO 10000	ANA02060
	ENTRY CDTRVT (C,D,DIST)	ANA02070
	GO TO 10000	ANA02080
	ENTRY CDTREV (C,D,DIST)	ANA02090
	GO TO 10000	ANA02100
	ENTRY CDT CIR (C,RAD,LT)	ANA02110
	WRITE (20,27) LETGO,NOREAD	ANA02120
27	FORMAT ('ENTRY CDT CIR',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA02130
	GO TO 10000	ANA02140
	ENTRY CDTEND (EMPNO,PART)	ANA02150
	NOREAD=1	ANA02160
	LETGO =2	ANA02170
	WRITE (20,28) LETGO,NOREAD	ANA02180
28	FORMAT ('ENTRY CDTEND',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA02190
	WRITE (20, 9) EMPNO, PART	ANA02200
9	FORMAT (2A4,5A4)	ANA02210
2	CALL DRAW (EMPNO,PART)	ANA02220
3	RETURN	ANA02230
	ENTRY CDT SPL (NOPTS,KIND,XYZ,ABC,S,FANGLE,FDERIV,OFFSET,	ANA02240
*	JMIN,JMAX,LT,IPARNT,UMIN,UMAX)	ANA02250
	GO TO 10000	ANA02260
	ENTRY CDT SP5 (NOPTS,KIND,XYZ,ABC,S,FANGLE,FDERIV,OFFSET,	ANA02270
*	JMIN,JMAX,LT,IPARNT,UMIN,UMAX)	ANA02280
	GO TO 10000	ANA02290

	ENTRY CDTDIM (ISW,IRET,LT,IFSPEC)	ANA02300
C	LETGO=2	ANA02310
	GO TO 11500	ANA02320
	ENTRY CDTBRK(P T1,PT2,DIST,WGLHI,WGLWID,NBRKS)	ANA02330
	GO TO 10000	ANA02340
	ENTRY CDTARO (PT1,PT2,NCHAR,TEXT,START,C, TXTHI, TXTWID)	ANA02350
	GO TO 10000	ANA02360
	ENTRY CDTSC T (PT1,PT2,C,D,E)	ANA02370
	GO TO 10000	ANA02380
	ENTRY CDTNTE (PT1,NCHAR,TEXT,NTHT, TXTHI, TXTWID)	ANA02390
	GO TO 10000	ANA02400
	ENTRY CDT CUT(P T1,DIR,TLRAD,CRNRAD)	ANA02410
	GO TO 10000	ANA02420
	ENTRY CDTDLT(P T1,NCHAR,TEXT,PT2, TXTHI, TXTWID, SL, CIR, DLTRAD, E1, E2)	ANA02430
	GO TO 10000	ANA02440
	ENTRY CDTBLN (PT1,NCHAR,TEXT,RAD,PT2, TXTHI, TXTWID)	ANA02450
	GO TO 10000	ANA02460
	ENTRY CDTT XT(START,ANG,NCHAR,CHHIGH,CHWIDE,TEXT)	ANA02470
	GO TO 10000	ANA02480
	ENTRY CDTT XL(P T1,START,PT2,NCHAR,ISVERT,TEXT, TXTHI, TXTWID,C,D)	ANA02490
	GO TO 10000	ANA02500
	ENTRY CDT SUP(START,ANG,NCHAR,CHHIGH,CHWIDE,TEXT,	ANA02510
1	FONT,SCALE,TURN,JUST,HORIZ,VERT,	ANA02520
1	SLANT,SPAN,HSPACE,VSPACE,LINewT,IFSUPR)	ANA02530
	GO TO 10000	ANA02540
	ENTRY CDT SYM (PT1,DIR,SCAL,MIRR,ISTN,ISN,IFFILL,IFXPND)	ANA02550
	GOTO 10000	ANA02560
	ENTRY CDTGSN(SYMTB,ISYMNO,IR)	ANA02570
C	LETGO=2	ANA02580
	RETURN	ANA02590
	ENTRY CDTESE (SYMTB,ISYMNO,IR)	ANA02600
C	LETGO=2	ANA02610
	RETURN	ANA02620
	ENTRY CDTGFN (SYMTB,ISYMNO,IR,SPACTB)	ANA02630
C	LETGO=2	ANA02640
	RETURN	ANA02650
	ENTRY CDTEFE (SYMTB,ISYMNO,IR)	ANA02660
C	LETGO=2	ANA02670
	RETURN	ANA02680
	ENTRY CDTMPL (XYZ,NOPTS,OFFSET,LT,IPARNT,ITYP)	ANA02690
	WRITE (20,29) LETGO,NOREAD	ANA02700
29	FORMAT ('ENTRY CDTMPL',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA02710
	GO TO 10000	ANA02720
	ENTRY CDT3DS (NOPTS,NPS,NC,NCALLS,XYZ,ABC,ABC2,HOMOG,LT,NPT)	ANA02730
C	LETGO=2	ANA02740
	WRITE (20,30) LETGO,NOREAD	ANA02750
30	FORMAT ('ENTRY CDT3DS',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA02760
	RETURN	ANA02770
	ENTRY CDTBCB (XYZ,UVEC,WVEC,TWIST,BCBID,LT)	ANA02780
	WRITE (20,31) LETGO,NOREAD	ANA02790
31	FORMAT ('ENTRY CDTBCB',2X,'LETGO= ',I2,' NOREAD= ',I2)	ANA02800
C	LETGO=2	ANA02810
	RETURN	ANA02820
	ENTRY CDTRUL(NOPTS,NPS,NC,NCALLS,XYZ,ABC,ABC2,HOMOG,LT,N2PTS,NP2,	ANA02830
*	NPT,N2T)	ANA02840
C	LETGO=2	ANA02850
	RETURN	ANA02860
	ENTRY CDT3DC (C,D,E,P,Q,LT,IFCIR,PT1,PT2,AMAJ,AMIN)	ANA02870



GO TO 10000	ANA02880
ENTRY CDTPLN (E1)	ANA02890
GO TO 10000	ANA02900
ENTRY CDT3DP (PT1,J)	ANA02910
GO TO 10000	ANA02920
ENTRY CDT3DD (PT1,RAD,LT)	ANA02930
GO TO 10000	ANA02940
ENTRY CDT3DL (PT1,PT2,LT)	ANA02950
GO TO 10000	ANA02960
ENTRY CDT3DA (PT1,PT2,LT)	ANA02970
GO TO 10000	ANA02980
ENTRY CDTHBP (J,HBP)	ANA02990
GO TO 10000	ANA03000
ENTRY CDTGRD( SHOFLG, TCLCKN, DSPLMT, XYORIG, XYMNSR, XYMXSR,	ANA03010
& NXSTEP, NYSTEP, XSTEP, YSTEP )	ANA03020
GO TO 10000	ANA03030
ENTRY CDTDTO(C,D,IDET,SCAL,IFMIRR,IFXPND,IFL)	ANA03040
IFXPND = 0	ANA03050
WRITE (20,21) C,D,IDET,SCAL	ANA03060
21 FORMAT (2X,6(F8.2,2X),I2,2X,F4.2)	ANA03070
11500 RETURN	ANA03080
C 999 STOP	ANA03090
END	ANA03100
C SUBROUTINE TO TEST CADET PROCESSING END	ANA03110
C	ANA03120
C	ANA03130
C	ANA03140
SUBROUTINE DRAW (EMPNO,PART)	ANA03150
COMMON /CDTCOM/ LETGO,NOREAD,CDTSHO,ELSHOW,IPRIN,MODSIZ,MDLLFT,	ANA03160
* FILDAT(2), MDLTXT(17), IWANT(9)	ANA03170
COMMON /SYMTB/ MXSLEN, WORK(3), SPACES(8000)	ANA03180
COMMON /ELCOM/ ELUNIT	ANA03190
INTEGER EMPNO(2),PART(5)	ANA03200
INTEGER CDTSHO,ELSHOW,ELUNIT	ANA03210
C    LETGO =1	ANA03220
WRITE (20,28)	ANA03230
28 FORMAT ('ENTERED DRAW ',2X)	ANA03240
WRITE (20, 9) EMPNO, PART	ANA03250
9    FORMAT (2A4,5A4)	ANA03260
WRITE(20,30) LETGO,NOREAD,CDTSHO,ELSHOW,IPRIN,MODSIZ,MDLLFT,	ANA03270
* FILDAT	ANA03280
30    FORMAT(2X,5(1X,I2),1X,'MODSIZ= ',2(1X,I6),1X,2A4)	ANA03290
RETURN	ANA03300
END	ANA03310

**Program DESIGN**

C		DES00010
C	DESIGN PROGRAM	DES00020
C		DES00030
	SUBROUTINE USRPGM(RDATA,*)	DES00040
	COMMON /CDTCOM/ LETGO,NOREAD,CDTSHO,ELSHOW,IPRIN,MODSIZ,MDLLFT,	DES00050
	* FILDAT(2), MDLTX(17), IWANT(9)	DES00060
	COMMON /SYMTB/ MXSLEN, WORK(3), SPACES(8000)	DES00070
	COMMON /ELCOM/ ELUNIT	DES00080
	DIMENSION RDATA(20), ERMSG (15)	DES00090
	DIMENSION XYPIV(2),XYLEV(2)	DES00100
	INTEGER CDTSHO,ELSHOW,ELUNIT	DES00110
	REAL*8 TEXT	DES00120
	I = RDATA(1)	DES00130
	GOTO (999,999,100,9999,9999,999,999),I	DES00140
100	I = RDATA(2)	DES00150
	GOTO (10,999),I	DES00160
10	SCAL=1.0	DES00170
	XYPIV(1) = RDATA (3)	DES00180
	XYPIV(2) = RDATA (4)	DES00190
	XYLEV(1) = RDATA (5)	DES00200
	XYLEV(2) = RDATA (6)	DES00210
	IDETNO = -INT(RDATA(7))	DES00220
	CALL DITTO(XYPIV,XYLEV, IDETNO, SCAL, &99)	DES00230
	NUMBER=1	DES00240
	ITYPE= 1	DES00250
	LENTXT = 8	DES00260
	TEXT = RDATA(9)	DES00270
	CALL ATRIBS(NUMBER,ITYPE,TEXT,LENTXT,&999)	DES00280
	GOTO 1000	DES00290
99	CALL MSGGEN ('ERROR IN DATA - CHECK PARAMETER DEFINITIONS')	DES00300
	GOTO 1000	DES00310
999	CALL MSGGEN ('PROGRAM UNDER DEVELOPMENT - TRY NEXT TIME')	DES00320
	GOTO 1000	DES00330
9999	CALL MSGGEN ('PROGRAM DISABLED - SEEK EXPERT ADVICE NOW')	DES00340
1000	RETURN	DES00350
	END	DES00360

Program MEHRAN (ASSEMBLE)

```

* MEHRAN ASSEMBLE PROGRAM USED TO DISPLAY SCREEN MENUES MEH00010
* TOP PORTION PERFORMS COMMUNICATION BETWEEN CADAM AND MACRO MEH00020
* PROGRAMS AND SHOULD NOT BE MODIFIED. TABLE AT THE END OF THIS MEH00030
* PROGRAM GENERATES SCREENS AND CAN BE APPENDED AS REQUIRED. MEH00040
  EJECT MEH00050
  PRINT OFF MEH00060
  MACRO MEH00070
  NAMESET &MACNAM MEH00080
  GBLC &NAME,&NAMEND MEH00090
  GBLC &VARBLD MEH00100
  GBLA &ERRCODE MEH00110
  LCLC &PAD MEH00120
&PAD SETC '$$$$$$' MEH00130
.* MEH00140
.* THIS MACRO ESTABLISHES MACRO PGM NAMES AND ENDING SYMBOLS MEH00150
.* MEH00160
.* GET MACRO NAME WITHOUT BLANKS AND QUOTES MEH00170
.* MEH00180
  BLDNAME &MACNAM MEH00190
  AIF ('&VARBLD' NE '').NMO MEH00200
  MNOTE 4,'BLANK OR NULL MACRO NAME SPECIFIED. ENTRY IGNORED.' MEH00210
&ERRCODE SETA 1 MEH00220
  MEXIT MEH00230
  .NMO ANOP MEH00240
&ERRCODE SETA 0 MEH00250
&NAME SETC '&VARBLD' MEH00260
  AIF (K'&NAME LE 6).NM1 MEH00270
  MNOTE 4,'&NAME IS TOO LONG FOR A MACRO NAME. TRUNCATED TO 6 CH*MEH00280
  ARACTERS.' MEH00290
&NAME SETC '&NAME'(1,6) MEH00300
  .NM1 ANOP MEH00310
&NAMEND SETC '&NAME' MEH00320
  AIF (K'&NAME EQ 6).NM2 MEH00330
&NAMEND SETC '&NAMEND'.'&PAD'(1,6-K'&NAME) MEH00340
  .NM2 ANOP MEH00350
&NAMEND SETC '&NAMEND'.'ND' MEH00360
  MEND MEH00370
  MACRO MEH00380
  VARNAME &VARNAM,&MNOTE=YES MEH00390
  GBLC &VARDEF MEH00400
  GBLC &VARBLD MEH00410
  GBLA &ERRCODE MEH00420
  LCLA &I MEH00430
  LCLC &VARWRK MEH00440
.* MEH00450
.* THIS MACRO BUILDS A VARIABLE NAME AND CHECKS FOR NULL MEH00460
.* (BLANK) NAME OR A NAME LONGER THAN 6 CHARACTERS. IF MEH00470
.* NAME IS NOT NULL, &ERRCODE IS SET TO 0. IF IT IS NULL, MEH00480
.* &ERRCODE IS SET TO 1. ALL LEADING, IMBEDDED, AND TRAILING MEH00490
.* BLANKS AND QUOTES ARE REMOVED. MEH00500
.* MEH00510
  BLDNAME &VARNAM MEH00520

```

```

AIF ('&VARBLD' EQ '').ERROR MEH00530
&ERRCODE SETA 0 MEH00540
&VARDEF SETC '&VARBLD' MEH00550
AIF (K'&VARDEF LE 6).DONE MEH00560
AIF ('&MNOTE' EQ 'NO').NOMNOTE MEH00570
MNOTE 4,'VARIABLE &VARNAM LONGER THAN 6 CHARACTERS. TRUNCATED *MEH00580
      TO 6 CHARACTERS.' MEH00590
.NOMNOTE ANOP MEH00600
&VARDEF SETC '&VARDEF'(1,6) MEH00610
.DONE ANOP MEH00620
      MEXIT MEH00630
.ERROR ANOP MEH00640
&ERRCODE SETA 1 MEH00650
      MEND MEH00660
      MACRO MEH00670
      BLDNAME &VARNAM MEH00680
      GBLC &VARBLD MEH00690
      LCLA &I MEH00700
.* MEH00710
.* THIS MACRO REMOVES BLANKS AND QUOTES FROM &VARNAM AND MEH00720
.* PLACES RESULT IN &VARBLD MEH00730
.* MEH00740
&VARBLD SETC '' MEH00750
&I SETA 0 MEH00760
.REMOVBLK ANOP MEH00770
&I SETA &I+1 MEH00780
AIF (&I GT K'&VARNAM).DONE MEH00790
AIF ('&VARNAM'(&I,1) EQ ' ').REMOVBLK MEH00800
AIF ('&VARNAM'(&I,1) EQ ''').REMOVBLK MEH00810
&VARBLD SETC '&VARBLD'.'&VARNAM'(&I,1) MEH00820
      AGO .REMOVBLK MEH00830
.DONE ANOP MEH00840
      MEND MEH00850
      MACRO MEH00860
&N MACNAME &MACNAM,&XSCREEN,&YSCREEN MEH00870
      GBLC &NAME,&NAMEND MEH00880
      GBLC &INDEX MEH00890
      GBLA &ERRCODE MEH00900
.* MEH00910
.* THIS MACRO ESTABLISHES INDEX PAGE ENTRIES FOR MEH00920
.* MACRO PGM NAMES MEH00930
.* MEH00940
AIF ('&INDEX' NE 'DONE').NAM1 MEH00950
MNOTE 8,'MACNAME MACRO IS MISPLACED - MUST PRECEED MACNMEND MA*MEH00960
      CRO. ENTRY IGNORED.' MEH00970
      MEXIT MEH00980
.NAM1 ANOP MEH00990
      NAMESET &MACNAM MEH01000
AIF (&ERRCODE NE 0).NAMDONE MEH01010
&N DS OF MEH01020
      DC X'0F000003' MEH01030
      DC A(&NAME-&SYSECT,&NAMEND-&NAME+4) MEH01040
      DC X'EE000005' MEH01050
      DC E'&XSCREEN,&YSCREEN' MEH01060
      DC CL8'&NAME' MEH01070
.NAMDONE ANOP MEH01080
      MEND MEH01090
      MACRO MEH01100

```

```

MACNMEND
GBLC &INDEX
.*
.* THIS MACRO TERMINATES THE INDEX PAGE ENTRIES
.*
AIF ('&INDEX' NE 'DONE').END1
MNOTE 8,'MACNMEND MACRO CAN BE USED ONLY ONCE. THIS CALL IGNOR*
ED.'
MEXIT
.END1 ANOP
&INDEX SETC 'DONE'
DC F'0' TERMINATE DISPLAY OF INDEX PAGE
MEND
MACRO
INITVAR
GBLC &VARINIT
GBLC &HEADER(3),&CHDR1(3),&CHDR2(3),&UNSETFL,&UNSETST
.*
.* THIS MACRO SETS INITIAL SETTINGS FOR HEADERS AND UNSET
.* VARIABLE FILL AND EMPHASIS CHARACTERS
.*
AIF ('&VARINIT' EQ 'INIT').EXIT
&VARINIT SETC 'INIT'
&HEADER(1) SETC 'MACRO NAME '
&HEADER(2) SETC '-5.0'
&HEADER(3) SETC '5.0'
&CHDR1(1) SETC ''
&CHDR1(2) SETC '-5.0'
&CHDR1(3) SETC '4.5'
&CHDR2(1) SETC ''
&CHDR2(2) SETC '0.0'
&CHDR2(3) SETC '4.5'
&UNSETFL SETC ' '
&UNSETST SETC ' '
.EXIT ANOP
MEND
MACRO
MACHDR &TITLE,&HEADR1,&HEADR2,&FILL=,&STAR=
GBLC &HEADER(3),&CHDR1(3),&CHDR2(3),&UNSETFL,&UNSETST
GBLC &INIT
LCLC &STRING
.*
.* THIS MACRO IS USED TO DEFINE TITLE POSITION,
.* COLUMN HEADINGS, AND UNSET VARIABLE IDENTIFIERS
.*
.* SET INITIAL VALUES
.*
INITVAR
.*
.* SET PAGE HEADER, REMOVING ANY QUOTES, AND HEADER X,Y LOC.
.*
AIF ('&TITLE(1)' EQ '').HDRND
&HEADER(1) SETC '&TITLE(1)'
AIF ('&HEADER(1)''(1,1) NE ''').HDR1
&HEADER(1) SETC '&HEADER(1)''(2,K'&HEADER(1)-2)
.HDR1 AIF ('&TITLE(2)' EQ '').HDR2
&HEADER(2) SETC '&TITLE(2)'
.HDR2 AIF ('&TITLE(3)' EQ '').HDRND

```

&HEADER(3) SETC '&TITLE(3)'	MEHO1690
.HDRND ANOP	MEHO1700
.*	MEHO1710
.* SET THE TWO COLUMN HEADERS, IF ANY	MEHO1720
.*	MEHO1730
AIF ('&HEADR1(1)' EQ '').CHDR1ND	MEHO1740
&CHDR1(1) SETC '&HEADR1(1)'	MEHO1750
AIF ('&CHDR1(1)'(1,1) NE '').CHDR1A	MEHO1760
&CHDR1(1) SETC '&CHDR1(1)'(2,K'&CHDR1(1)-2)	MEHO1770
.CHDR1A AIF ('&HEADR1(2)' EQ '').CHDR1B	MEHO1780
&CHDR1(2) SETC '&HEADR1(2)'	MEHO1790
.CHDR1B AIF ('&HEADR1(3)' EQ '').CHDR1ND	MEHO1800
&CHDR1(3) SETC '&HEADR1(3)'	MEHO1810
.CHDR1ND ANOP	MEHO1820
AIF ('&HEADR2(1)' EQ '').CHDR2ND	MEHO1830
&CHDR2(1) SETC '&HEADR2(1)'	MEHO1840
AIF ('&CHDR2(1)'(1,1) NE '').CHDR2A	MEHO1850
&CHDR2(1) SETC '&CHDR2(1)'(2,K'&CHDR2(1)-2)	MEHO1860
.CHDR2A AIF ('&HEADR2(2)' EQ '').CHDR2B	MEHO1870
&CHDR2(2) SETC '&HEADR2(2)'	MEHO1880
.CHDR2B AIF ('&HEADR2(3)' EQ '').CHDR2ND	MEHO1890
&CHDR2(3) SETC '&HEADR2(3)'	MEHO1900
.CHDR2ND ANOP	MEHO1910
.*	MEHO1920
.* SET UNSET VARIABLE FILL AND EMPHASIS CHARACTERS, IF ANY	MEHO1930
.*	MEHO1940
AIF ('&FILL' EQ '').STAR	MEHO1950
&STRING SETC '&FILL'	MEHO1960
AIF ('&STRING'(1,1) NE '').UNSETF	MEHO1970
&STRING SETC '&STRING'(2,K'&STRING-2)	MEHO1980
.UNSETF AIF ('&STRING' EQ '').STAR	MEHO1990
&UNSETFL SETC '&STRING'(1,1)	MEHO2000
.STAR AIF ('&STAR' EQ '').STARDON	MEHO2010
&STRING SETC '&STAR'	MEHO2020
AIF ('&STRING'(1,1) NE '').CHKSTAR	MEHO2030
&STRING SETC '&STRING'(2,K'&STRING-2)	MEHO2040
.CHKSTAR AIF ('&STRING' EQ '').STARDON	MEHO2050
AIF ('&STRING' EQ 'YES').SETSTR	MEHO2060
AIF ('&STRING' EQ 'NO').NOSTAR	MEHO2070
MNOTE 4, 'STAR=&STAR IS AN INVALID SETTING. NO ASSUMED'	MEHO2080
AGO .NOSTAR	MEHO2090
.SETSTR ANOP	MEHO2100
&UNSETST SETC '* '	MEHO2110
AGO .STARDON	MEHO2120
.NOSTAR ANOP	MEHO2130
&UNSETST SETC ' '	MEHO2140
.STARDON ANOP	MEHO2150
MEND	MEHO2160
MACRO	MEHO2170
MACDEF &MACNAM	MEHO2180
GBLC &INDEX	MEHO2190
GBLC &NAME, &NAMEND	MEHO2200
GBLC &HEADER(3), &CHDR1(3), &CHDR2(3), &UNSETFL, &UNSETST	MEHO2210
GBLC &VARDEF	MEHO2220
GBLA &ERRCODE	MEHO2230
LCLA &UNSET, &I, &VARLEN, &J	MEHO2240
LCLC &STRING, &FILL	MEHO2250

```

LCLC  &XVAL,&YVAL
MEH02260
.*
MEH02270
.*
THIS MACRO GENERATES THE DISPLAY FOR THE MACRO PGM
MEH02280
DEFINITION PAGE
MEH02290
.*
MEH02300
.*
MAKE SURE MACRO IS PROPERLY PLACED
MEH02310
.*
MEH02320
AIF  ('&INDEX' EQ 'DONE').START
MEH02330
MNOTE 8,'MACDEF MACRO IS MISPLACED - MUST FOLLOW MACNMEND MACR*MEH02340
O. THIS ENTRY IGNORED.'
MEH02350
MEXIT
MEH02360
.START ANOP
MEH02370
.*
MEH02380
.*
MAKE SURE TITLE AND COLUMN HEADINGS HAVE BEEN SET
MEH02390
.*
MEH02400
INITVAR
MEH02410
.*
MEH02420
.*
BEGIN BY GETTING A COUNT OF THE UNSET VARIABLES
MEH02430
.*
MEH02440
&UNSET  SETA  0
MEH02450
&I      SETA  1
MEH02460
.UNSETCT ANOP
MEH02470
&I      SETA  &I+1
MEH02480
AIF  (&I GT N'&SYSLIST).UNSETDN
MEH02490
AIF  (T'&SYSLIST(&I,4) NE 'N').UNSETCT
MEH02500
AIF  (&SYSLIST(&I,4) EQ 0).UNSETCT
MEH02510
VARNAME &SYSLIST(&I,1),MNOTE=NO
MEH02520
AIF  (&ERRCODE NE 0).UNSETCT
MEH02530
AIF  ('&SYSLIST(&I,5)' EQ '').UNSETVR
MEH02540
AIF  ('&SYSLIST(&I,5)' EQ ''''').UNSETVR
MEH02550
AGO   .UNSETCT
MEH02560
.UNSETVR ANOP
MEH02570
&UNSET  SETA  &UNSET+1
MEH02580
AGO   .UNSETCT
MEH02590
.UNSETDN ANOP
MEH02600
.*
MEH02610
.*
ESTABLISH START AND END LABELS FOR MACRO
MEH02620
.*
MEH02630
NAMESET &MACNAM
MEH02640
AIF  (&ERRCODE NE 0).EXIT
MEH02650
.*
MEH02660
.*
SET INITIAL GT 15 WITH UNSET VARIABLE COUNT
MEH02670
.*
MEH02680
&NAME  DC   X'OF000002'          START OF MACRO DEFINITION
MEH02690
        DC   F'&UNSET'          UNSET VARIABLE COUNT
MEH02700
.*
MEH02710
.*
SET NOTES FOR MACRO NAME HEADER AND ANY COLUMN HEADERS
MEH02720
.*
MEH02730
&STRING SETC  '&HEADER(1)'. '&NAME'
MEH02740
&I      SETA  (K'&STRING+3)/4
MEH02750
DC      X'OF000002'          SET UP MACRO NAME TITLE NOTE
MEH02760
DC      F'0'                INDICATE THIS ENTRY IS NOT A VARIABLE
MEH02770
DC      X'EE00',Y(&I+3)
MEH02780
DC      E'&HEADER(2),&HEADER(3)'      SET X,Y POSITION ON SCREEN
MEH02790
DC      CL(4*&I)'&STRING'
MEH02800
AIF  ('&CHDR1(1)' EQ '').HEADER2
MEH02810
&I      SETA  (K'&CHDR1(1)+3)/4
MEH02820
DC      X'OF000002'          SET UP FIRST COLUMN HEADER
MEH02830

```

	DC	F'0'	INDICATE THIS ENTRY IS NOT A VARIABLE	MEH02840
	DC	X'EE00',Y(&I+3)		MEH02850
	DC	E'&CHDR1(2),&CHDR1(3)'	SET X,Y POSITION ON SCREEN	MEH02860
	DC	CL(4*&I)'&CHDR1(1)'		MEH02870
.HEADER2	AIF	('&CHDR2(1)' EQ '' )	.BLDVAR	MEH02880
&I	SETA	(K'&CHDR2(1)+3)/4		MEH02890
	DC	X'OF000002'	SET UP SECOND COLUMN HEADER	MEH02900
	DC	F'0'	INDICATE THIS ENTRY IS NOT A VARIABLE	MEH02910
	DC	X'EE00',Y(&I+3)		MEH02920
	DC	E'&CHDR2(2),&CHDR2(3)'	SET X,Y POSITION ON SCREEN	MEH02930
	DC	CL(4*&I)'&CHDR2(1)'		MEH02940
.BLDVAR	ANOP			MEH02950
.	*			MEH02960
.	*		GO THROUGH VARIABLE DEFINITION LIST AND BUILD NOTES	MEH02970
.	*		FOR EACH WITH A GT 15 PRECEDING GIVING PARTICULARS	MEH02980
.	*		ABOUT THE VARIABLE	MEH02990
.	*			MEH03000
&XVAL	SETC	'0.0'		MEH03010
&YVAL	SETC	'0.0'		MEH03020
&I	SETA	1		MEH03030
.VARLOOP	ANOP			MEH03040
&I	SETA	&I+1		MEH03050
	AIF	(&I GT N'&SYSLIST)	.DONE	MEH03060
.	*			MEH03070
.	*		SET VARIABLE NAME	MEH03080
.	*			MEH03090
		VARNAME &SYSLIST(&I,1),MNOTE=YES		MEH03100
	AIF	(&ERRCODE EQ 0)	.GOODVAR	MEH03110
&J	SETA	&I-1		MEH03120
	MNOTE	4,'VARIABLE &J HAS A BLANK(NULL) NAME. ENTRY SKIPPED.'		MEH03130
	AGO	.VARLOOP		MEH03140
.GOODVAR	ANOP			MEH03150
.	*			MEH03160
.	*		ESTABLISH SET/UNSET VARIABLE FLAG AND VARIABLE LENGTH	MEH03170
.	*			MEH03180
	AIF	(T'&SYSLIST(&I,4) EQ 'N')	.GOODLEN	MEH03190
	MNOTE	4,'LENGTH=&SYSLIST(&I,4) SPECIFIED FOR VARIABLE &VARDEF	*MEH03200	
		IS NOT NUMERIC. ENTRY SKIPPED.'		MEH03210
	AGO	.VARLOOP		MEH03220
.GOODLEN	AIF	(&SYSLIST(&I,4) NE 0)	.POSLEN	MEH03230
	MNOTE	4,'LENGTH=0 SPECIFIED FOR VARIABLE &VARDEF IS INVALID. E*	MEH03240	
		ENTRY SKIPPED.'		MEH03250
	AGO	.VARLOOP		MEH03260
.POSLEN	ANOP			MEH03270
&VARLEN	SETA	&SYSLIST(&I,4)		MEH03280
&UNSET	SETA	1		MEH03290
&STRING	SETC	' '		MEH03300
&FILL	SETC	'&SYSLIST(&I,5)'		MEH03310
	AIF	('&FILL' EQ '' )	.UNSET0	MEH03320
	AIF	('&FILL'(1,1) NE '' )	.UNSET1	MEH03330
&FILL	SETC	'&FILL'(2,K'&FILL-2)		MEH03340
.UNSET1	AIF	('&FILL' NE '' )	.SETVAR	MEH03350
.UNSET0	ANOP			MEH03360
&UNSET	SETA	0		MEH03370
&STRING	SETC	'&UNSETST'(1,2)		MEH03380
&FILL	SETC	'&UNSETFL'		MEH03390
	AIF	('&UNSETFL' EQ ' ' )	.SETVAR	MEH03400
&J	SETA	1		MEH03410



```

.FILLOOP AIF (&J GE &VARLEN).SETVAR MEH03420
&FILL SETC '&FILL'.'&UNSETFL' MEH03430
&J SETA &J+1 MEH03440
AGO .FILLOOP MEH03450
.SETVAR ANOP MEH03460
.* MEH03470
.* MEH03480
.* MEH03490
AIF ('&SYSLIST(&I,2)' EQ '').SETYVAL MEH03500
&XVAL SETC '&SYSLIST(&I,2)' MEH03510
.SETYVAL AIF ('&SYSLIST(&I,3)' EQ '').SETVAR1 MEH03520
&YVAL SETC '&SYSLIST(&I,3)' MEH03530
.SETVAR1 ANOP MEH03540
.* MEH03550
.* MEH03560
.* MEH03570
&J SETA &I-1 MEH03580
DC X'OF000004' MEH03590
DC A(&UNSET,&J,&VARLEN) DEFINE VARIABLE PARTICULARS MEH03600
.* MEH03610
.* MEH03620
.* MEH03630
&J SETA (10+&VARLEN+3)/4 MEH03640
DC X'AE00',Y(&J+3) MEH03650
DC E'&XVAL,&YVAL' SET X,Y POSITION MEH03660
DC CL2'&STRING',CL6'&VARDEF',CL2'=' ',CL(4*&J-10)'&FILL' MEH03670
.* MEH03680
.* MEH03690
.* MEH03700
AGO .VARLOOP MEH03710
.* MEH03720
.* MEH03730
.* MEH03740
.* MEH03750
.DONE ANOP MEH03760
&NAMEND DC F'0' END OF MACRO DEFINITION MEH03770
.EXIT ANOP MEH03780
MEND MEH03790
PRINT ON MEH03800
EJECT MEH03810
CADPARMC CSECT MEH03820
SPACE MEH03820
.* MEH03830
.* MEH03840
.* MEH03850
.* MEH03860
.* MEH03870
SPACE MEH03880
MACNAME IDENTY,-12.0,12.0 MEH03890
MACNAME SPECIF,-12.0,10.0 MEH03900
MACNAME DESIGN,-12.0,8.0 MEH03910
MACNAME ANALYS,-12.0,6.0 MEH03920
MACNAME EVALUT,-12.0,4.0 MEH03930
MACNAME SELECT,-12.0,2.0 MEH03940
MACNAME INSTAL,-12.0,0.0 MEH03950
MACNAME NAMUPI,902.,2.54 MEH03960
MACNMEND MEH03960
MACHDR ('MEHRAN MACRO ',-7.0,12.5), *MEH03970
('CONFIRM CURRENT VALUES',-7.7,11.0), *MEH03980
('YOU MAY ENTER NEW VALUES',-8.3,10.), *MEH03990

```

```

                FILL='?',STAR=YES
MACDEF NAMUPI,(JUNK,0.0,0.0,4.0)
MACDEF IDENTY,(IDENTY,900,0,1,1),
    (PROJCT,-3.5,4.0,6,1.0),
    (DESIGN,-3.5,3.0,6,2.0),
    (GOALS,-3.5,2.0,6,3.0),
    (CAUSES,-3.5,1.0,6,4.0)
MACDEF SPECIF,(SPECIF,900,0,1,2),
    (DATA,-3.5,4.0,6,1.0),
    (DRAWNG,-3.5,3.0,6,2.0),
    (CRITER,-3.5,2.0,6,3.0),
    (LIMITS,-3.5,1.0,6,4.0)
MACDEF DESIGN,(DESIGN,900,0,1,3),
    (2,1007,1,20,'/INTERACTIVE/BATCH/'),
    (3,1003,2,12,'ORIGIN/PIVOT'),
    (5,1003,2,17,'ORIENTATION/LEVER'),
    (X2,1002,0,9,'DETAIL NO'),
    (H,1012,0,17,'FACILITY IDENTITY'),
    (M2,1008,2,1,2)
*
    (L,1005,2,8,SYMTB007)
MACDEF ANALYS,(ANALYS,900,0,1,4),
    (2,1007,1,28,'/EXTRACT/CALCULATE/DISPLAY/'),
    (3,1003,2,12,'ORIGIN POINT'),
    (M2,1008,2,1,2),
    (5,1003,2,13,'LEVER POINT '),
    (M3,1008,2,1,3),
    (7,1002,0,9,'CENTRE X '),
    (8,1002,0,9,'CENTRE Y '),
    (X,1009,0,1,1),
    (M3,1002,0,13,'MAT DEL POINT'),
    (8,1002,0,13,'MAT REC POINT'),
    (X,1009,0,1,1),
    (M2,1002,0,9,'IDENTITY '),
    (6,1002,0,8,'DETAILS '),
    (7,1002,0,9,'CELL NO. '),
    (8,1002,0,8,'FACTORY ')
MACDEF EVALUT,(EVALUT,900,0,1,5),
    (2,1007,1,31,'/COMPARE / REPORT / SAVE /'),
    (3,1003,2,12,'ORIGIN POINT'),
    (M2,1008,2,1,2),
    (5,1003,2,13,'LEVER POINT '),
    (M3,1008,2,1,3),
    (7,1002,0,9,'CENTRE X '),
    (8,1002,0,9,'CENTRE Y '),
    (X,1009,0,1,1),
    (M3,1002,0,13,'MAT DEL POINT'),
    (8,1002,0,13,'MAT REC POINT'),
    (X,1009,0,1,1),
    (M2,1002,0,9,'IDENTITY '),
    (6,1002,0,8,'DETAILS '),
    (7,1002,0,9,'CELL NO. '),
    (8,1002,0,8,'FACTORY ')
MACDEF SELECT,(SELECT,900,0,1,6),
    (LAYOUT,-3.5,1.0,6,1.0)
MACDEF INSTAL,(INSTAL,900,0,1,2),
    (LAYOUT,-3.5,4.0,6,1.0),
    (BUILDG,-3.5,3.0,6,2.0),
    (2,1007,1,31,'/ INSTAL1 / INSTAL2/ INSTAL3/'),

```

```

MEHO4000
MEHO4010
*MEHO4020
*MEHO4030
*MEHO4040
*MEHO4050
MEHO4060
*MEHO4070
*MEHO4080
*MEHO4090
*MEHO4100
MEHO4110
*MEHO4120
*MEHO4130
*MEHO4140
*MEHO4150
*MEHO4160
*MEHO4170
MEHO4180
MEHO4190
*MEHO4200
*MEHO4210
*MEHO4220
*MEHO4230
*MEHO4240
*MEHO4250
*MEHO4260
*MEHO4270
*MEHO4280
*MEHO4290
*MEHO4300
*MEHO4310
*MEHO4320
*MEHO4330
*MEHO4340
MEHO4350
*MEHO4360
*MEHO4370
*MEHO4380
*MEHO4390
*MEHO4400
*MEHO4410
*MEHO4420
*MEHO4430
*MEHO4440
*MEHO4450
*MEHO4460
*MEHO4470
*MEHO4480
*MEHO4490
*MEHO4500
MEHO4510
*MEHO4520
MEHO4530
*MEHO4540
*MEHO4550
*MEHO4560
*MEHO4570

```

(3,1003,2,12,'ORIGIN POINT'),	*MEH04580
(M2,1008,2,1,2),	*MEH04590
(5,1003,2,13,'LEVER POINT '),	*MEH04600
(M3,1008,2,1,3),	*MEH04610
(7,1002,0,9,'CENTRE X '),	*MEH04620
(8,1002,0,9,'CENTRE Y '),	*MEH04630
(X,1009,0,1,1),	*MEH04640
(M3,1002,0,13,'MAT DEL POINT'),	*MEH04650
(8,1002,0,13,'MAT REC POINT'),	*MEH04660
(X,1009,0,1,1),	*MEH04670
(M2,1002,0,9,'IDENTITY '),	*MEH04680
(6,1002,0,8,'DETAILS '),	*MEH04690
(7,1002,0,9,'CELL NO. '),	*MEH04700
(8,1002,0,8,'FACTORY ')	MEH04710
	MEH04720

END

**APPENDIX C**

**THE USERS MANUAL**

## **MEHRAN MODEL USERS MANUAL**

### **C.1 INTRODUCTION**

The MEHRAN model provides the CAFL designers and engineers with the methodology to establish graphics and CAFL-manufacturing databases and make use of this information in layout design studies.

The Users Manual given at this point describes the first release of MEHRAN, using CATIA release 2.2, CADAM release 20 and SQL/DS release 1. The MEHRAN system presently employs an IBM3081 and runs under the VM/SP operating system at the University of Liverpool.

This document assumes that the users have a basic knowledge of the VM/SP operating system the three commercial software packages (CADAM, CATIA and SQL/DS). For users convenience, a few useful references on these packages are given at the end of this document. Novice users are recommended to consult appropriate supporting documents when required. This manual is organised into five sections:

1. Graphics database
2. CAFL-manufacturing database
3. Generating layout designs
4. Using MEHRAN model programs
5. Further information sources

### **C.2 GRAPHICS DATABASE**

The MEHRAN graphics database consists of a CATIA based 3-D solid model library, CADAM based 2-D facilities database and layout area images.

## **CATIA Based 3-D Solid Models**

There are 47 images in the MEHRAN solid model file owned by the user ES04. This file can be accessed by any other CATIA user having access permissions defined. There are two screen setups defined for each model, one displaying the isometric view of the solid model and other showing four view images. Hard copy of any screen setup can be obtained using normal CATIA plotting facilities e.g. Buffer Plot (Screen dump) and Sheet Plot (only four view screen).

Additional models can be added to this database by constructing facility solid model images using the normal CATIA features. The CATIA functions which are helpful in this process are; POINT, LINE, SOLID, SOLID2, IMAGE, INDICATE, ERASE, PLANE, TRANSFER and AUXVIEW.

The actual transfer process is same for CADAM to CATIA or CATIA to CADAM transfer. However, CATIA models require additional preparation within the MEHRAN model as described following.

### **Prerequisite :**

1. Group password files are defined (User Guide UG 31/2).
2. Know passwords of the users between which files are to be transferred.

### **Preparation of CATIA image :**

1. Display the image (either of MEHRAN screen) on CATIA terminal.
2. Perform the hidden line removal process by selecting HLR switch on the CATIA screen.

3. Save the model and leave the CATIA<sub>1</sub>.
4. Repeat for all facility models that would be transferred.

Transfer process :

1. Log into an ordinary alphanumeric terminal.
2. Access the CATIA disks e.g. by typing "RUNICF" and pressing PF03 afterwards.
3. Type "CATCAD MSE", this will start CATIA to CADAM transfer program and initialise CADAM group MSE as the receiving group (default is ENG). Menu options for type of transfer (2-D or 3-D) and direction of transfer (CADAM to CATIA or vice versa) will progressively appear. Successful information identification will lead to a list of models which can be selected by typing "S" in the select field.
4. Check that models are transferred correctly by logging into the receiving system.

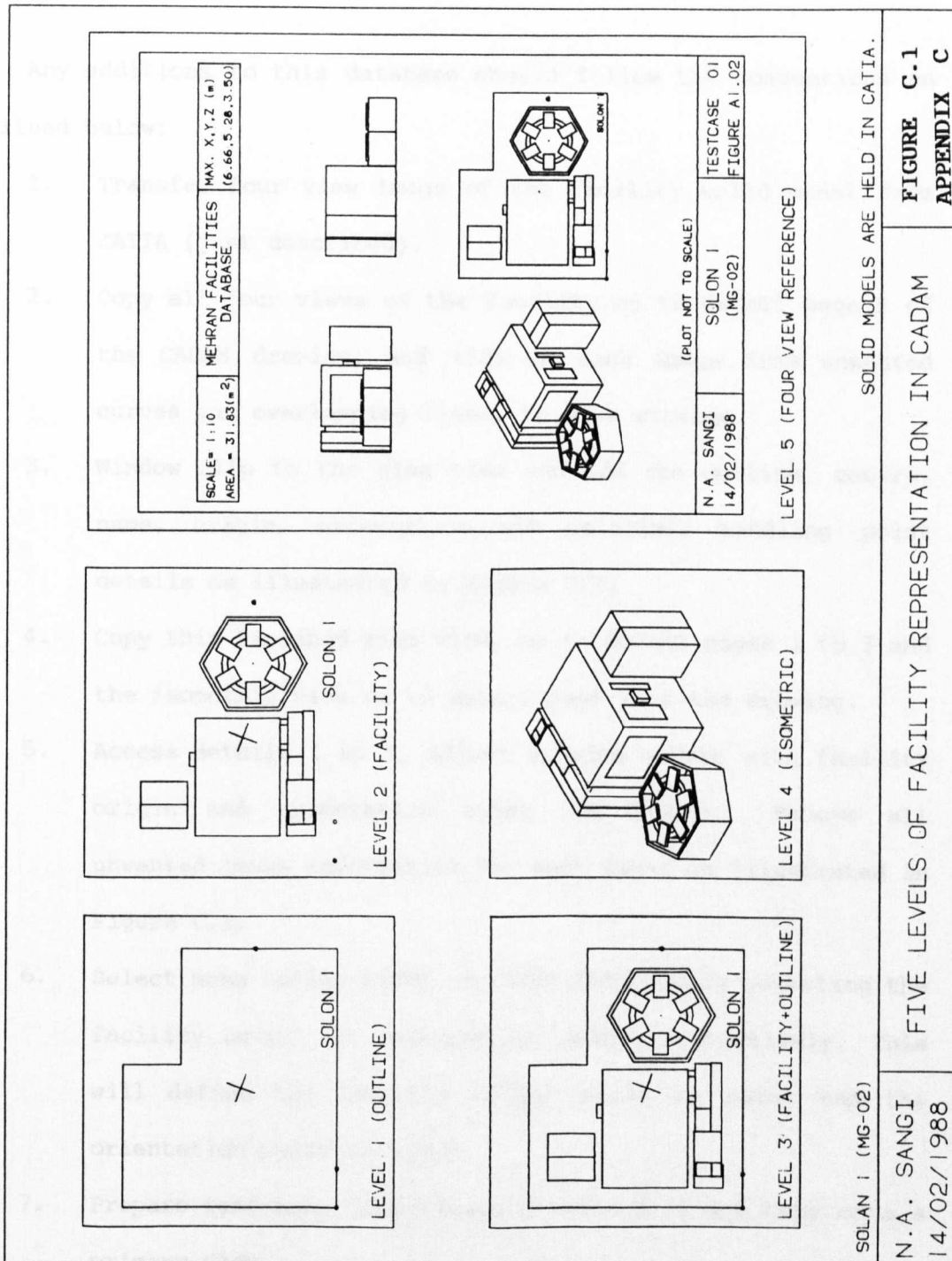
#### **CADAM Based 2-D Facilities Database**

The standard library of facilities contains 47 facilities. All 47 facilities are available for use to any user within CADAM group MSE. In each file five levels (detail pages) are used as illustrated in Figure C.1. Levels (detail pages) 1 to 3 are for use in layout composite generation whereas Levels 4 and 5 are for reference use

---

1

In the latest update (referred to as "Bug Fix") of CATIA, the process of transfer between CADAM and CATIA has been normalised. There is no need now to specially prepare solid models and generate 2-D "draw" views prior to actual transfer.



SOLID MODELS ARE HELD IN CATIA.

FIGURE C.1  
APPENDIX C

FIVE LEVELS OF FACILITY REPRESENTATION IN CADAM

SOLON 1 (MG-02)

N.A. SANGI  
14/02/1988

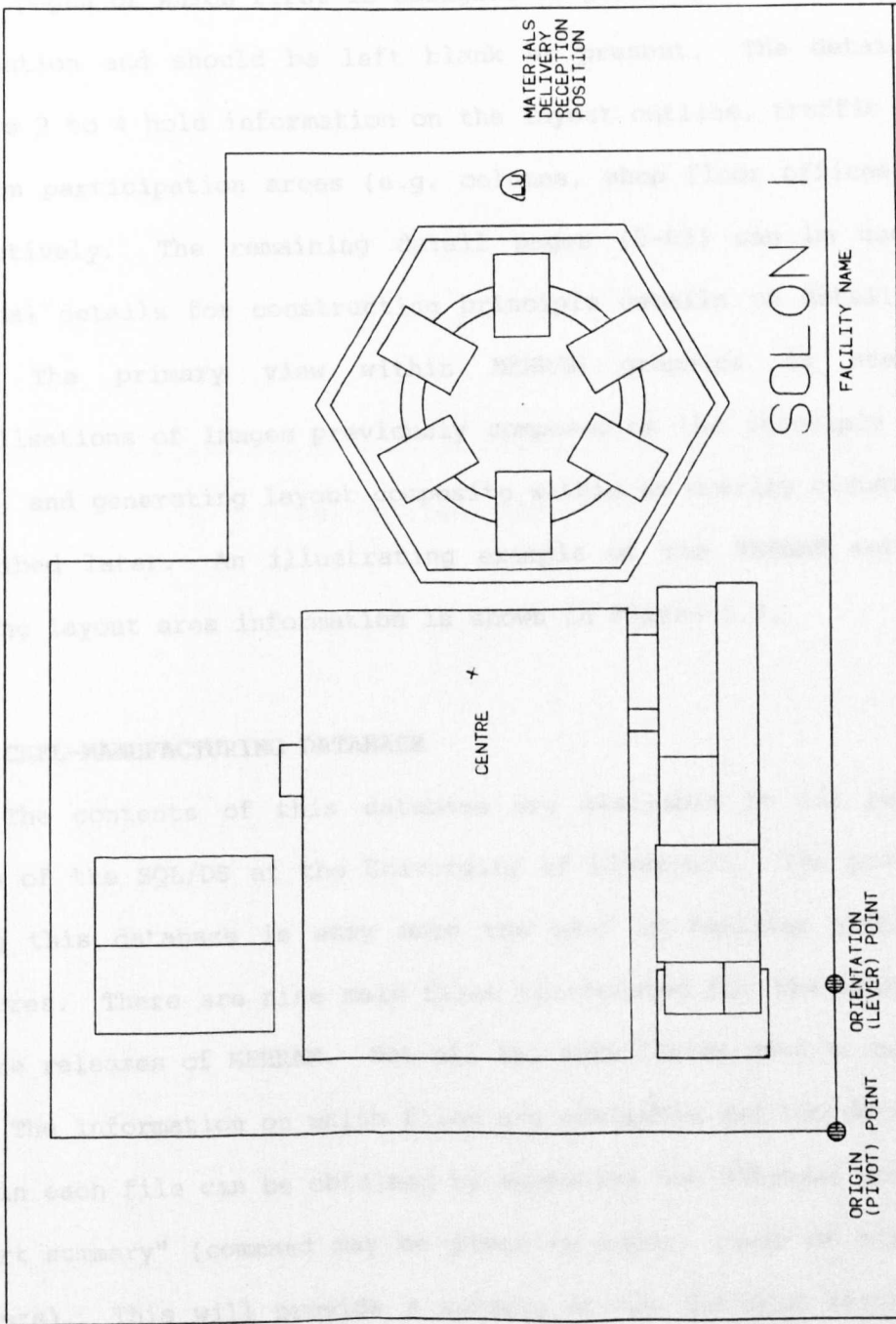


only. Hard copy of the level 5 is given in Appendix A of the thesis and can also be obtained using normal CADAM plotting features.

Any additions to this database should follow the conventions as outlined below:

1. Transfer four view image of the facility solid model from CATIA (just described).
2. Copy all four views of the facility on to detail page 5 of the CADAM drawing, and tidy up each image from unwanted curves and overlapping lines. to save storage.
3. Window clip to the plan view and add the outline, centre, name, origin, orientation and materials handling point details as illustrated in Figure C.2.
4. Copy this finished plan view, on to detail pages 1 to 3 and the isometric view on to detail page 4 of the drawing.
5. Access details 1 to 3, adjust drawing origin with facility origin and orientation along the X-Axis. Remove all unwanted image information for each level as illustrated in Figure C.1.
6. Select menu option PIVOT or LEVER followed by selecting the facility origin or orientation points respectively. This will define the facility origin point as pivot and the orientation point as lever.
7. Prepare reference information (Figure C.1) and copy onto a primary view.
8. Add plotting information to obtain hard copy and transfer into MEHRAN standard library when satisfied.

The CADAM functions DETAIL, ANALYSIS, NOTE, LINE, POINT and GROUP will be helpful in preparing this database record.



**FIGURE C.2**  
**APPENDIX C**

MEHRAN FACILITIES DATABASE RECORD  
(LEVEL 3)

N.A. SANGI  
22/02/1988

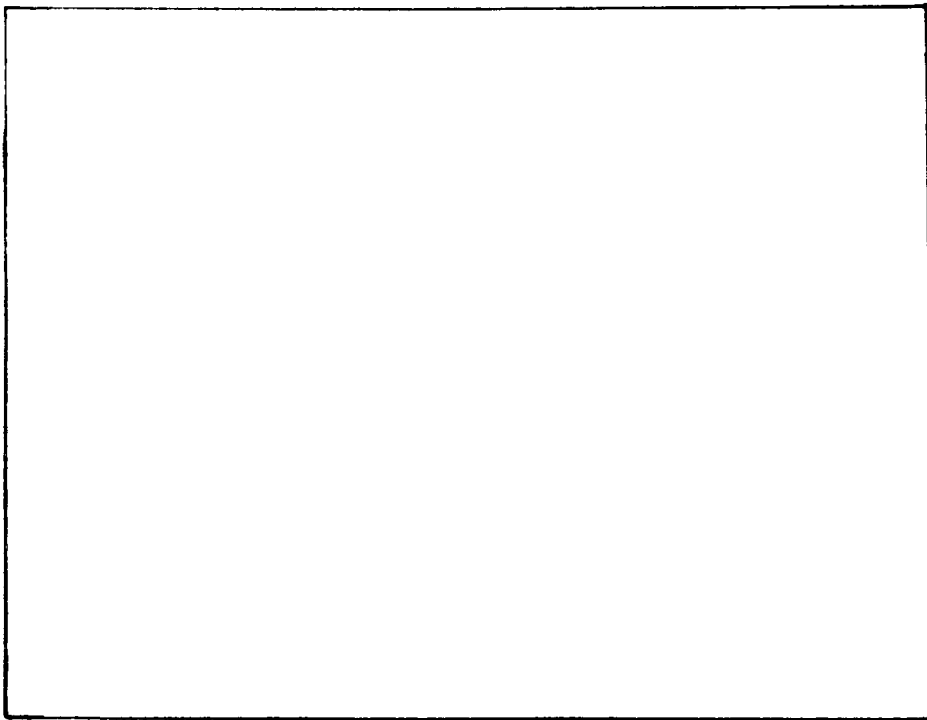
## **Layout Area**

The MEHRAN method of storing layout area requires four principle detail pages of which first is assigned to geometry interface related information and should be left blank at present. The detail page numbers 2 to 4 hold information on the layout outline, traffic system and non participation areas (e.g. columns, shop floor offices etc.) respectively. The remaining detail pages (5-63) can be used for internal details for constructing principle details on detail pages 1-4. The primary view within MEHRAN graphics is used for visualisations of images previously composed on the principle detail pages, and generating layout composite within an overlay structure as described later. An illustrating example of the MEHRAN method of storing layout area information is shown in Figure C.3.

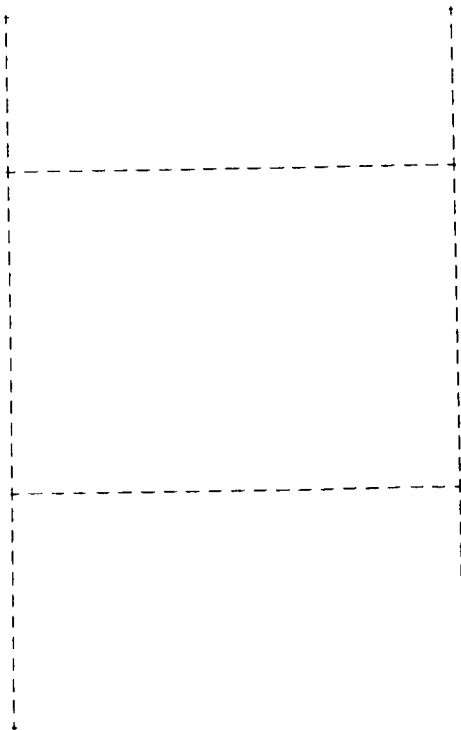
### **C.3 CAFL-MANUFACTURING DATABASE**

The contents of this database are available to all permitted users of the SQL/DS at the University of Liverpool. The process of using this database is easy once the user is familiar with SQL/DS features. There are nine main files constructed for the present and future releases of MEHRAN. Not all the data fields need to be filled in. The information on which files are available and the data fields within each file can be obtained by accessing the database and typing "start summary" (command may be given in upper, lower or mixed case letters). This will provide a summary on the database structure of the all database files. Pressing PF04 while viewing the query result will produce a printed copy of the query result.

The data can be loaded, unloaded, modified and displayed using standard SQL/DS commands and following the database structure



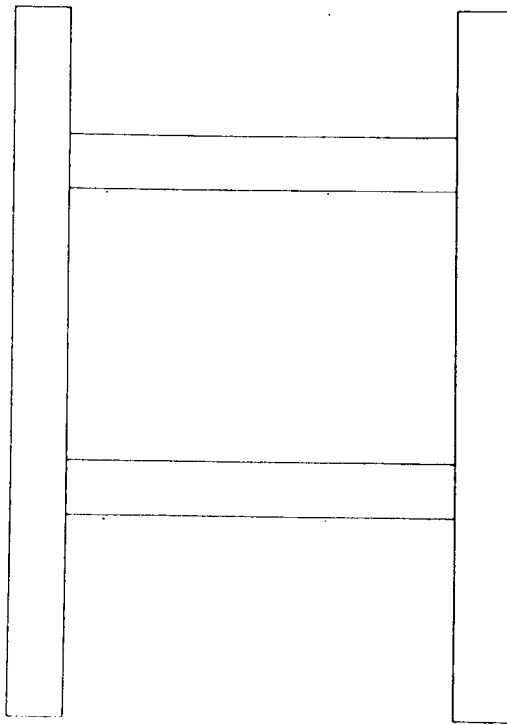
**(A) Outline (D2)**



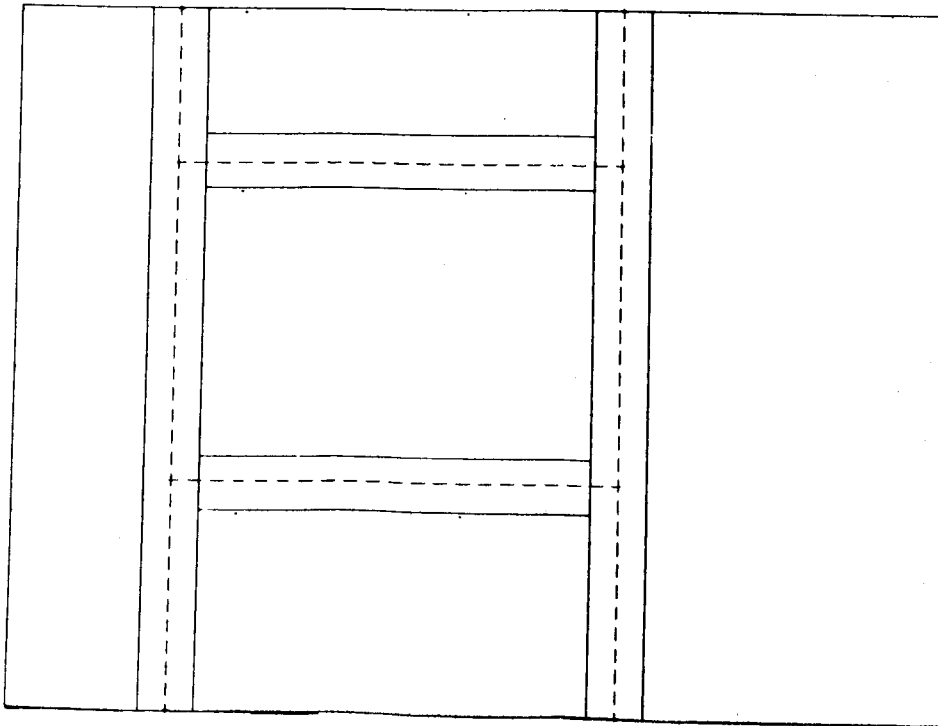
**(B) Traffic Routes (D3)**

**FIGURE C.3 Illustrated Example of Layout Area Composition.**

**(Continued on next page)**



(C) Non Participation Areas (D4)



(D) Layout Area Composed From Detail Pages D2-D4 (PV)

FIGURE C.3 Illustrated Example of Layout Area Composition.

conventions. Two reference documents are listed on SQL/DS in section C.6.

#### **C.4 GENERATING LAYOUT DESIGNS**

The process of layout design generation is performed in three stages; collection, overlaying and layout design.

##### **Collection**

Deciding on the facilities and level of representation i.e. 1 to 3, (for example see Figure C.1) is a prerequisite to starting the collection process. Note down the CADAM file names for each unique facility.

1. Access the CADAM system and open a new CADAM drawing file for facilities.
2. Press CADAM function DETAIL and select menu option STDLIB.
3. Prompts will appear as to the file name and the detail number, key-in appropriate information and CADAM system will automatically transfer that image on the detail page of the current file. Note down the detail page against each unique facility image.
4. Repeat steps 2 and 3 for all facilities (maximum 63).
5. File the drawing when finished.

This process can be done once only by collecting each level of facilities into a separate file and copying appropriate file each time layout study is performed.

## **Overlaying**

After collection is complete overlaying is performed by the following method:

1. Press OVERLAY function key of CADAM, select menu option START and define an overlay file.
2. Select the menu option MEMBER, a new menu will appear and the option ADD will be automatically selected. Add Layout Area file by selecting from drawing index (optionally up to 11 other files e.g. Material Handling file can be added into this overlay file).
3. Save the overlay relationship.

The overlay images of each file will have a different colour assigned to each overlay member with the active drawing shown in green (default) colour. Selecting the menu option CHOOSE followed by selection of any member drawing will change the status of that drawing as active (confirmed when colour of that drawing will change to green). The list or images of the member drawings can be displayed alternatively by selecting the menu switch "LIST/NOLIST".

## **Layout Design**

Layout design can be performed in two ways; the first method makes use of the standard CADAM process of copying "Ditto" onto the primary view. The second method makes use of specialised MEHRAN geometry interface program DESIGN. This program customises the CADAM method of "ditto" copy into four simple steps and is therefore easier and quicker.

Preliminary to both methods is the overlaying of images of the layout area and facilities, with the facilities drawing as the active

drawing. The list of the unique facilities identifying detail page location (compiled during collection stage) is a crucial support to the designer during this stage.

**a) Using CADAM**

1. Press CADAM function DETAIL and select menu option DITTO. The active detail page number will appear in the message area of CADAM screen.
2. Change active detail number to the facility image that would be located (consult the list prepared during collection).
3. Prompts will ask X,Y location of pivot point followed by the angle of orientation. The facility (on the active detail) will appear on the primary view with the facility origin matched to the defined pivot point at defined angle with the X-Axis.
4. Press GROUP function and select menu option ATTRIBUTE.
5. Assign facility identity (maximum eight characters) as attribute number 1.
6. Repeat the process for all facilities.
7. When finished this task file the drawing.

The process of attribute assignment can be performed after all facilities have been located.

**b) Using DESIGN**

1. Press CADAM function MACRO and select program DESIGN. Menu option INTERACTIVE will be automatically selected.
2. Progressively four prompts will appear requesting the; origin (pivot) point, orientation (lever) point, detail



number on which facility is stored and the facility identity. The facility will appear on the screen and menu option changed.

3. Select any one menu option; SAVE to accept facility, RESTART to reject the image, SAVE+RESTART to accept and restart the cycle for the next facility location and MENU1 to reject the image and end the DESIGN session.
4. When finished with the DESIGN session file the drawing.

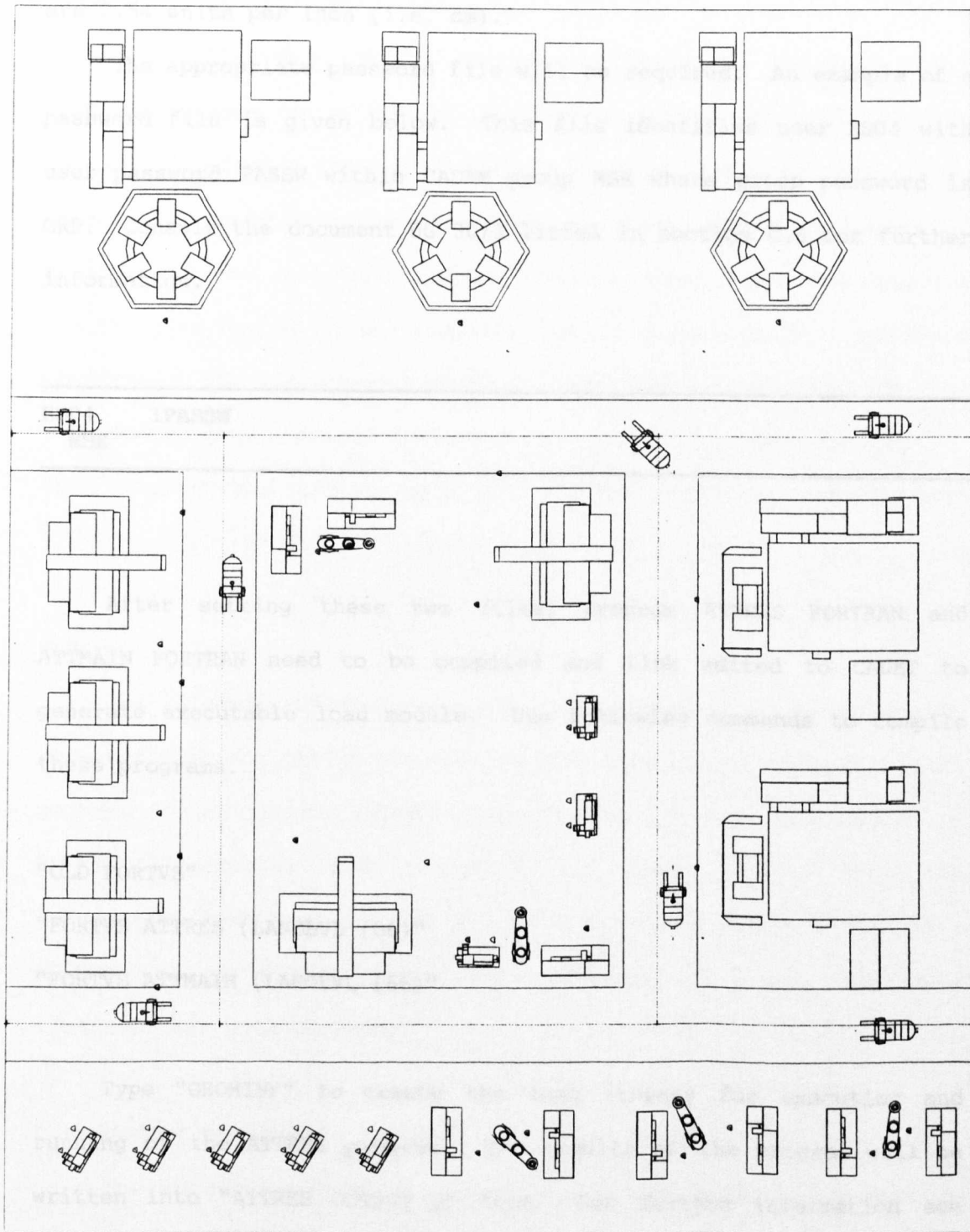
An illustrating example of completed drawing is shown in Figure C.4.

#### **C.5 USING MEHRAN SOFTWARE**

There are four main GI programs available within MEHRAN software suite; ATTRES, IMPROV, ANALYS and DESIGN. The first two programs work on an alphanumeric terminal (outside CADAM), the remaining two programs run as macro programs within CADAM function key MACRO. The program listing is given in Appendix B and illustrating examples of data files and output produced are given in Appendix D. Operation of program DESIGN has been described in section C.4. The remaining programs are described below:

##### **ATTRES**

This program extracts the origin, orientation and attribute text data. Running this program requires to setup password and drawing data files in which passwords and drawing names ( a maximum of four drawings) are supplied. An example ATTRES data file is given below.



PROTOTYPE TEST CASE COMPOSITE LAYOUT

This file will initialise drawing PROTOTYPE-MASTER within user ES04. Output will be directed to print channel 06 and drawing units are 2.54 units per inch (i.e. cm).

The appropriate password file will be required. An example of a password file is given below. This file identifies user ES04 with user password PASSW within CADAM group MSE where group password is GRP. Consult the document UG 30/3 listed in section C.6 for further information.

---

**ES04 1PASSW**  
**MSE**

---

After setting these two files, program ATTRES FORTRAN and ATTMAIN FORTRAN need to be compiled and link edited to CADET to generate executable load module. Use following commands to compile these programs.

"OLD FORTVS"

"FORTVS ATTRES (LANGLVL (66))"

"FORTVS ATTMAIN (LANGLVL (66))"

Type "GEOMINF" to create the load library for execution and running of the ATTRES program. The results of the program will be written into "ATTRES OUTPUT A" file. For further information see reference documents given in section C.6.

## **IMPROV**

This program reads data from "ATTRES OUTPUT A" file plus the "SEQUENCE DATA A" file. The output will be written into "IMPROV OUTPUT A" file. The program can be run by typing "IMPROV". This program requires three integer input parameters; NSET, NUM and IDD. The NSET identifies number of products flowing within the cell (i.e. number of routing sets in the sequence file), NUM sets number of machines in the cell (maximum 60) and the final input IDD requests the identity number of the facility for which optimisation should be performed. The value supplied for IDD must not be more than NUM.

The program returns optimised X,Y values for that facility on the terminal and writes data as well as the final results into "IMPROV OUTPUT A" file.

## **ANALYS**

The program ANALYS, was under development and was originally combined with the DESIGN program. ANALYS runs by selecting the macro program ANALYS within CADAM. This program has been disabled after systems changeover and therefore has been removed from the interactive load module. The all macro programs within interactive MEHRAN (except DESIGN), have been disabled until new read/write routines have been confirmed.

## **C.6 FURTHER INFORMATION SOURCES**

The information sources identified following are commented on according to their contents. All documents listed in this section are available in the computer laboratory at the University of Liverpool.

1. CADAM User Manuals.

These manuals provide reference information on using CADAM standard functions.

2. CADAM Geometry Interface Installation Guide.

This document is a good reference on development and understanding of CADAM geometry interface procedures. For use in interface program development and problem identification.

3. Introduction to CADAM on IBM4341 (UG 30/3).

This is a local document describing the CADAM setup at the University and how to run geometry interface programs at the University of Liverpool.

4. Introduction to CATIA on IBM4341 (UG 31/2).

This is a local document describing the CATIA setup at the University of Liverpool.

4. CATIA User Manuals.

These manuals provide reference information on using CATIA standard functions. For use in generating solid models.

6. SQL/Data System, Terminal User's Reference for VM/System Product.

This document is a good reference on SQL/DS usage.

7. SQL DESIGN (Software Note).

This describes SQL/DS screen design procedures developed and enhanced at the University of Liverpool.

## **APPENDIX D**

### **TEST CASE RESULTS**

- D1 THE SAMPLE DATA**
- D2 THE SAMPLE OUTPUT OF PROGRAMS**
- D3 THE SCREEN TEMPLATES**
- D4 SUMMARY STATISTICS**

**D1**

**D1 THE SAMPLE DATA**

Sample Sequence Data Used in Program IMPROV

PRODID	SEQNO	MACHID	MHCOST	PRODID	SEQNO	MACHID	MHCOST
69422425	1	LG-11	4500.0	69422516	1	LG-19	4086.0
69422425	2	LG-08	2500.0	69422516	2	LG-56	4560.0
69422425	3	LG-24	3500.0	69422516	3	LG-50	3240.0
69422425	4	LG-04	4500.0	69422516	4	LG-28	4320.0
69422425	5	LG-41	1215.0	69422516	5	LG-57	3480.0
69422425	6	LG-15	750.0	69422516	6	LG-55	300.0
69422425	7	LG-11	2000.0	69422516	7	LG-26	2000.0
69422511	1	LG-53	2000.0	69422516	8	LG-29	2000.0
69422511	2	LG-43	2000.0	69422516	9	LG-12	7500.0
69422511	3	LG-56	2000.0	64421489	1	LG-48	3700.0
69422511	4	LG-35	2000.0	64421489	2	LG-40	4900.0
69422511	5	LG-16	2000.0	64421489	3	LG-17	300.0
69422511	6	LG-29	2000.0	64420559	1	LG-44	3240.0
69422511	7	LG-55	2000.0	64420559	2	LG-32	4450.0
69422513	1	LG-57	2000.0	64420559	3	LG-11	1215.0
69422513	2	LG-19	2000.0	64420559	4	LG-04	300.0
69422513	3	LG-10	2000.0	64420559	5	LG-07	170.0
69422513	4	LG-31	2000.0	64421310	1	LG-24	3240.0
69422513	5	LG-39	2000.0	64421310	2	LG-34	4450.0
69422513	6	LG-14	2000.0	64421310	3	LG-55	1215.0
69422513	7	LG-24	2000.0	64421310	4	LG-03	300.0
69422513	8	LG-40	2000.0	64421310	5	LG-47	170.0
69422247	1	LG-44	1125.0	69422350	1	LG-25	2000.0
69422247	2	LG-45	625.0	69422350	2	LG-51	1000.0
69422247	3	LG-01	875.0	69422350	3	LG-27	3000.0
69422247	4	LG-16	2600.0	64422613	1	LG-58	900.0
69422247	5	LG-48	1215.0	64422613	2	LG-22	680.0
69422247	6	LG-13	750.0	64422613	3	LG-31	2700.0
69422247	7	LG-16	2000.0	64422613	4	LG-57	380.0
69422073	1	LG-49	1500.0	64422613	5	LG-08	275.0
69422073	2	LG-34	1500.0	64422613	6	LG-50	192.0
69422073	3	LG-22	2183.0	64422613	7	LG-56	1500.0
69422073	4	LG-29	2600.0	64422613	8	LG-44	390.0
69422073	5	LG-47	600.0	64422614	1	LG-40	900.0
69422073	6	LG-52	300.0	64422614	2	LG-54	680.0
69422073	7	LG-10	3300.0	64422614	3	LG-05	2700.0
69422255	1	LG-59	1500.0	64422614	4	LG-53	380.0
69422255	2	LG-55	1500.0	64422614	5	LG-05	275.0
69422255	3	LG-03	2183.0	64422614	6	LG-36	495.0
69422255	4	LG-09	2600.0	64422614	7	LG-53	192.0
69422255	5	LG-23	600.0	64422614	8	LG-53	1500.0
69422255	6	LG-45	2183.0	64422614	9	LG-10	428.0
69422255	7	LG-37	3300.0	69422436	1	LG-24	900.0
69422527	1	LG-48	5100.0	69422436	2	LG-34	680.0
69422527	2	LG-12	4140.0	69422436	3	LG-12	2700.0
69422527	3	LG-30	1020.0	69422436	4	LG-38	380.0
69422527	4	LG-55	1020.0	69422436	5	LG-08	275.0
69422527	5	LG-13	6000.0	69422436	6	LG-35	192.0
				69422436	7	LG-52	1500.0
				69422436	8	LG-27	390.0

(Continued on next page)



**Sample Sequence Data Used in Program IMPROV**

<u>PRODID</u>	<u>SEQNO</u>	<u>MACHID</u>	<u>MHCOST</u>	<u>PRODID</u>	<u>SEQNO</u>	<u>MACHID</u>	<u>MHCOST</u>
69422098	1	LG-54	1095.0	64421775	1	LG-15	932.0
69422098	2	LG-57	648.0	64421775	2	LG-55	1074.0
69422098	3	LG-01	2530.0	64421775	3	LG-37	680.0
69422098	4	LG-16	420.0	64421775	4	LG-17	355.0
69422098	5	LG-36	389.0	64421775	5	LG-42	275.0
69422098	6	LG-16	192.0	64421775	6	LG-15	630.0
69422098	7	LG-52	1500.0	64421775	7	LG-39	192.0
69422098	8	LG-30	424.0	64421775	8	LG-25	428.0
69422100	1	LG-52	1095.0	64421776	1	LG-39	932.0
69422100	2	LG-30	648.0	64421776	2	LG-13	1074.0
69422100	3	LG-07	2530.0	64421776	3	LG-47	680.0
69422100	4	LG-26	420.0	64421776	4	LG-50	355.0
69422100	5	LG-50	389.0	64421776	5	LG-11	275.0
69422100	6	LG-40	192.0	64421776	6	LG-31	192.0
69422100	7	LG-32	1500.0	64421776	7	LG-27	398.0
69422100	8	LG-57	424.0	64422064	1	LG-08	847.0
69422110	1	LG-01	684.0	64422064	2	LG-28	596.0
69422110	2	LG-12	1390.0	64422064	3	LG-57	1720.0
69422110	3	LG-25	900.0	64422064	4	LG-56	355.0
69422110	4	LG-47	355.0	64422064	5	LG-40	275.0
69422110	5	LG-56	275.0	64422064	6	LG-25	592.0
69422110	6	LG-23	192.0	64422064	7	LG-11	192.0
69422110	7	LG-56	1500.0	64422064	8	LG-56	428.0
69422110	8	LG-38	428.0	64422065	1	LG-03	847.0
64423829	1	LG-14	633.0	64422065	2	LG-01	596.0
64423829	2	LG-30	1640.0	64422065	3	LG-46	1720.0
64423829	3	LG-31	2700.0	64422065	4	LG-43	355.0
64423829	4	LG-39	380.0	64422065	5	LG-25	275.0
64423829	5	LG-41	275.0	64422065	6	LG-49	192.0
64423829	6	LG-37	192.0	64422065	7	LG-19	390.0
64423829	7	LG-18	1500.0				
64423829	8	LG-07	390.0				
64423830	1	LG-24	633.0				
64423830	2	LG-59	1640.0				
64423830	3	LG-19	2700.0				
64423830	4	LG-11	380.0				
64423830	5	LG-30	275.0				
64423830	6	LG-49	192.0				
64423830	7	LG-18	1500.0				
64423830	8	LG-02	428.0				

Sample Location Data Used in Program IMPROV  
(Output of ANALYS Program)

INDEX	MACHID	PIVOTX	PIVITY	INDEX	MACHID	PIVOTX	PIVITY
11000000000000							
1	LG-01	28.500	16.750	31	LG-31	8.200	6.560
2	LG-02	14.960	20.630	32	LG-32	29.070	20.840
3	LG-03	41.500	10.100	33	LG-33	10.500	11.820
4	LG-04	24.720	16.000	34	LG-34	30.510	15.430
5	LG-05	41.600	29.820	35	LG-35	20.060	15.540
6	LG-06	9.500	6.000	36	LG-36	8.900	6.500
7	LG-07	14.550	9.000	37	LG-37	18.770	12.000
8	LG-08	35.290	16.310	38	LG-38	11.820	-10.500
9	LG-09	23.250	17.850	39	LG-39	16.000	-24.720
10	LG-10	21.150	20.740	40	LG-40	16.000	-24.720
11	LG-11	34.690	37.270	41	LG-41	8.220	-16.880
12	LG-12	132.950	47.630	42	LG-42	8.200	6.560
13	LG-13	10.770	7.600	43	LG-43	-17.590	21.080
14	LG-14	38.650	12.060	44	LG-44	12.060	-38.650
15	LG-15	22.080	16.890	45	LG-45	-12.060	38.650
16	LG-16	14.000	9.870	46	LG-46	-12.620	20.490
17	LG-17	24.910	17.990	47	LG-47	-14.960	-20.630
18	LG-18	10.800	7.800	48	LG-48	-12.250	24.950
19	LG-19	24.950	12.250	49	LG-49	-21.300	23.480
20	LG-20	8.600	9.150	50	LG-50	-11.820	10.500
21	LG-21	28.700	19.370	51	LG-51	1.900	34.140
22	LG-22	21.080	17.590	52	LG-52	9.870	-14.000
23	LG-23	9.250	6.100	53	LG-53	-16.890	22.080
24	LG-24	6.100	9.200	54	LG-54	-17.850	23.250
25	LG-25	17.800	12.900	55	LG-55	-20.840	29.070
26	LG-26	20.490	12.620	56	LG-56	20.740	-21.150
27	LG-27	23.480	21.300	57	LG-57	20.740	-21.150
28	LG-28	13.600	11.050	58	LG-58	12.900	-17.800
29	LG-29	15.250	6.450	59	LG-59	17.990	-24.910
30	LG-30	16.880	8.220	60	LG-60	-17.990	24.910

Sample Products Data File (SQL/DS) Output

PROID	PERIOD	QUANT	ORDSIZ
64422876	8687	200	100
64422901	8687	88	44
64422902	8687	87	44
69421377	8687	40	40
69421950	8687	30	30
69421970	8687	352	176
69422425	8687	0	0
69422247	8687	740	62
69422073	8687	0	0
69422255	8687	740	62
69422527	8687	0	0
69422516	8687	0	0
64421489	8687	12	12
64420559	8687	150	50
64421310	8687	504	56
69422350	8687	0	0
64422613	8687	548	61
64422614	8687	548	61
69422436	8687	0	0
69422098	8687	320	46
69422100	8687	960	120
69422110	8687	200	20
64423829	8687	85	43
64423830	8687	85	43
64421775	8687	500	125
64421776	8687	500	125
64422064	8687	750	68
64422065	8687	750	68
69420020	8687	130	43
69420021	8687	130	43
69420022	8687	0	0
69420023	8687	0	0
69420251	8687	250	63
69420252	8687	250	63
69420703	8687	1288	129
69421447	8687	8000	170
69421696	8687	4616	159
69421963	8687	490	54
69421592	8687	40	40
69421593	8687	40	40
64422036	8687	40	20
64422037	8687	40	20
64421919	8687	95	32
64421920	8687	95	32
64423614	8687	125	42
64423615	8687	125	42
64423710	8687	5	5
64423711	8687	5	5
69421379	8687	40	40

D2

D2 THE SAMPLE OUTPUT OF PROGRAMS

## Sample Output of ATTRES Program

POSITIONAL FILE FOR ATTRIBUTE 2

DETNO	ATTRIBUTE NAME	PIVOT POINT			LEVER POINT		
3	CNC 0062	1150.000	900.000	0.0	1050.000	900.000	0.0
3	CNC 0063	1150.000	300.000	0.0	1050.000	300.000	0.0
2	LATH0010	-712.886	-2.232	0.0	-612.886	-2.232	0.0
2	LATH0009	-1050.000	800.000	0.0	-1000.000	886.602	0.0
2	LATH0008	-1050.000	650.000	0.0	-1000.000	736.602	0.0
7	FRKLO023	-650.000	-350.000	0.0	-550.000	-350.000	0.0
7	FRKLO023	150.000	550.000	0.0	50.000	550.000	0.0
7	FRKLO023	400.000	-850.000	0.0	400.000	-750.000	0.0
7	FRKLO023	-834.926	-862.459	0.0	-834.925	-762.459	0.0
7	FRKLO023	300.000	-350.000	0.0	370.710	-279.289	0.0
7	FRKLO023	400.000	800.000	0.0	400.000	900.000	0.0
7	FRKLO023	-800.000	800.000	0.0	-800.000	700.000	0.0
2	LATH0007	-1050.000	500.000	0.0	-1000.000	586.602	0.0
2	LATH0005	-1050.000	350.000	0.0	-1000.000	436.602	0.0
2	LATH0006	-1050.000	200.000	0.0	-1000.000	286.602	0.0
6	MILLO054	-247.055	-898.178	0.0	-247.055	-798.178	0.0
3	CNC 0064	1153.418	-350.490	0.0	1053.418	-350.490	0.0
5	CNC 0045	-750.000	950.000	0.0	-750.000	850.000	0.0
5	CNC 0043	-50.000	950.000	0.0	-50.000	850.000	0.0
5	CNC 0044	-395.883	948.780	0.0	-395.883	848.780	0.0
1	RBT 0033	-415.230	811.857	0.0	-415.230	711.857	0.0
1	RET 0032	-50.602	799.951	0.0	-50.602	699.951	0.0
4	CNC 0019	63.996	494.853	0.0	63.996	394.853	0.0
4	CNC 0018	250.000	250.000	0.0	150.000	250.000	0.0
4	CNC 0017	-750.000	-250.000	0.0	-650.000	-250.000	0.0
5	CNC 0046	-750.094	149.572	0.0	-650.094	149.572	0.0
5	CNC 0041	300.000	-250.000	0.0	300.000	-150.000	0.0
1	RET 0037	0.0	250.000	0.0	70.711	320.710	0.0
1	RET 0012	0.0	100.000	0.0	100.000	100.000	0.0
1	RBT 0034	-425.648	249.287	0.0	-525.648	249.287	0.0
2	LATH0011	-350.000	-200.000	0.0	-350.000	-100.000	0.0
2	LATH0012	-150.000	-200.000	0.0	-150.000	-100.000	0.0
6	MILLO055	302.121	-896.690	0.0	302.121	-796.690	0.0
4	CNC 0024	-1159.371	-634.752	0.0	-1159.371	-734.751	0.0
4	CNC 0021	-967.383	-174.873	0.0	-967.383	-74.873	0.0
4	PIVOT	-967.383	-174.873	0.0	-967.383	-74.873	0.0
4	CNC 0023	-958.453	-585.638	0.0	-958.453	-485.638	0.0
4	CNC 0025	-964.406	-948.780	0.0	-964.406	-848.780	0.0
4	CNC 0020	-1157.883	164.455	0.0	-1157.883	64.455	0.0
4	CNC 0022	-1166.813	-252.264	0.0	-1166.812	-352.264	0.0

Sample Output of IMPROV Program

Notes:

1. Part 1 of the output is the facility X,Y location data used in the program.
2. Part 2 prints default value of deflection and the facility identity (22) used in optimisation calculations.
3. Part 3 shows values of local optimisation during iteration. Initial sum of Cost X Distance matrix, decreasing sum with corresponding X,Y coordinates is given at this stage.
4. Next three tables print first 10 values of cost, flow and distance matrices respectively as calculated by the program.
5. Finally new location data has been updated in the location file the facility 22.

1	LG-01	28.500	16.750
2	LG-02	14.960	20.630
3	LG-03	41.500	10.100
4	LG-04	24.720	16.000
5	LG-05	41.600	29.820
6	LG-06	9.500	6.000
7	LG-07	14.550	9.000
8	LG-08	35.290	16.310
9	LG-09	23.250	17.850
10	LG-10	21.150	20.740
11	LG-11	34.690	37.270
12	LG-12	132.950	47.630
13	LG-13	10.770	7.600
14	LG-14	38.650	12.060
15	LG-15	22.080	16.890
16	LG-16	14.000	9.870
17	LG-17	24.910	17.990
18	LG-18	10.800	7.800
19	LG-19	24.950	12.250
20	LG-20	8.600	9.150
21	LG-21	28.700	19.370
22	LG-22	21.080	17.590
23	LG-23	9.250	6.100
24	LG-24	6.100	9.200
25	LG-25	17.800	12.900
26	LG-26	20.490	12.620
27	LG-27	23.480	21.300
28	LG-28	13.600	11.050
29	LG-29	15.250	6.450
30	LG-30	16.880	8.220
31	LG-31	8.200	6.560
32	LG-32	29.070	20.840
33	LG-33	10.500	11.820
34	LG-34	30.510	15.430
35	LG-35	20.060	15.540
36	LG-36	8.900	6.500
37	LG-37	18.770	12.000
38	LG-38	11.820	-10.500
39	LG-39	16.000	-24.720
40	LG-40	16.000	-24.720

DX= 1.38MACHINE= LG-22

1410.9031	1413.4946	8.0156	4.5256
1410.9031	1412.1807	7.6718	4.1818
1410.9031	1411.5364	7.8437	4.3537
1410.9031	1411.2180	7.9296	4.4396
1410.9031	1411.0601	7.9726	4.4826
1410.9031	1410.9814	7.9941	4.5041

1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2600.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	170.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(Continued on next page)



### Sample Output of INALYS Program

(Data extracted from the Original Layout of Industrial Test Case)

INDEX No.	DET. NO.	PIVOT POINT (X,Y,Z)		LEVER POINT (X,Y,Z)			
1	26	4009.96	3130.15	0.0	109.00	0.0	0.0
2	30	3354.74	1937.58	0.0	340.88	0.0	0.0
3	26	4009.96	2630.15	0.0	109.00	0.0	0.0
4	26	2050.75	3796.27	0.0	109.00	0.0	0.0
5	10	1931.58	5309.21	0.0	37.40	0.0	0.0
6	36	1458.12	5537.25	0.0	103.00	0.0	0.0
7	26	4009.96	1530.15	0.0	109.00	0.0	0.0
8	26	4009.96	2130.15	0.0	109.00	0.0	0.0
9	26	4009.96	3530.15	0.0	109.00	0.0	0.0
10	27	4050.19	4023.13	0.0	192.50	0.0	0.0
11	31	1145.71	5720.15	0.0	81.59	-0.00	0.0
12	31	1145.71	5020.15	0.0	81.59	-0.00	0.0
13	21	537.39	4939.12	0.0	67.91	0.0	0.0
14	19	293.82	5743.82	0.0	45.28	0.0	0.0
15	21	537.39	4339.12	0.0	67.91	0.0	0.0
16	21	637.60	5708.11	0.0	67.91	0.0	0.0
17	3	3328.91	2367.62	0.0	200.00	0.0	0.0
18	3	3004.40	4784.97	0.0	188.50	0.0	0.0
19	3	3004.40	5384.96	0.0	188.50	0.0	0.0
20	4	4046.37	4841.94	0.0	273.50	0.0	0.0
21	17	3271.46	1393.19	0.0	57.00	0.0	0.0
22	16	4188.31	612.66	0.0	222.00	0.0	0.0
23	23	2688.99	870.68	0.0	23.62	0.0	0.0
24	32	2454.03	3341.61	0.0	105.50	0.0	0.0
25	27	1014.55	1053.48	0.0	325.00	0.0	0.0
26	24	2381.47	1118.49	0.0	501.18	0.0	0.0
27	11	1901.61	2676.30	0.0	12.20	0.0	0.0
28	11	1515.40	2286.45	0.0	12.20	0.0	0.0
29	7	2233.10	3112.59	0.0	95.50	0.0	0.0
30	11	1515.56	1955.10	0.0	12.20	0.0	0.0
31	12	1525.23	2022.33	0.0	20.67	0.0	0.0
32	15	1460.23	2697.74	0.0	57.00	0.0	0.0
33	15	1460.23	2997.74	0.0	57.00	0.0	0.0
34	25	787.35	1836.32	0.0	325.00	0.0	0.0
35	14	1417.55	1669.44	0.0	86.81	0.0	0.0
36	1	2158.95	2114.79	0.0	87.01	0.0	0.0
37	17	1926.13	1525.17	0.0	26.77	0.0	0.0
38	6	2279.45	1626.20	0.0	44.29	0.0	0.0
39	33	2548.26	1454.65	0.0	143.70	0.0	0.0
40	35	369.88	3033.69	0.0	100.39	0.0	0.0
41	32	2110.47	1348.53	0.0	105.50	0.0	0.0
42	32	2454.03	2041.61	0.0	105.50	0.0	0.0
43	29	2707.79	670.40	0.0	21.65	0.0	0.0
44	18	2362.02	4662.98	0.0	200.00	0.0	0.0
45	18	2362.02	5235.91	0.0	200.00	0.0	0.0
46	18	2158.44	4826.44	0.0	200.00	0.0	0.0
47	18	2158.44	4253.52	0.0	200.00	0.0	0.0
48	18	2158.44	3680.61	0.0	200.00	0.0	0.0
49	18	2362.02	4090.06	0.0	200.00	0.0	0.0
50	5	1547.10	5416.59	0.0	1.00	0.0	0.0
51	2	654.69	4456.12	0.0	123.23	0.0	0.0
52	9	454.87	3833.23	0.0	58.76	0.0	0.0
53	22	1530.99	3691.42	0.0	169.68	0.0	0.0
54	22	661.66	4156.54	0.0	169.68	0.0	0.0
55	13	1540.66	3270.56	0.0	75.79	0.0	0.0
56	34	448.92	3583.95	0.0	51.38	0.0	0.0
57	7	2130.12	2735.69	0.0	95.50	0.0	0.0
58	32	2454.03	2641.61	0.0	105.50	0.0	0.0
59	32	2454.03	2341.61	0.0	105.50	0.0	0.0
60	28	1420.10	2247.40	0.0	105.10	0.0	0.0



### Sample Output of INALYS Program

(Data extracted on the centre of the facilities)

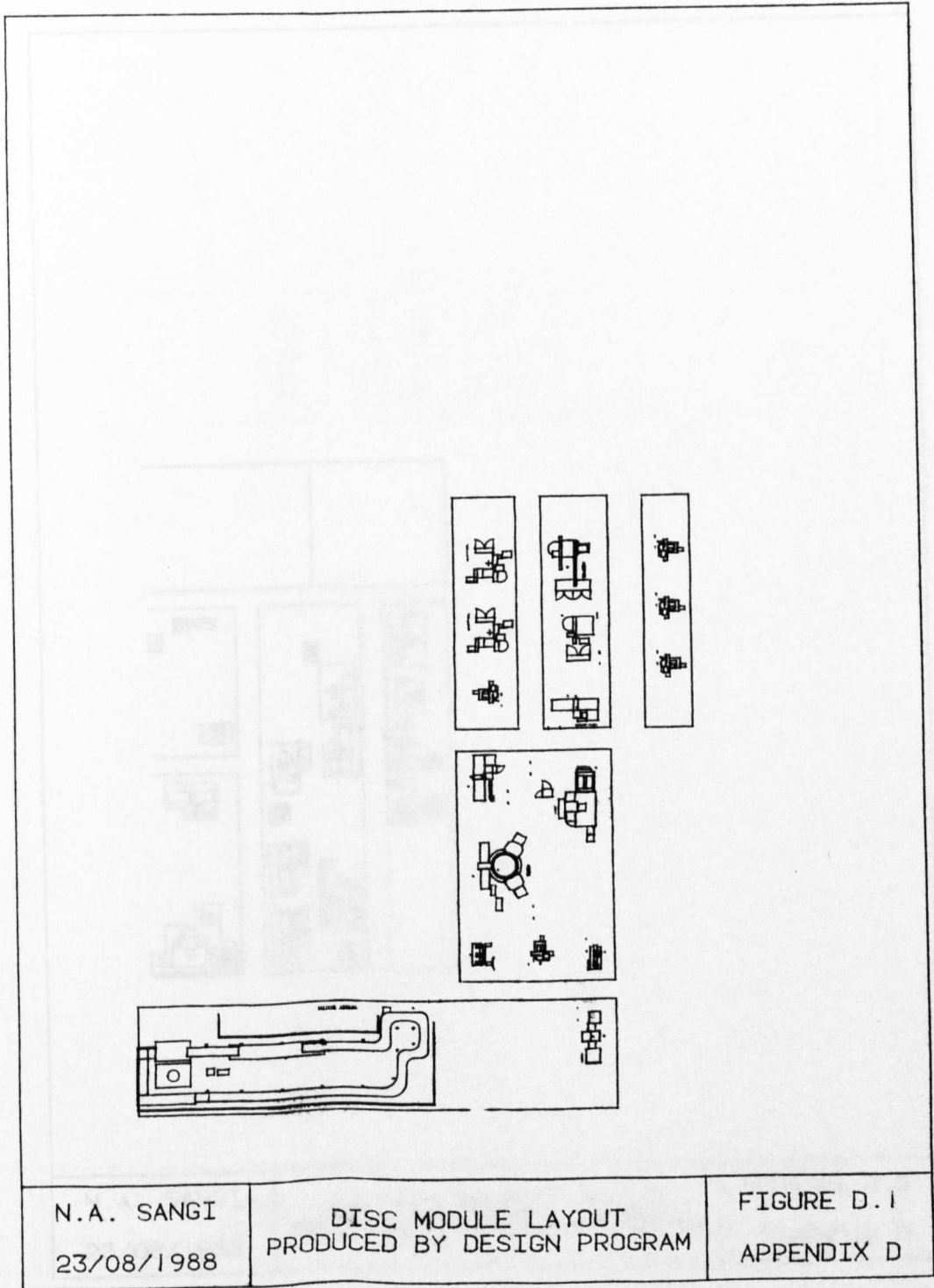
INDEX No.	CENTRE POINT (X,Y,Z)			ORIENTATION (X,Y,Z)		
1	64.00	45.50	0.0	1.00	0.0	0.0
2	100.39	46.26	0.0	1.00	0.0	0.0
3	51.38	74.80	0.0	1.00	0.0	0.0
4	143.70	27.95	0.0	1.00	0.0	0.0
5	105.50	50.00	0.0	1.00	0.0	0.0
6	81.59	43.31	0.0	1.00	0.0	0.0
7	340.88	210.48	0.0	1.00	0.0	0.0
8	21.65	11.81	0.0	1.00	0.0	0.0
9	106.10	54.13	0.0	1.00	0.0	0.0
10	192.50	130.25	0.0	1.00	0.0	0.0
11	109.00	95.00	0.0	1.00	0.0	0.0
12	325.00	258.00	0.0	1.00	0.0	0.0
13	501.18	165.85	0.0	1.00	0.0	0.0
14	23.62	18.11	0.0	1.00	0.0	0.0
15	169.68	29.72	0.0	1.00	0.0	0.0
16	67.91	44.09	0.0	1.00	0.0	0.0
17	45.28	23.13	0.0	1.00	0.0	0.0
18	200.00	115.00	0.0	1.00	0.0	0.0
19	26.77	22.63	0.0	1.00	0.0	0.0
20	222.00	82.50	0.0	1.00	0.0	0.0
21	57.00	51.50	0.0	1.00	0.0	0.0
22	86.81	54.13	0.0	1.00	0.0	0.0
23	75.79	50.98	0.0	1.00	0.0	0.0
24	20.67	12.20	0.0	1.00	0.0	0.0
25	12.20	20.47	0.0	1.00	0.0	0.0
26	37.40	50.39	0.0	1.00	0.0	0.0
27	58.76	30.31	0.0	1.00	0.0	0.0
28	200.00	146.50	0.0	1.00	0.0	0.0
29	95.50	80.50	0.0	1.00	0.0	0.0
30	44.29	12.99	0.0	1.00	0.0	0.0
31	68.59	23.52	0.0	1.00	0.0	0.0
32	123.23	41.54	0.0	1.00	0.0	0.0
33	87.01	69.29	0.0	1.00	0.0	0.0
34	19.29	13.78	0.0	1.00	0.0	0.0
35	3900.96	3035.15	0.0	-1.00	0.0	0.0
36	3144.26	2278.46	0.0	0.0	1.00	0.0
37	3900.96	2535.15	0.0	-1.00	0.0	0.0
38	3187.19	3906.47	0.0	1.00	0.0	0.0
39	2078.83	5507.61	0.0	1.00	0.0	0.0
40	1584.11	5626.82	0.0	1.00	0.0	0.0
41	3900.96	1535.15	0.0	-1.00	0.0	0.0
42	3900.96	2035.15	0.0	-1.00	0.0	0.0
43	3900.96	3535.15	0.0	-1.00	0.0	0.0
44	3925.94	4220.62	0.0	0.0	1.00	0.0
45	1316.21	5398.91	0.0	0.0	-1.00	0.0
46	1316.21	4698.91	0.0	0.0	-1.00	0.0
47	425.39	5111.62	0.0	0.0	1.00	0.0
48	384.88	5565.57	0.0	0.0	-1.00	0.0
49	425.39	4711.62	0.0	0.0	1.00	0.0
50	749.60	5535.61	0.0	0.0	-1.00	0.0
51	3182.41	3067.62	0.0	0.0	1.00	0.0
52	3140.65	1537.97	0.0	0.0	1.00	0.0
53	4105.81	834.66	0.0	0.0	1.00	0.0
54	2781.99	541.58	0.0	1.00	0.0	0.0
55	2504.03	3236.11	0.0	0.0	-1.00	0.0
56	1341.54	1308.95	0.0	1.00	-0.01	0.0
57	1256.57	752.99	0.0	-1.00	0.01	0.0
58	1982.21	2628.25	0.0	0.0	-1.00	0.0
59	1596.00	2238.40	0.0	0.0	-1.00	0.0
60	2394.10	2921.59	0.0	0.0	-1.00	0.0

### Sample Output of INALYS Program

(Rectilinear distance calculations)

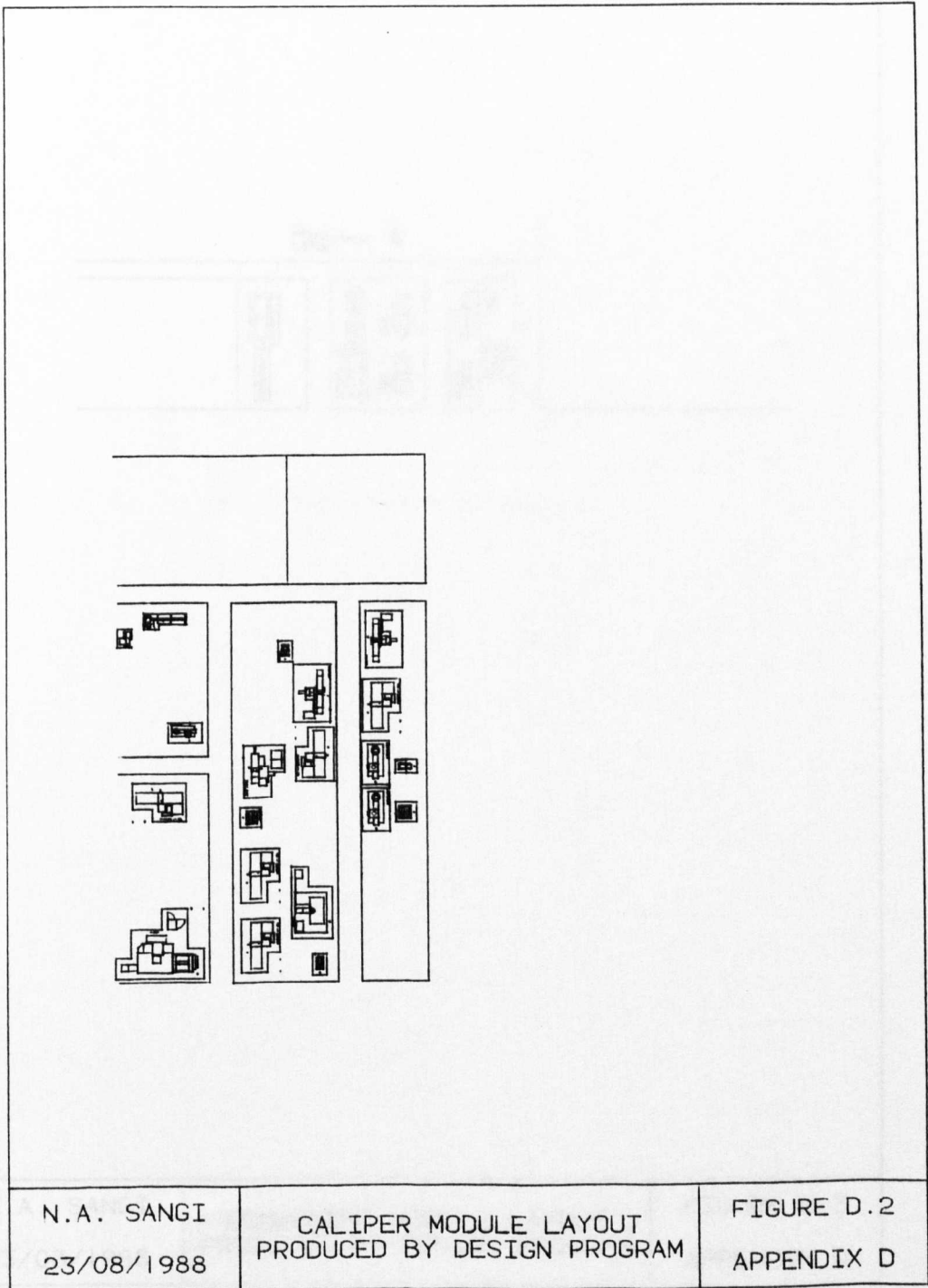
INDEX No.	X-DIST	Y-DIST	TOTAL	CUMULATIVE
1	655.22	1132.57	1847.79	1847.79
2	655.22	692.57	1347.79	3195.57
3	349.21	1156.12	2115.33	5310.90
4	1129.16	1512.94	2642.11	7953.00
5	473.46	228.04	701.50	8654.50
6	2551.84	3937.10	6458.93	15113.43
7	0.0	500.00	500.00	15613.43
8	0.0	1500.00	1500.00	17113.43
9	46.22	397.98	444.21	17557.63
10	2910.48	1692.02	4602.50	22160.13
11	0.0	700.00	700.00	22860.13
12	608.32	81.03	689.35	23549.48
13	243.57	804.70	1048.27	24597.75
14	243.57	1204.70	1448.27	26046.01
15	100.21	1158.99	1269.20	27315.21
16	2691.31	2840.49	5531.80	32847.01
17	324.51	1917.34	2241.86	35088.87
18	0.0	600.00	600.00	35688.86
19	1041.97	543.03	1585.00	37273.86
20	774.92	3448.75	4223.66	41497.52
21	916.86	780.52	1697.38	43194.90
22	1499.33	258.02	1757.35	44952.25
23	234.96	2470.93	2705.88	47658.13
24	1439.48	2288.13	3727.61	51385.74
25	1366.92	65.01	1431.93	52817.66
26	479.86	1557.80	2037.66	54855.32
27	386.21	389.84	776.05	55631.37
28	717.70	826.14	1543.84	57175.21
29	717.54	1157.49	1875.03	59050.24
30	9.67	67.23	76.90	59127.14
31	65.00	675.41	740.41	59867.54
32	0.0	300.00	300.00	60167.54
33	672.38	1151.43	1823.80	62001.34
34	629.70	166.87	796.58	62797.92
35	741.40	445.35	1186.75	63984.66
36	232.82	439.62	722.44	64707.10
37	353.31	1.03	354.34	65061.44
38	268.82	171.55	440.36	65501.80
39	2178.39	1579.04	3757.43	69259.19
40	1740.60	1185.16	2925.75	72184.94
41	343.56	133.08	536.63	72721.56
42	253.76	1371.21	1624.97	74346.50
43	345.77	3992.58	4338.35	78684.81
44	0.0	572.93	572.93	79257.69
45	203.58	409.46	613.04	79870.69
46	0.0	572.92	572.92	80443.56
47	0.0	572.92	572.92	81016.44
48	203.58	409.45	613.03	81629.44
49	814.92	1326.53	2141.44	83770.87
50	892.41	960.46	1852.87	85623.69
51	199.82	622.89	822.72	86446.37
52	1076.12	141.81	1217.93	87664.25
53	969.13	465.12	1334.25	88998.50
54	878.80	835.98	1764.78	90763.25
55	1093.74	318.38	1412.12	92175.31
56	1733.20	853.26	2586.46	94761.75
57	273.91	94.07	367.99	95129.69
58	0.0	300.00	300.00	95429.62
59	1033.93	94.22	1128.14	96557.75
60	1311.10	2247.40	3558.50	100116.19

Sample Output of DESIGN Program



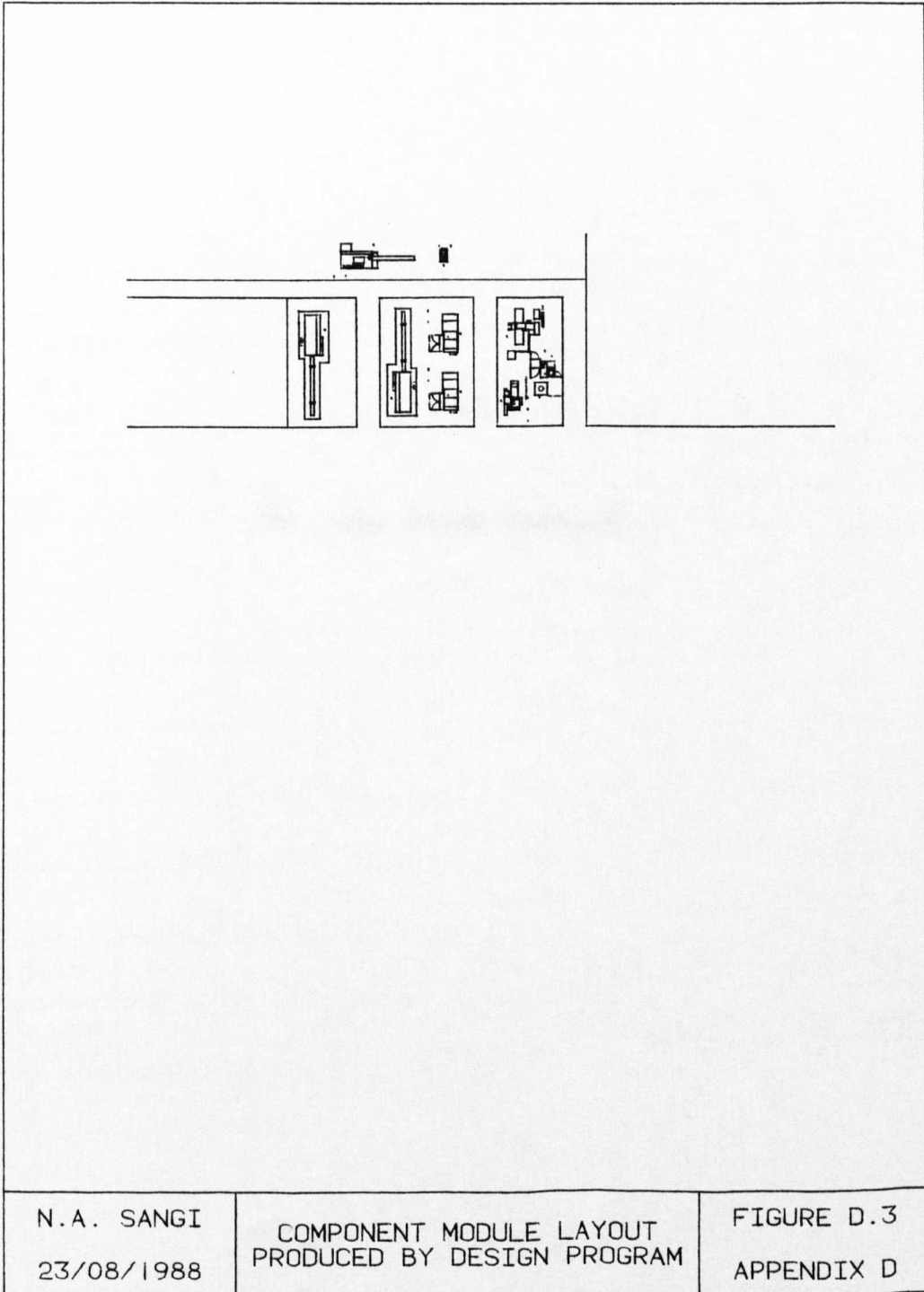
(Continued on next page)

Sample Output of DESIGN Program



(Continued on next page)

Sample Output of DESIGN Program



(Continued on next page)

D3

D3 THE SCREEN TEMPLATES



### Screen Templates

## MEHRAN ANALYSIS MODULE DECISION SUMMARY

FACTORY LUCAS GIRLING....	PROJECT CELLULAR LAYOUT DESIGN
DATE .....	VERSION .....
TIME .....	DESIGNER NAZIR A. SANGI.....

CELL ID.	MINIMUM MOVES	MOVE COSTS	FININ. COST	CONST'T SATSF'N	COMPT'R CHOICE	MNGMT. CHOICE	DES'NER CHOICE	SELECTED ORDER
	1	2	3	4	5	6	7	

TOTAL					DECISION SUPPORT			
-------	--	--	--	--	------------------	--	--	--

WEIGHT FACTOR				
---------------	--	--	--	--

NOTE: RUN "EVALUT" PROGRAM TO GET UPDATE SUMMARY.

Screen Templates

MEHRAN ANALYSIS MODULE LOCATION SUMMARY

FACTORY LUCAS GIRLING....	PROJECT CELLULAR LAYOUT DESIGN
CELL .....	DESIGNER NAZIR A. SANGI.....
(PLEASE RUN XXXXXX PROGRAM FIRST TO GET UPTODATE INFORMATION)	

FACILITY NO. IDENTITY	LOCATION (X,Y)		ORIENTATION
	CENTER	LOAD/UNLOAD	ANGLE (DEG)
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			



Screen Templates

MEHRAN FACILITIES DATABASE

MEHRAN ANALYSIS MODULE DISTANCE SUMMARY

FACTORY LUCAS GIRLING....	PROJECT CELLULAR LAYOUT DESIGN
CELL .....	DESIGNER NAZIR A. SANGI.....
(PLEASE RUN XXXXXX PROGRAM FIRST TO GET UPTO DATE INFORMATION)	

NO.	FACILITY		DISTANCE		TOTAL
	FROM	TO	CENTRIODS	RECTILINEAR	TRAFFIC
1.	ORIGIN				
2.	CENTER				
3.	LOAD POINT				
4.	UNLOAD PT.				
5.	HEIGHT				
6.	WID. X LEN.				
7.	WEIGHT				
8.	SERVICES				
9.	ELECT. (KW)				
10.	AIR (CARG)				
11.	GAS (CARG)				
12.	SPECIAL				
13.	NOISE CLASS				
14.	SAFETY CLASS				
15.	SIZE CLASS				
16.	FACILITY INDEX				
17.	AREA INDEX				
18.	SPECIAL				
19.					
20.					

Screen Templates

MEHRAN FACILITIES DATABASE

FACTORY LUCAS GIRLING....      PROJECT CELLULAR LAYOUT DESIGN FACILITY .....      DESIGNER NAZIR A. SANGI..... (PLEASE RUN XXXXXXX PROGRAM FIRST TO GET UPTODATE INFORMATION)	
<ol style="list-style-type: none"> <li>1. TOTAL AREA</li> <li>2. NET AREA</li> <li>3. ORIGIN</li> <li>4. CENTER</li> <li>5. LOAD POINT</li> <li>6. UNLOAD PT.</li> <li>7. HEIGHT</li> <li>8. WID. X LEN.</li> <li>9. WEIGHT</li> <li>10. SERVICES:</li> <li>11. ELECT. (KW)</li> <li>12. AIR (BARS)</li> <li>13. GAS (BARS)</li> <li>14. SPECIAL?</li> <li>15. NOISE CLASS</li> <li>16. SAFETY CLASS</li> <li>17. SIZE CLASS</li> <li>18. FACILITY INDEX</li> <li>19. AREA INDEX</li> <li>20. SPECIAL</li> </ol>	DRAW ID. DATE                      SCALE

**D4**

**D4    SUMMARY STATISTICS**  
**(47 FACILITIES)**

## Summary Statistics - Design Time

(All Facilities)

Serial Number	Facilities Identity	CATIA Time	CADAM Time	Total Time of Solids	Number of Sessions	Number of 2D to 3D	Source Facility	Derived Facility
1	LG-33	6	20	26	5	1	0	0
2	LG-05	10	10	20	4	1	0	0
3	LG-07	10	22	32	4	1	0	0
4	LG-25	11	22	33	4	1	0	0
5	LG-23	17	20	37	7	1	0	0
6	LG-36	18	35	53	7	1	0	0
7	LG-24	20	27	47	11	1	0	0
8	LG-08	20	33	53	21	1	0	1
9	LG-48	21	34	55	6	1	0	0
10	LG-13	23	32	55	6	1	0	0
11	LG-12	24	29	53	12	1	0	0
12	LG-77	26	30	56	8	1	0	0
13	LG-22	27	21	48	16	1	0	1
14	LG-02	28	31	59	8	1	0	0
15	LG-34	40	24	64	9	1	0	0
16	LG-50	40	26	66	12	1	0	0
17	MG-04	40	25	65	8	3	0	0
18	LG-15	43	29	72	11	1	0	0
19	LG-73	45	20	65	12	2	0	0
20	LG-46	45	30	75	11	1	0	0
21	LG-14	50	27	77	8	1	0	0
22	MG-03	50	28	78	21	1	0	1
23	LG-35	52	23	75	14	1	0	0
24	LG-06	53	24	77	17	2	0	0
25	LG-01	54	26	80	12	2	0	0
26	LG-61	55	41	96	19	2	0	0
27	LG-55	60	30	90	11	2	0	0
28	LG-76	61	30	91	10	1	0	0
29	LG-19	63	26	89	10	2	0	0
30	LG-03	65	33	98	10	3	0	0
31	LG-27	70	23	93	10	1	0	0
32	MG-01	75	36	111	9	2	0	0
33	LG-20	80	33	113	15	2	0	0
34	LG-09	82	23	105	10	2	0	0
35	LG-30	91	31	122	10	1	0	0
36	LG-40	100	32	132	16	4	0	0
37	LG-57	120	26	146	6	1	0	0
38	MG-02	120	38	158	21	1	0	0
39	LG-58	150	30	180	18	3	0	0
40	MG-05	165	30	195	20	1	0	0
41	MG-09	190	30	220	14	3	0	0
42	LG-04	210	41	251	12	3	0	0
43	LG-39	260	52	312	36	6	1	0
44	MG-08	280	30	310	17	6	0	0
45	MG-10	290	30	320	14	3	0	0
46	MG-07	310	25	335	18	3	0	0
47	MG-06	340	32	372	6	6	1	0
	<b>Total</b>	<b>4010.00</b>	<b>1350.00</b>	<b>5360.00</b>	<b>566.00</b>	<b>88.00</b>	<b>2.00</b>	<b>3.00</b>
	<b>Average</b>	<b>85.32</b>	<b>28.72</b>	<b>114.04</b>	<b>12.04</b>	<b>1.87</b>	<b>0.04</b>	<b>0.06</b>

## Summary Statistics - Design Time

(Industrial Test Case Facilities)

Serial Number	Facilities Identity	CATIA Time	CADAM Time	Total Time of Solids	Number Sessions	Number of 2D to 3D	Source Facility	Derived Facility
1	LG-33	6	20	26	5	1	0	0
2	LG-05	10	10	20	4	1	0	0
3	LG-07	10	22	32	4	1	0	0
4	LG-25	11	22	33	4	1	0	0
5	LG-23	17	20	37	7	1	0	0
6	LG-36	18	35	53	7	1	0	0
7	LG-24	20	27	47	11	1	0	0
8	LG-08	20	33	53	21	1	0	1
9	LG-48	21	34	55	6	1	1	0
10	LG-13	23	32	55	6	1	0	0
11	LG-12	24	29	53	12	1	0	0
12	LG-77	26	30	56	8	1	0	0
13	LG-22	27	21	48	16	1	0	1
14	LG-02	28	31	59	8	1	1	0
15	LG-50	40	26	66	12	1	1	0
16	LG-34	40	24	64	9	1	0	0
17	LG-15	43	29	72	11	1	0	0
18	LG-46	45	30	75	11	1	1	0
19	LG-73	45	20	65	12	2	0	0
20	LG-14	50	27	77	8	1	0	0
21	LG-35	52	23	75	14	1	0	0
22	LG-06	53	24	77	17	2	0	0
23	LG-01	54	26	80	12	2	0	0
24	LG-61	55	41	96	19	2	0	0
25	LG-55	60	30	90	11	2	0	0
26	LG-76	61	30	91	10	1	0	0
27	LG-19	63	26	89	10	2	0	0
28	LG-03	65	33	98	10	3	0	0
29	LG-27	70	23	93	10	1	0	0
30	LG-20	80	33	113	15	2	0	0
31	LG-09	82	23	105	10	2	0	0
32	LG-30	91	31	122	10	1	0	0
33	LG-40	100	32	132	16	4	1	0
34	LG-57	120	26	146	6	1	0	0
35	LG-58	150	30	180	18	3	0	0
36	LG-04	210	41	251	12	3	0	0
37	LG-39	260	52	312	36	6	1	0
Total		2,150.00	1,046.00	3,196.00	418.00	59.00	6.00	2.00
Average		58.11	28.27	86.38	11.30	1.59	0.16	0.05

## Summary Statistics - Design Time

(Prototype Test Case Facilities)

Serial Number	Facilities Identity	CATIA Time	CADAM Time	Total Time of	Number of Solids	Number of Sessions	Source 2D to 3D	Derived Facility
1	MG-04	40	25	65	8	3	0	0
2	MG-03	50	28	78	21	1	0	1
3	MG-01	75	36	111	9	2	0	0
4	MG-02	120	38	158	21	1	0	0
5	MG-05	165	30	195	20	1	0	0
6	MG-09	190	30	220	14	3	0	0
7	MG-08	280	30	310	17	6	0	0
8	MG-10	290	30	320	14	3	0	0
9	MG-07	310	25	335	18	3	0	0
10	MG-06	340	32	372	6	6	1	0
Total		1860.00	304.00	2164.00	148.00	29.00	1.00	1.00
Average		186.00	30.40	216.40	14.80	2.90	0.10	0.10

## Summary Statistics - Storage

(All Facilities)

Serial Number	Facility Identity	Level 1 Outline	Level 2 Facility	level 3 Faci+Out	Unmodified Plan view	Total CADAM	CATIA Solid
1	LG-05	0.27	0.34	0.48	0.33	1.55	15.12
2	LG-33	0.22	0.41	0.50	0.42	1.92	9.59
3	LG-07	0.21	0.40	0.50	0.42	1.79	9.66
4	LG-25	0.22	0.48	0.57	0.49	2.27	9.23
5	LG-02	0.67	0.57	0.76	0.52	2.83	26.26
6	LG-23	0.22	0.57	0.66	0.61	2.77	12.52
7	LG-57	0.23	0.58	0.67	0.66	3.45	28.20
8	LG-73	0.22	0.59	0.69	0.73	4.34	17.75
9	LG-34	0.27	0.58	0.72	0.73	4.53	14.90
10	LG-48	0.22	0.64	0.73	0.80	4.36	12.10
11	LG-13	0.31	0.59	0.78	0.87	3.60	14.09
12	MG-01	0.22	0.95	0.88	0.87	5.25	32.10
13	LG-30	0.23	0.79	0.89	0.87	4.04	15.00
14	LG-09	0.29	0.63	0.77	0.94	4.41	27.27
15	LG-36	0.32	0.43	0.62	0.94	4.26	15.17
16	LG-24	0.30	1.02	1.12	0.98	12.13	87.09
17	LG-77	0.22	0.69	0.79	0.98	4.33	14.40
18	LG-15	0.22	0.64	0.74	1.01	5.93	20.05
19	MG-05	0.22	0.62	0.71	1.02	8.12	39.92
20	LG-27	0.28	0.79	0.93	1.05	4.29	28.83
21	LG-19	0.26	0.89	1.04	1.10	5.02	16.12
22	LG-35	0.31	0.90	0.90	1.20	7.11	56.39
23	LG-12	0.34	1.03	1.23	1.20	5.93	42.85
24	MG-04	0.22	0.93	1.02	1.20	9.07	24.27
25	LG-14	0.22	0.71	0.80	1.29	6.62	17.19
26	LG-46	0.19	1.04	1.17	1.29	7.14	18.61
27	LG-50	0.27	0.79	0.93	1.36	6.26	19.68
28	LG-01	0.32	1.06	1.20	1.37	5.81	20.45
29	LG-04	0.26	0.98	1.10	1.50	6.67	52.05
30	LG-03	0.27	0.81	0.95	1.52	8.36	56.82
31	LG-76	0.23	0.79	0.88	1.55	7.31	18.47
32	LG-40	0.36	1.44	1.68	1.59	7.54	29.10
33	LG-20	0.32	1.07	1.26	1.69	7.95	56.40
34	MG-03	0.41	2.16	2.30	1.78	8.20	44.38
35	LG-58	0.27	1.13	1.27	2.44	9.17	51.92
36	LG-22	0.23	1.19	1.29	2.46	11.29	30.28
37	LG-61	0.22	1.21	1.30	2.58	13.41	92.67
38	LG-08	0.23	1.15	1.25	2.70	11.79	34.45
39	LG-55	0.23	0.93	1.02	2.86	13.55	36.83
40	MG-02	0.41	1.51	1.65	3.21	12.71	47.41
41	LG-06	0.27	1.18	1.32	3.26	12.77	30.66
42	MG-06	0.22	0.85	0.95	3.40	12.45	169.89
43	MG-10	0.18	1.79	1.85	4.20	19.30	54.24
44	MG-08	0.18	0.62	0.67	4.31	25.26	74.36
45	MG-09	0.22	1.24	1.33	5.40	18.00	58.71
46	LG-39	0.39	4.52	4.61	9.47	33.97	228.08
47	MG-07	0.16	1.94	1.99	17.79	70.69	92.16
Total		12.55	46.17	51.47	98.96	449.52	1,923.69
Average		0.27	0.98	1.10	2.11	9.56	40.93

**Summary Statistics - Storage**

(Industrial Test Case Facilities)

Serial Number	Facility Identity	Level 1 Outline	Level 2 Facility	level 3 Faci+Out	Unmodified Plan view	Total CADAM	CATIA Solid
1	LG-01	0.32	1.06	1.20	1.37	5.81	20.45
2	LG-02	0.67	0.57	0.76	0.52	2.83	26.26
3	LG-03	0.27	0.81	0.95	1.52	8.36	56.82
4	LG-04	0.26	0.98	1.10	1.50	6.67	52.05
5	LG-05	0.27	0.34	0.48	0.33	1.55	15.12
6	LG-06	0.27	1.18	1.32	3.26	12.77	30.66
7	LG-07	0.21	0.40	0.50	0.42	1.79	9.66
8	LG-08	0.23	1.15	1.25	2.70	11.79	34.45
9	LG-09	0.29	0.63	0.77	0.94	4.41	27.27
10	LG-12	0.34	1.03	1.23	1.20	5.93	42.85
11	LG-13	0.31	0.59	0.78	0.87	3.60	14.09
12	LG-14	0.22	0.71	0.80	1.29	6.62	17.19
13	LG-15	0.22	0.64	0.74	1.01	5.93	20.05
14	LG-19	0.26	0.89	1.04	1.10	5.02	16.12
15	LG-20	0.32	1.07	1.26	1.69	7.95	56.40
16	LG-22	0.23	1.19	1.29	2.46	11.29	30.28
17	LG-23	0.22	0.57	0.66	0.61	2.77	12.52
18	LG-24	0.30	1.02	1.12	0.98	12.13	87.09
19	LG-25	0.22	0.48	0.57	0.49	2.27	9.23
20	LG-27	0.28	0.79	0.93	1.05	4.29	28.83
21	LG-30	0.23	0.79	0.89	0.87	4.04	15.00
22	LG-33	0.22	0.41	0.50	0.42	1.92	9.59
23	LG-34	0.27	0.58	0.72	0.73	4.53	14.90
24	LG-35	0.31	0.90	0.90	1.20	7.11	56.39
25	LG-36	0.32	0.43	0.62	0.94	4.26	15.17
26	LG-39	0.39	4.52	4.61	9.47	33.97	228.08
27	LG-40	0.36	1.44	1.68	1.59	7.54	29.10
28	LG-46	0.19	1.04	1.17	1.29	7.14	18.61
29	LG-48	0.22	0.64	0.73	0.80	4.36	12.10
30	LG-50	0.27	0.79	0.93	1.36	6.26	19.68
31	LG-55	0.23	0.93	1.02	2.86	13.55	36.83
32	LG-57	0.23	0.58	0.67	0.66	3.45	28.20
33	LG-58	0.27	1.13	1.27	2.44	9.17	51.92
34	LG-61	0.22	1.21	1.30	2.58	13.41	92.67
35	LG-73	0.22	0.59	0.69	0.73	4.34	17.75
36	LG-76	0.23	0.79	0.88	1.55	7.31	18.47
37	LG-77	0.22	0.69	0.79	0.98	4.33	14.40
	sum	10.11	33.56	38.12	55.78	260.47	1,286.25
	Average	0.27	0.91	1.03	1.51	7.04	34.76



### Summary Statistics - Storage

(Prototype Test Case Facilities)

Serial Number	Facility Identity	Level 1 Outline	Level 2 Facility	Level 3 Faci+Out	Unmodified Plan view	Total CADAM	CATIA Solid
1	MG-01	0.22	0.95	0.88	0.87	5.25	32.10
2	MG-02	0.41	1.51	1.65	3.21	12.71	47.41
3	MG-03	0.41	2.16	2.30	1.78	8.20	44.38
4	MG-04	0.22	0.93	1.02	1.20	9.07	24.27
5	MG-05	0.22	0.62	0.71	1.02	8.12	39.92
6	MG-06	0.22	0.85	0.95	3.40	12.45	169.89
7	MG-07	0.16	1.94	1.99	17.79	70.69	92.16
8	MG-08	0.18	0.62	0.67	4.31	25.26	74.36
9	MG-09	0.22	1.24	1.33	5.40	18.00	58.71
10	MG-10	0.18	1.79	1.85	4.20	19.30	54.24
	sum	2.44	12.61	13.35	43.18	189.05	637.44
	Average	0.24	1.26	1.34	4.32	18.91	63.74

### Average Storage of Facilities

Description	Prototype Test Case (Kbytes)	Industrial Test Case (Kbytes)	Overall Average (Kbytes)	Maximum Possible Facilities *
3-D Solids	63.74	34.76	40.93	24
2-D Total	18.91	7.04	9.56	-NA-
2-D Plan (original)	4.32	1.51	2.11	37
2-D Plan (Facility+Outline)	1.34	1.03	1.10	72 #
2-D Plan (Facility)	1.26	0.91	0.98	81 #
2-D Plan (Outline)	0.24	0.27	0.27	296 #

\* Based on CATIA file size (1000 Kbytes) and CADAM file size (80 Kbytes).

# Limited to 63 unique machine tools by number of details.

## **APPENDIX E**

### **THE INTERNATIONAL SURVEY**

- E1 THE QUESTIONNAIRE**
- E2 SURVEY RESPONDENTS AND MAILING LIST**
- E3 SOFTWARE, MODELS AND COMPUTERS**
- E4 SURVEY RESPONSES**
- E5 SURVEY ILLUSTRATIONS**

E1

**THE QUESTIONNAIRE  
(WITH SUMMARY RESPONSES)**

THE DEVELOPMENT OF  
COMPUTER-AIDED FACILITIES LAYOUT (CAFL) SYSTEMS  
INTERNATIONAL SURVEY 1985

N.A. Sangi  
J. Driscoll  
Department of Industrial Studies  
The University of Liverpool,  
Liverpool L69 3BX  
England

SECTION A

PERSONAL INFORMATION ON AUTHORS/USERS

A.1	Name .....	61.....
A.2	Mailing Address .....	
	.....	
	.....	
A.3	Telephone No. .... Telex No. ....	
A.4	Would you describe your Computer Aided Facilities Layout (CAFL) interests as:	
	1. Development of CAFL software. (Please answer sections B, C and E)	44
	2. Marketing CAFL software (Please answer sections C and D)	6
	3. Use of CAFL software. (Please answer section E)	25
	4. No interests in CAFL (Please skip to section F)	8

---

NOTE Within this questionnaire the following conventions are used.  
[ ] Please tick if applicable  
\* Please delete as applicable  
... Please enter requested information

CAFL INTERNATIONAL SURVEY 1985

SECTION B

DEVELOPMENT OF CAFL SOFTWARE

This section to be answered by CAFL Software AUTHORS

**CAFL INTERNATIONAL SURVEY 1985**

**SECTION B**

**DEVELOPMENT OF CAFL SOFTWARE**

Note : The authors of CAFL software should answer this section.

B.1 When did your CAFL work originally start : 19...**44**

B.2 List significant software or models developed in your CAFL work :

Name of the Program	Started	Completed
1. ....	19... <b>76.</b>	19.... <b>75.</b>
2. ....	19.....	.....
3. ....	19.....	19.....
4. ....	19.....	19.....

B.3 Estimate how many people have significantly contributed in your CAFL work :

1 only	<b>12</b>	2-5	<b>27</b>	6-12	<b>4</b>	12+	<b>3</b>
--------	-----------	-----	-----------	------	----------	-----	----------

B.4 Estimate Total Man Years spent on your CAFL work .....**45**

B.5 Identify the Disciplines/Professions of the people who have contributed in your CAFL team :

Architecture	<b>13</b>	Computer Science	<b>19</b>
Building Science	<b>1</b>	Industrial Engineering	<b>38</b>
Business Administration	<b>5</b>	O.R./Systems Engineering	<b>20</b>
Civil Engineering	<b>3</b>	Other (specify).....	<b>3</b>

B.6 Name the most dominant Discipline/Profession in your CAFL team :

.....**43..**

B.7 Has any program, or any part of program been professionally written? (for commercial/special purposes \*)

Yes **12**                      No **33**    (if no skip to question B.8)

Name the professionally written software versions and host computers of your program.

Software title	Computer	Purpose
1. ....	.....	.....
2. ....	.....	.....
3. ....	.....	.....

B.8 Is your CAFL work still continuing :

Yes **37**                      No **8**    (Discontinued in 19....**8**)

**CAFL INTERNATIONAL SURVEY 1985**

**SECTION C**

**CONTENTS OF CAFL SOFTWARE**

This section to be answered by CAFL software AUTHORS

CAFL INTERNATIONAL SURVEY 1985

SECTION C

CONTENTS OF CAFL SOFTWARE

- Notes: 1. This section only relates to computer based software.  
 2. If more than one significantly different software versions have been developed, SECTION C should be photocopied for each.

C.1 Name of the program .....56

C.2 THE COMPUTER

2.1 Manufacturer ..... Model .....55

2.3 Please identify the peripheral devices used :

Input devices		Output devices	
Card reader	11	Line printer	36
Paper/Magnetic Tape reader	9	Graph plotter	21
Terminal Keyboard	43	Alpha-numeric Terminal	10
Graphic Tablet/Mouse	13	Colour Graphics Terminal	19
Large Digitizer	3	Monochrome graphics Terminal	16
Light pen	8	Other .....	1
Other .....	6		

2.4 Which computer language us used :

Assembler/Machine Code	1	BASIC	12
ALGOL	1	FORTTRAN	31
Other (Please specify) .....	20		

2.5 Does your software rely on commercially available software in order to function (e.g. DOGS, CADAM, CATIA, LOTUS etc.)

Yes 14 No 41

If YES please specify the package .....14

.....  
 .....



C.3 WORKING MODE

3.1 Is the program working mode :           Interactive    **41**           Batch       **18**

3.2 Which of the following tasks are undertaken by the program.

Data verification	<b>30</b>
Layout drafting (CAD)	<b>20</b>
Layout generation (design of a layout)	<b>39</b>
Layout improvement	<b>35</b>
Layout analysis (based on some criteria)	<b>37</b>
Layout simulation (by animation)	<b>2</b>
Dynamic layout analysis (life-cycle evaluation)	<b>4</b>
Dynamic simulation (kinematic movement)	<b>2</b>
3-D solid modelling	<b>1</b>
Other (please specify) .....	<b>10</b>

3.3 Would you describe your CAFL software as being an appropriate application of any of the following Advanced Technologies :

AI Artificial Intelligence	<b>7</b>
ES Expert Systems	<b>8</b>
CAD Computer Aided Design	<b>33</b>
FMS Flexible Manufacturing Systems	<b>10</b>
AMT Advanced Manufacturing Technology	<b>8</b>
Other (please specify) .....	<b>4</b>

3.4 What is the maximum number of facilities that can be dealt within n any one problem?

1-10	<b>5</b>	11-20	<b>8</b>	21-30	<b>5</b>	31-40	<b>8</b>
41-50	<b>2</b>	51-60	<b>5</b>	61-100	<b>6</b>	100 +	<b>17</b>

If the exact number of facilities is known, please specify .....

C.4 DATA VERIFICATION

4.1 Where required, how are the following areas of data verified :

	Not Required	By designer	By computer	Not verified
The layout area	<b>4</b>	<b>27</b>	<b>20</b>	<b>2</b>
Facilities	<b>1</b>	<b>30</b>	<b>17</b>	<b>1</b>
Closeness desirability tables	<b>7</b>	<b>23</b>	<b>11</b>	<b>1</b>
Materials movement information	<b>5</b>	<b>26</b>	<b>19</b>	<b>1</b>
Initial layout designs	<b>6</b>	<b>15</b>	<b>21</b>	<b>2</b>

4.2 Where additional verification takes place, please specify

.....**8**.....  
 .....  
 .....  
 .....

C.5 PROBLEM REPRESENTATION AND GRAPHICS

Layout area.

5.1 Is the layout area represented by:

2-D unlimited space	9	2-D rectangle area	17
2-D matrix	15	2-D variable outline space	13
2-D multi-storey space	3	3-D space	1
Other (please specify) .....			6

Facilities

5.2 Are facilities represented by :

Non-dimensional points	9	2-D unit matrix areas	18
2-D proportional matrix area	14	2-D outline	22
3-D wire frame models	1	3-D solid models	0
Other (please specify) .....			3

5.3 Does your software have the ability to :

Fix facilities	35	Plot architectural detail	5
Plot service mains	9	Consider obstructions	21
Consider traffic systems	23	The database of facilities	19
Use fixed facility shapes	23	To overlay layouts	7
Zoom and window layouts	11	Other (specify) .....	10

5.4 Are there any graphics features in your software not yet defined :

Yes	16	No	29
If YES (please specify) .....			
.....			
.....			

5.5 How is activity within the layout area represented :

Closeness desirability tables	31
Inter-facility movement tables	25
Activity list (e.g. manufacturing programme)	16
Other (please specify) .....	10
.....	
.....	

C.6 LAYOUT DESIGN

6.1 How does your software approach the layout of facilities

Provides drafting system only	2	Go to section D
Improves an existing layout	27	Answer C.6.2
Constructs a new layout	32	Answer C.6.3
Utilizes a special approach	20	

6.2 IMPROVEMENT PROGRAMS.

This section may be passed if your software does not involve an improvement algorithm.

A How is an initial layout created :

Specified by designer	23	Designed by computer	4
Randomly generated	3	Other (specify) .....	0

B Can fixed facilities be specified : Yes 24 No 1

C How are new layouts generated :

Randomly	0	Exchange of neighbours	5
Exchange of equal areas	6	Any exchange	14
Other (please specify) .....			9

D How many facilities are exchanged each time :

Two	10	Three	3	Four	1	Unlimited	9
Other (please specify) .....							5

E Do facilities change shape during exchange : Yes 9 No 17

F How is the improvement process terminated :

After a fixed no. of iterations	3	By the designer	16
Improvement below defined level	12	Other (specify) .....	2

G Can the designer interfere in this process : Yes 19 No 6

6.3 CONSTRUCTION PROGRAMS

This section may be passed if your software does not involve generation of an original layout.

A How are facilities selected for placement on the layout :

Specified by designer	16	In rank order	17
Randomly	2	Other (specify).....	7

If in rank order, describe method of ranking :

.....  
 .....  
 .....

C.6 LAYOUT DESIGN (Continued)

6.3 CONSTRUCTION PROGRAMS (Continued)

B How is the location of each facility determined :

By designer	<b>18</b>	Min/Max criteria position	<b>12</b>
Randomly	<b>2</b>	Other (specify) .....	<b>9</b>

If placed according to criteria, describe criteria :

.....

.....

.....

C Do facilities change shape during placement :      Yes **17**    No **14**

D On completion, is the layout adjusted to suit practical requirements :

Yes	<b>20</b>	No	<b>12</b>
-----	-----------	----	-----------

6.4 OTHER PROCEDURES

A If your procedure is not an improvement or construction approach, describe briefly the basis of the procedure :

.....**20**

.....

.....

.....

B Does the procedure actually produce a layout ?      Yes **13**    No **11**

C.7 LAYOUT EVALUATION

7.1 Which evaluation criteria are employed in the software?

Closeness desirability	<b>27</b>	Answer C.7.2.
Material movement	<b>36</b>	Answer C.7.3.
Financial appraisal	<b>8</b>	Answer C.7.4
Other	<b>11</b>	Answer C.7.5

7.2 CLOSENESS DESIRABILITY MODELS

A Describe the subjective scale for matrix entries :

.....**24**

.....

.....

B Describe how the subjective scale is converted into a numerate scale :  
.....23  
.....  
.....

C Is more than one desirability matrix possible?    Yes 10    No 15

D If YES, describe how the matrices are combined?  
.....10  
.....  
.....  
.....

E Describe how neighbours are identified for scoring purposes :  
.....19  
.....  
.....

7.3 MATERIAL MOVEMENT MODELS

A How are movement distances calculated :

Straight Line distances	18	Rectangular co-ordinate	22
Traffic route length	12	Other (specify).....	5

B How are the start and finish of journeys determined :

Facility centriods	28	Designer specified points	11
Other (specify) .....			3

C How is the distance converted to the layout criteria :

Totalled to give total movement distance	13
Multiplied by cost per distance	14
Multiplied by cost per distance + Fixed movement cost	6
Other (please specify) .....	2
.....	

D Is a material handling system selected as part of the program :

Yes	6	No	29
-----	---	----	----

7.4 FINANCIAL APPRAISAL

A Are any of the following additional costs considered :

Facility Re-location costs	7	Production loss costs	4
Production savings	3		
Other costs/benefits (please specify)	.....1		

.....

B Are any of the following techniques included in the financial evaluation :

Rate of return on capital	2	Discounted cash flow	6
Pay back period	1	Other (specify).....	0

7.5 MISCELLANEOUS EVALUATION

A If your method of layout evaluation has not been adequately covered, please describe your evaluation model here :

.....11

.....

.....

.....

**CAFL INTERNATIONAL SURVEY 1985**

**SECTION D**

**MARKETING OF CAFL SOFTWARE**

This section to be answered by CAFL software COMMERCIAL SUPPLIERS

CAFL INTERNATIONAL SURVEY 1985

SECTION D

MARKETING OF CAFL SOFTWARE

This section is directed at CAFL software sold commercially or used as part of commercial consultancy work.

For non commercial software this section is not required.

Information in this section may be published in the survey analysis. information considered confidential should not therefore be given but marked with the letter "C".

For each piece of commercial software enter :

D.1	Approx. cost.	Estimated number of applications
Software name .....	.....	.....
Supplier & Address .....		
.....		
.....		
Software name .....	.....	.....
Supplier & Address .....		
.....		
.....		
Software name .....	.....	.....
Supplier & Address .....		
.....		
.....		
Software name .....	.....	.....
Supplier & Address .....		
.....		
.....		



**CAFL INTERNATIONAL SURVEY 1985**

**SECTION E**

**THE USE OF CAFL SOFTWARE**

This section to be answered by CAFL software USERS.

SECTION E

THE USE OF CAFL SOFTWARE

Note: This section is directed at the users of either academic or commercial facility layout software.

E.1 For each piece of software you have used answer the following :

A	Name of Software	Supplier	Host computer	In use for
	.....64	.....38	.....35	49 yrs
	.....	.....	.....	...yrs
	.....	.....	.....	...yrs
	.....	.....	.....	...yrs

B On which application has the software been used :  
(eg. Industrial, Office, Building, Warehouse layout etc.)

.....20.....8.....5.....6.....9.....  
.....

E.2 For each phase of the use of cAFL software please indicate the level of ease or difficulty :

(Please rank answers)

1= very difficult 3= Difficult 5= Not difficult 7= Easy 9= very easy

Obtaining information	20
Defining layout criteria	18
Selecting a CAFL program/model	19
Data entry	23
Data validation	21
Running the software	22
Interpreting results	21
Converting results to practical layout	20

F.3 For each piece of software you have used answer the following :  
 (This section should be photocopied for each software)

A Does the software include :  
 (Please grade your answer on the scale 0= Non-existent to 9= excellent)

	Grade
Good documentation	39
Automated data collection	40
Data modification	38
Data verification	39
Interactive working	42
Batch background operation	36
Expert system guidance	39
Error diagnostics	39
Construction layouts	36
Improvement layouts	36
Other (please specify).....	16
On-line graphics	35
2-D	40
3-D	38
Solid modelling	38
Colour	37
Quantitative evaluation	39
Qualitative evaluation	39
Financial criteria	37
Life-cycle costing	40
Complex (please specify) .....	28
Line printer	35
Graphical drawings	34
Other (please specify) .....	20

B Please rate your overall impression of the software :

Very poor 1    Weak 6    Usable 14    Good 17    Very good 5

C Does the present level of the software have any significant shortcomings :

Yes            38            No            5

If YES (please specify) .....

.....

D Are there any additional features you would like to be available :

Yes            33            No            8

If YES (please specify) .....

**CAFL INTERNATIONAL SURVEY 1985**

**SECTION F**

**GENERAL COMMENTS**

**This section to be answered by ALL respondents**

CAFL INTERNATIONAL SURVEY 1985

SECTION F

GENERAL COMMENTS

This space has been provided for your valued comments and suggestions, should you wish to make any.

.....23

.....

.....

.....

.....

.....

.....

If you know of other interested persons to whom we should send a copy of this questionnaire, please identify them here :

Name .....	13	Name .....	
Address .....		Address .....	
.....		.....	
.....		.....	

The authors of this survey wish to thank you for your kind contribution and would appreciate copies of any documentation or publications relating to your Computer Aided Facility Layout (CAFL) work.

Do you wish to receive a personal copy of the survey results :

Yes	45	No	1
-----	----	----	---

Please return the questionnaire to :

CAFL SURVEY  
DEPARTMENT OF INDUSTRIAL STUDIES  
THE UNIVERSITY OF LIVERPOOL  
LIVERPOOL L69 3BX  
ENGLAND

Thank you.

**E2**

**SURVEY RESPONDENTS AND MAILING LIST**

**SURVEY RESPONDENTS**

**COMPUTER AIDED FACILITIES LAYOUT (CAFL)**

**INTERNATIONAL SURVEY 1985-86**

Ref. No.	Name	Country	Sections					
			Answered					
			A	B	C	D	E	F
2	Afentakis, P.	USA	1	1	0	0	0	0
6	Awane, H.	Japan	1	1	2	0	1	1
11	Blair, E.L.	USA	1	1	1	0	0	0
14	Carrie, A.S.	UK	1	1	2	0	3	1
15	Chaudhuri, D.	India	1	1	1	0	1	1
16	Christofides, N.	UK	1	1	1	1	0	1
18	Cox, J.F.	USA	1	1	1	0	0	1
19	Cross, K.F.	USA	1	1	1	0	2	1
20	Cullinane, T.P.	USA	1	1	1	0	2	1
21	Cummings, G.F.	Ireland	1	0	0	0	0	1
22	Cyros, K.L./MIT	USA	1	1	1	1	1	1
23	Deisenroth, M.P.	USA	1	1	1	0	0	1
28	Driscoll, J.	UK	1	1	1	0	1	1
29	Egbelu, P.J.	USA	1	0	0	0	5	0
31	Enscore, E.E. Jr.	USA	1	1	1	0	3	1
34	Fisher, E.L.	USA	1	1	1	0	0	1
35	Flynn, B.B.	USA	1	0	0	0	1	1
36	Fortenberry, J.C.	USA	1	0	0	0	1	1
37	Foulds, L.R.	New Zealand	1	1	1	0	0	1
38	Francis, R.L.	USA	1	1	1	0	1	1
40	Gaston, G.K.	USA	1	1	1	0	0	1
41	Gero, J.S.	Australia	1	1	1	0	0	0
42	Gibson, D.F.	USA	1	1	1	0	0	1
43	Giffin, J.W.	USA	1	1	1	0	0	1
44	Gordon, J.H.	UK	1	1	0	0	1	1
49	Hitchings, G.G.	Ireland	1	1	1	0	1	1
50	Hollier, R.H.	UK	1	1	1	0	1	1
51	Hosni, Y.A.	USA	1	1	1	0	0	0
52	Hutchinson, G.K.	USA	0	1	1	0	0	0
53	Jacobs, R.F.	USA	1	1	1	0	0	1

Ref. No.	Name	Country	Sections					
			Answered					
			A	B	C	D	E	F
56	Kalchik, S.S.	USA	1	0	0	0	0	1
57	Kaltnekar, Z.	Yugoslavia	1	0	0	0	0	0
60	Kletz, T.A.	UK	1	0	0	0	0	0
66	Lewis, W.P.	Australia	1	0	0	0	0	0
67	Lilly, M.T.	Nigeria	1	1	1	0	5	1
69	Mahapatra, P.B.	India	1	1	1	0	0	1
70	Majid, E.E.E.	Kuwait	1	1	1	0	1	0
71	Manivannan, S.	USA	1	1	1	1	0	1
73	Matto, R.	Finland	1	1	1	0	0	0
74	McRoberts, K.	USA	0	0	0	0	1	0
76	Montreuil, B.	Canada	1	1	4	0	6	1
78	Moore, J.M.	USA	1	1	2	1	0	1
81	Nicol, L.M.	UK	1	1	1	0	0	1
84	Nof, S.Y.	USA	1	1	4	0	0	1
86	O'Brien, C.	UK	1	1	4	0	0	1
87	O'Connor, T.	USA	1	0	0	0	0	0
88	Oksala, T.	Finland	1	1	1	0	0	0
89	Orr, J.	USA	1	0	0	0	0	1
90	Oser, J.	Austria	1	0	0	0	1	1
96	Rosenblatt, M.J.	Israel	1	0	0	0	1	1
97	SHARE Program Library	USA	1	0	0	0	0	0
98	Saho, S.	India	1	1	1	0	0	1
101	Seppanen, J.	Finland	1	1	0	0	0	1
103	Shelbourn, K.D.	USA	1	0	0	0	2	1
104	Smith, J.M.	USA	1	1	2	0	0	1
105	Steudel, H.J.	USA	1	1	1	0	0	0
107	Strahan, B.S.	USA	1	0	0	0	0	1
108	Teicholz, E.	USA	1	1	1	0	0	0
114	T & W Systems	USA	1	1	1	1	0	1
115	Vollman, T.E.	USA	1	0	0	0	0	1
116	Warnecke, H.J.	W. Germany	1	1	1	0	1	1
117	Webster, D.B.	USA	1	1	1	0	2	1
120	Wrennall, W.	USA	1	1	1	1	1	1



**SURVEY RESPONDENTS AND MAILING LIST**

**COMPUTER AIDED FACILITIES LAYOUT (CAFL)  
INTERNATIONAL SURVEY 1985-86**

Ref. No.	Name	Country	
1	Abdul-Barr, S.E.Z.	Egypt	No reply
2	Afentakis, P.	USA	
3	Anderson, D.	USA	Postal return
4	Apple, J.M.	USA	Postal return
5	Arndt, G.	New Zealand	No reply
6	Awane, H.	Japan	
7	BASICOMP, Inc.	USA	No reply
8	Bafna, K.M.	USA	No reply
9	Bazzara, M.S.	USA	Postal return
10	Biles, W.E.	USA	No reply
11	Blair, E.L.	USA	
12	Block, E.L.	Australia	No reply
13	Buffa, E.S.	USA	No reply
14	Carrie, A.S.	UK	
15	Chaudhuri, D.	India	
16	Christofides, N.	UK	
17	CAD Group, Inc.	USA	No reply
18	Cox, J.F.	USA	
19	Cross, K.F.	USA	
20	Cullinane, T.P.	USA	
21	Cummings, G.F.	Ireland	
22	Cyros, K.L.	USA	
23	Deisenroth, M.P.	USA	
24	DesRosier, A.G.	USA	No reply
25	Dillon, R.	USA	Postal return
26	Donaghey, C.E.	USA	No reply
27	Drezner, Z.	USA	Postal return
28	Driscoll, J.	UK	
29	Egbelu, P.J.	USA	
30	El-Said-Rashid, F.M.	Egypt	No reply
31	Enscore, E.E. JR.	USA	
32	Erlenkotter, D.	USA	No reply
33	Filley, R.D.	USA	No reply
34	Fisher, E.L.	USA	
35	Flynn, B.S.	USA	
36	Fortenberry, J.C.	USA	
37	Foulds, L.R.	New Zealand	
38	Francis, R.L.	USA	
39	Fuchs, I.	USA	No reply
40	Gaston, G.K.	USA	
41	Gero, J.S.	Australia	
42	Gibson, D.F.	USA	
43	Giffin, J.W.	USA	
44	Gordon, J.H.	UK	
45	Hales, H.L.	USA	No reply
46	Heisterburg, R.J.	USA	Postal return
47	Hill, I.D.	Canada	No reply
48	Hintzman, F.H. JR.	USA	Postal return
49	Hitchings, G.G.	Ireland	
50	Hollier, R.H.	UK	

Ref. No.	Name	Country	
51	Hosni, Y.A.	USA	
52	Hutchinson, G.K.	USA	
53	Jacobs, F.R.	USA	
54	Johnson, K.H.	USA	Postal return
55	Juel, H.	Denmark	Postal return
56	Kalchik, S.A.	USA	
57	Kaltnekar, Z.	Yugoslavia	
58	Kalvaitis, R.	USA	Postal return
59	Khalil, T.M.	USA	Postal return
60	Kletz, T.A.	UK	
61	Kooy, C.	USA	No reply
62	Krawczyk, R.J.	USA	Postal return
63	Lea, K.	USA	Postal return
64	Lee, R.C.	USA	Postal return
65	Levary, R.R.	USA	No reply
66	Lewis, W.P.	Australia	
67	Lilly, M.T.	Nigeria	
68	Love, R.F.	Canada	Postal return
69	Mahapatra, P.B.	India	
70	Majid, E.E.E.	Kuwait	
71	Manivannan, S.	USA	
72	Martinelli, G.	Switzerland	Postal return
73	Matto, R.	Finland	
74	McRoberts, K.	USA	
75	Milner, D.A.	UK	No reply
76	Montreuil, B.	Canada	
77	Moodie, C.	USA	No reply
78	Moore, J.M.	USA	
79	Nawara, G.M.	Saudi Arabia	No reply
80	Neghabatt, F.O.	Iran	No reply
81	Nicol, L.M.	UK	
82	Nikai, S.	Japan	No reply
83	Nisanci, I.M.	Turkey	No reply
84	Nof, S.Y.	USA	
85	Nozari, A.	USA	Postal return
86	O'Brien, C.	UK	
87	O'Conner, T.	USA	
88	Oksala, T.	Finland	
89	Orr, J.	USA	
91	Oser, J.	Austria	
91	Parsons, W.H.	USA	Postal return
92	Raker, D.	USA	No reply
93	Rinderer, D.	USA	No reply
94	Ritzman, L.P.	USA	Postal return
95	Roczaniak, M.	Poland	Postal return
96	Rosenblatt, M.J.	Israel	
97	SHARE Program Library	USA	
98	Saho, S.	India	
99	Saxiabin, M.	Canada	Postal return
100	Sekhan, G.S.	Iraq	No reply

Ref. No.	Name	Country	
101	Seppanen, J.	Finland	
102	Sharman, M.P.	USA	No reply
103	Shelbourn, K.D.	USA	
104	MacGregor-Smith, J.	USA	
105	Steudel, H.J.	USA	
106	Stitt, F.	USA	No reply
107	Strahan, B.S.	USA	
108	Teicholz, E.	USA	
109	Tompkins, J.A.	USA	Postal return
110	Tyberghein, M.B.	USA	Postal return
111	Van-Roy T.J.	Belgium	Postal return
112	Venugopal, S.	India	No reply
113	Vergin, R.C.	Canada	Postal return
114	T & W Systems	USA	
115	Vollman, T.E.	USA	
116	Warnecke, H.J.	W.Germany	
117	Webster, D.B.	USA	
118	White, J.A.	USA	No reply
119	Wilhelm, M.R.	USA	No reply
120	Wrennall, W.	USA	
121	Yoshimoto, K.	Japan	No reply
122	Zoller, K.	W.Germany	Postal return

E3

**SOFTWARE, MODELS AND COMPUTERS**

**COMPUTER AIDED FACILITIES LAYOUT (CAFL)  
INTERNATIONAL SURVEY 1985-86**

Software No.	Software Title	Respondent Reference No.	Sections
1	* AFENTAKIS	2	B
2	ALDEP	15,29,31,38,49 50,74,76,96,117	E
3	ALPS-1 (ALPS)	6	B C E
4	ALVARI	88	B C
5	ARCHADES	120	B E
6	AUTOCAD	19	E
7	BLOCK	37	B C
8	BLOCK/PLAN	43	B C
9	C-STUDY	86	B C
10	CADAPPLE	114	B D
11	CADFLO 1.3 (CADFLO)	76	B C
12	CAFL	71	B C E
13	Computer Aided Facilities Layout	15	B C D
14	CAN-Q	14	E
15	CAPLAD	86	B C
16	* CARRIE - 1	14	B
17	* CARRIE - 2	14	B C
18	CFR	71	B
19	CIA II	23	B
20	CLUMP	31	B C
21	COFAD	29,50,76	E
22	COMPOSITA	88	B
23	CORELAP	14,15,20,29,31 36,38,50,76,78,117	B E
24	CRAFT	14,20,29,31,35 38,44,49,50,67 76,96,117	E
25	Computer Room Layout - CAD	6	B C E
26	* CULLINAIN	20	B C
27	CUTFIT	17	B C D
28	DECOL	49	B C
29	DELTA/PLAN	43	B
30	DELTAHEDRON	37	B
31	Decision Support	120	B
32	DUAL	(50),81	B C
33	EDITOR	103	E
34	ENTREPOT	76	B C
35	EVAL	51	B (C)
36	FADES 1.0 (FADES)	34,84	B C
37	FADES 1.1	34	B
38	FALSA	69	B C
39	FILING I	11	B
40	FILING II	11	B
41	FILING III	11	B C
42	FLAP	117	E
43	FMS MODEL	52	B
44	FOREST	42	B
45	GASTON	40	B C
46	Graph Grammar Model and Algorithm	101	B
47	GRAPPLE	86	B C

Software		Respondent	Sections
No.	Software Title	Reference No.	
48	HABMS	52	B C
49	ICEM FACILITIES	76	E
50	IMAGE	103	E
51	IMPROVE	67	E
52	INDECES	84	B C
53	INLAYT	86	B C
54	INSITE	22	B D
55	INSITE-CAD	22	B C D E
56	INTALA	116	B C E
57	INTERLAY	17	B D
58	INVOPLAN	120	B
59	Knowledge Based Planning	41	B C
60	LAYCON	49	B
61	LAYOPT	73	B C
62	LAYPLA	90	E
63	MACE	98	B
64	MAFLAD I	104	B C
65	MAFLAD II	104	B C
66	Match Layout System	76	B C
67	MCAP	19	B C E
68	MicroCRAFT	51	B C
69	MINICRAFT	18	B C
70	MODULAP	116	B
71	Moment Arm Computation	44	E
72	MS-S1 -S4	67	B C
73	MUGHAL	98	B C
74	OFFICE	53	B C
75	PALLADIO TEST	88	B
76	Planar Graph Model	101	B
77	PLANET	23,29,38,50,74,76	B C E
78	PLANTAPT	14	B C
79	PLANTLAYOUT	51	B
80	RELAY 1, 2A-2B	67,70	B C E
81	RELGEN	51	B (C)
82	RMA/Microvector	120	B E
83	Robotic Cell	52	B
84	SCORELAP	78	B C
85	SEAMPLAN	42	B C
86	SIMSHOP	105	B C
87	SINDECS	84	B C
88	SINDECS-R	84	B C
89	SLPCALC	78	B C D
90	SPACE	108	B C
91	SPACEPLAN 3000	120	C D E
92	SPLAN	37	B
93	Stacker Crane	52	B
94	Terminal Sampling	49	B
95	TRANWARE	38	B C
96	Tree Layout System (Approach)	76	B C
97	TYMCALC	78	D
98	UA1-UA3	28,67	B C E
99	VersaCAD	114	B C D
100	WAD	78	D
101	* WEBSTER	117	B C

\* Authors name

**COMPUTER AIDED FACILITIES LAYOUT (CAFL)  
INTERNATIONAL SURVEY 1985-86**

Software No.	Software Title	*----- Computer Manufacturer -----*	-----* Model
2	ALDEP	Burroughs IBM DEC CDC	 370 Vax  
3	ALPS-1 (ALPS)	Hitachi	M-280
5	ARCHADES	Apple	IIE
6	AUTOCAD	Wang	PC
8	BLOCK/PLAN	IBM	
9	C-STUDY	PRIME	400 - 800
11	CADFLO 1.3 (CADFLO)	Chromatics CDC	CG 1999 Cyber 170 Cyber 180
12	CAFL	IBM IBM	370 4341
13	Computer Aided Facilities Layout	IBM	370
15	CAPLAD	HP	9845
17	* CARRIE - 2	CV (Sun) Acorn DEC	 BBC Micro Vax
20	CLUMP	DEC IBM	Vax 11/750 370
21	COFAD	CDC IBM DEC	Cyber  Vax
23	CORELAP	IBM DEC CDC	370 Vax Cyber
24	CRAFT	IBM CDC CDC DEC DEC	4341 Cyber 170 Cyber 855 20 Vax
25	Computer Room Layout - CAD	Hitachi	M-280
26	* CULLINAIN	IBM	370
27	CUTFIT	DEC IBM	Vax 11/750 PC AT
28	DECOL	DEC	Vax 11/750 Vax 11/780
32	DUAL	DEC	Vax 11/780
33	EDITOR	DEC	Vax 11/750
34	ENTREPOT	Chromatics	CG 1999
35	FVAL	Apple	II
36	FADES 1.0 (FADES)	DEC	Vax 11/750 Vax 11/780
38	FALSA	DEC	20
41	FILING III	Texas Inst. IBM	PC PC
42	FLAP	IBM	PC
45	GASTON	IBM	PC XT

Software No.	Software Title	*---- Computer Manufacturer	----* Model
47	GRAPPLE	PRIME	400 - 800
49	ICEM FACILITIES	CDC	Cyber
50	IMAGE	DEC	PDP 11/34
51	IMPROVE	IBM	4341
52	INDECES	AMDAHL	MTS
53	INLAYT	PRIME	400 - 800
55	INSITE-CAD	IBM	PC AT
56	INTALA	DEC	Vax 11/780
58	INVOPLAN	Sun	
59	Knowledge Based Planning	Sun	2/120
60	LAYCON	DEC	Vax 11/780
61	LAYOPT	Elliot Burroughs	503
62	LAYPLA	DEC	11/750
63	MACE	Burroughs	
64	MAFLAD I	CDC	Cyber 175
65	MAFLAD II	DEC	Vax 11/750
66	Match Layout System	Chromatics CDC	CG 1999 Cyber 170 Cyber 800 VS 100
67	MCAP	Wang	
68	MicroCRAFT	Apple	
69	MINICRAFT	HP	3000
71	Moment Arm Computation	Altos	Micro
72	MS-S1 -S4	IBM	4341
73	MUGHAL	Burroughs	
74	OFFICE	IBM	EC 1030 3033
77	PLANET	IBM CDC DEC Univac	4341 Cyber Vax
78	PLANTAPT	ICL	1900
79	PLANTLAYOUT	Apple	IIe
80	RELAY 1, 2A-2B	ICL IBM	1906S 4341
81	RELGEN	Apple	
82	RMA/Microvector	HP	85
84	SCORELAP	Apple IBM Honeywell	IIe 360
85	SEAMPLAN	HP	2100MX
87	SINDECS	CDC	
88	SINDECS-R	CDC	
89	SLPCALC	IBM Apple Tandy	PC PC PC



Software No.	Software Title	*---- Computer Manufacturer	----* Model
90	SPACE	IBM	XT - AT
91	SPACEPLAN 3000	Sun	
92	SPLAN	DEC	Vax
95	TRANWARE	DEC	Vax
96	Tree Layout System (Approach)	Chromatics	CG 1999
		CDC	Cyber 170
			Cyber 800
			1906S
98	UA1-UA3	ICL	
99	VersaCAD	IBM	
		Tandy	
		HP	
101	* WEBSTER	IBM	3031

\* Authors name

**E4**

**SURVEY RESPONSES**

## Notes

Following conventions are used in preparing this data.

1. The column "Ref. No." represents the reference number of each individual respondent. The names of individuals are also listed.
2. The column "Soft. No." represents the program reference. The list of program titles and "Soft. No." is given in Appendix E3.
3. All other titles of the columns correspond to the question numbers in the actual document (Appendix E1).
4. All questions with multiple options are posted in the same columns with each digit representing one option. The order 1, 2, ... n represents the order of options as shown in an example below.

### Example Question B.5

Order	Option	Order	Option
1.	Architecture	5.	Computer Science
2.	Building Science	6.	Industrial Engineering
3.	Business Administration	7.	O.R/System Engineering
4.	Civil Engineering	8.	Other (specify) .....

5. In questions requiring yes/no answers following codes are used:  
0 or Blank = No answer  
1 = Yes  
2 = No
6. In all other questions the code numbers represent as under:  
0 or Blank = No answer  
1 = Answer  
2, 3, ... = In the option "other" 2,3 ... options were specified.
7. The descriptive answers are recorded as "answer" or "no answer". The text is not recorded in database but is used directly from the questionnaire for comments.
8. The questions requiring a numerical value as an answer (e.g. years of experience) are not coded.

Section A (The Personal Information on Authors/Users)

Ref. No.	Name of Respondent	Country	A.4
2	Afentakis, P	USA	1000
6	Awane, H	Japan	1010
11	Blair, E L	USA	1000
14	Carrie, A S	UK	1010
15	Choudhri, D	India	1010
16	Christofides, N	UK	1100
18	Cox, J F	USA	1000
19	Cross, K F	USA	1010
20	Cullinane, T P	USA	1010
21	Cummings, G F	Ireland	0001
22	Cyros, K L / MIT	USA	1000
23	Deisenroth, M P	USA	1000
28	Driscoll, J	UK	1010
29	Egbelu, P J	USA	0010
31	Enscore, E E Jr.	USA	1010
34	Fisher, E L	USA	1000
35	Flynn, B B (Miss)	USA	0010
36	Fortenberry, J C	USA	0010
37	Foulds, L R	New Zealand	1000
38	Francis, R L	USA	1010
40	Gaston, G K	USA	1000
41	Gero, J S	Australia	1000
42	Gibson, D F	USA	1000
43	Giffin, J W	USA	1000
44	Gordon, J H	UK	1010
49	Hitchings, G G	Ireland	1010
50	Hollier, R H	UK	1010
51	Hosni, Y A	USA	1000
52	Hutchinson, G K	USA	0000
53	Jacobs, R F	USA	1000
56	Kalchik, S S (Miss)	USA	0010
57	Kaltnekar, Z	Yugoslavia	0001
60	Kletz, T A	UK	0001
66	Lewis, W P	Australia	0001
67	Lilly, M T	Nigeria	1010
69	Mahapatra, P B	India	1000
70	Majid E E E	Kuwait	1000
71	Manivannan, S	USA	1100
73	Matto, R	Finland	1000
74	McRoberts, K	USA	0000
76	Montreuil, B	Canada	1010
78	Moore, J M	USA	1110
81	Nicol, L M	UK	1000
84	Nof, S Y	USA	1000
86	O'Brien, C	UK	1000
87	O'Conner, T	USA	0001
88	Oksala, T	Finland	1000
89	Orr, J	USA	0010
90	Oser, J	W. Germany	0010
96	Rosenblatt, M J	Israel	0010

Ref. No.	Name of Respondent	Country	A.4
97	SHARE Program Library	USA	0001
98	Saho, S	India	0000
101	Seppanen, J	Finland	1000
103	Shelbourn, K D	USA	0010
104	Smith, J M	USA	1000
105	Steudel, H J	USA	1000
107	Strahan, B S	USA	0001
108	Teicholz, E	USA	1100
114	VersaCAD / T & W Systems	USA	1100
115	Vollaman, T E	USA	0001
116	Warnecke, H J	W. Germany	1010
117	Webster, D B	USA	1010
120	Wrennall, W/ Leawood Inc.	USA	1110

**Section B (The Development of CAFL Software)**

Ref. No.	Soft. No.	B.1		B.2		B.3		B.4								B.5								B.6		B.7		B.8	
		St Res	St Dev	Fin Dev	Team size	Man Yrs	Disciplines 12345678								Dom. Disc	Prof Asst	Cont. Res.	Disc. Res.											
2	1	84	84	85	1	0.3	00000000								0	2	1	0											
6	3	73	73	77	2	12.0	00001110								8	2	2	60											
6	25	-	81	85																									
11	39	80	80	82	2	4.0	00000110								6	2	1	0											
11	40		82	84																									
11	41		84	86																									
14	78	66	71	78	2	4.0	00000100								6	2	1	0											
14	16		82	86																									
14	17		85	86																									
15	13	81	81	83	2	4.5	00001110								6	2	1	0											
16	27	78	78	83	3	35.0	00001110								7	1	1	0											
16	57		79	84																									
18	69	80	0	0	2	0.1	00100010								3	2	2	84											
19	67	83	83	85	2	2.0	00000100								6	1	1	0											
20	26	66	68	70	2	2.5	10000100								6	2	2	72											
22	55	84	84	85	2	2.0	10001000								1	2	1	0											
23	77	69	69	71	1	2.0	00000100								6	2	1	0											
23	19		79	86																									
28	98	72	72	75	2	5.0	00000100								6	2	1	0											
31	20	80	81	82	2	1.0	00000100								6	2	1	0											
34	36	81	81	84	2	3.0	00001100								6	2	1	0											
34	37		84	86																									
37	30	75	75	76	2	20.0	00001110								6	2	1	0											
37	7		83	84																									
37	92		84	85																									
38	95	83	83	85	1	0.1	00000110								7	2	2	85											
40	45	82	82	85	1	2.3	00000100								6	2	1	0											
41	59	83	83	0	2	3.0	10000000								0	2	1	0											
42	85	76	76	82	2	8.0	00011110								6	2	2	82											
42	44		72	78																									
43	29	81	83	84	2	3.0	00000110								7	2	1	0											
43	08		84	85																									
44	71	67	0	0	2	0.0	00000100								6	2	1	0											
49	94	70	70	73	3	10.0	00001110								6	1	0	0											
49	60		73	80																									
49	28		80	86																									
50		82			1	0.5	00000100								6	2	1	0											
51	68	76	82	83	2	2.0	00000100								6	1	1	0											
51	35		80	80																									
51	81		80	80																									

**Notes:**

1. Prg. Ref. See appendix B.1 for detail and software name.
2. B.5 Within this column; 1 to 8 represent the disciplines, Arch., Buil. Sc., Bus. Admin., Civil Engg., Comp. Sc. Ind. Engg., OR/System and "Other" respectively.

Ref. No.	Soft. No.	B.1 St Res	B.2 St Dev	B.3 Fin Dev	B.4 Team size	B.4 Man Yrs	B.5 Disciplines 12345678	B.6 Dom. Disc	B.7 Prof Asst	B.8 Cont. Res.	Disc. Res.
52	48	70	82	82	1	3.0	00001110	8	0	1	0
52	43		70	71							
52	93		83	83							
52	83		82	82							
53	74	75	75	78	1	2.0	10100100	8	2	2	81
67	72	82	82	85	1	3.0	00000100	6	2	1	0
69	38	78	78	80	1	2.0	11111110	0	2	1	0
70	80	77	77	80	2	4.0	00000100	6	2	2	80
71	18	81	82	82	2	4.0	00011101	6	1	1	0
71	12		82	83							
73	61	69	69	72	2	2.0	10001100	1	2	1	0
76	66	78	79	80	4	10.0	00001110	6	2	1	0
76	96		80	84							
76	34		83	85							
76	11		83	85							
78	23	73	73	74	4	5.0	10000110	6	1	1	0
78	84		79	79							
78	89		82	83							
81	32	83	83	99	1	0.1	00100100	6	2	1	0
84	52	73	73	76	3	25.0	00000110	6	2	1	0
84	87		79	80							
84	88		82	84							
84	36		83	84							
86	9	74	74	78	2	8.0	00000100	6	2	1	0
86	53		74	78							
86	47		79	80							
86	15		81	82							
88	22	67	72	82	2	5.0	10001011	1	1	1	0
98	73	0	0	0	2	6.0	00000100	6	1	1	0
98	63		-	-							
101	76	69	69	70	1	2.0	10001110	5	1	2	75
101	46		71	75							
104	64	81	82	83	2	7.5	10000010	7	2	1	0
104	65		83	85							
105	86	78	77	85	1	1.0	00000100	6	2	1	0
108	90	0	84	85	2	3.0	10001000	1	1	1	0
114	99	77	81	82	4	10.0	10101001	5	2	1	0
114	10		78	81							
116	70	65	65	76	3	12.0	00000100	6	1	1	0
116	56		80	83							
117	101	75	0	0	2	2.0	00001110	6	2	1	0
120	31	81	81	82	2	12.0	10001110	6	1	1	0

Notes:

1. Prg. Ref. See appendix B.1 for detail and software name.
2. B.5 Within this column; 1 to 8 represent the disciplines, Arch., Buil. Sc., Bus. Admin., Civil Engg., Comp. Sc. Ind. Engg., OR/System and "Other" respectively.

Section C (The Contents of CAFL Software)

Res. Ref.	C.1 (Prg. Ref.)	C.2.3		C.2.4	C.2.5 Commercial Support
		Input	Output	Language	
		Devices	Devices	12345	
		1234567	123456		
6	3	1100000	100000	10010	2
6	3	1111000	010010	00011	2
11	41	0000000	110010	00100	1
14	78	1010000	100000	00010	2
14	16	0010100	001110	00101	1
15	13	1000000	100000	00010	2
16	27	0011000	010010	00010	2
18	69	0010000	100000	00100	2
19	67	0000000	000000	00001	2
20	26	0100000	000000	00010	2
22	55				0
23	77	1000000	100000	00010	2
28	98	1010000	110000	00010	2
31	20	1010000	100100	00010	2
34	36	0010002	101011	00012	2
37	7	1110000	100100	00100	2
38	95	0010000	100100	00010	1
40	45	0010001	100000	00100	2
41	59	0011000	000100	00001	2
42	85	0111100	110100	00010	2
43	8	0010000	100100	00100	2
49	94	0110000	110000	00010	2
50	102	0010000	110000	00010	1
51	68	0010000	000000	00100	2
52	48	0010001	101000	00001	1
53	74	0000000	010100	00010	2
67	72	0011010	111010	00010	2
69	38	0010000	100000	00010	2
70	80	0010000	100000	00010	2
71	18	1010000	101000	00001	2
73	61	0000000	000000	01000	2
76	11	0011010	110010	00101	2
76	34	0011010	110010	00100	2
76	66	0011010	110010	00101	2
76	96	0011010	110010	00101	2
78	23	1000001	110110	00010	2
78	89	0000001	001110	00000	1
81	32	0010000	000100	00010	1
84	36	0010000	100000	00012	1
84	52	0010000	100000	00010	1
84	87	0010000	100000	00010	1
84	88	0010000	100000	00010	1
86	9	0010010	010100	00010	1
86	15	0011000	011100	00100	2
86	47	0010000	010100	00010	1
86	53	0010010	010100	00010	2
88	22	0010010	001100	00011	1
98	73	1000000	100000	00010	2
104	64	0010000	001000	00001	2
104	65	0010000	001010	00010	2
105	86	0110000	100100	00010	2
108	90	0010000	100010	00001	2
114	99	0001100	110110	00001	2
116	56	0011000	010010	00001	2
117	101	0110000	110000	00001	2
120	91	0111000	100100	00001	2



	C.3.1		C.3.2							C.3.3						C.3.4
	Mode	Program	Tasks							Advanced Technology						Max. Faci
	12	12345678910	12345678910	123456	123456	123456	123456	123456	123456	123456	123456	123456	123456	123456		
6	3	01	1011100000	000100										7		
6	3	10	0111000000	111000										8		
11	41	10	1011100000	001000										4		
14	78	01	1000100001	000000										8		
14	16	10	1111100000	000000										3		
15	13	01	1111100000	001000										2		
16	27	10	1011100000	001000										7		
18	69	10	0001100000	000000										2		
19	67	10	1000000000	000000										1		
20	26	11	0001000000	001000										5		
22	55	10	1111000000	001001										8		
23	77	01	1010000000	000000										7		
28	98	10	1010001000	001000										8		
31	20	01	1010000000	000000										7		
34	36	10	1111100003	111110										3		
37	7	10	1111000000	011001										8		
38	95	10	0111100000	000001										1		
40	45	10	0010100000	010000										2		
41	59	10	0010000000	100000										8		
42	85	10	0111100010	001000										2		
43	8	10	0011100000	000001										3		
49	94	11	1011101001	011110										7		
50	102	10	0111100000	001000										1		
51	68	10	1011100000	001000										4		
52	48	11	0000000100	000110										6		
53	74	10	0111100000	101000										6		
67	72	10	1111111100	001000										8		
69	38	00	0010000000	001000										8		
70	80	11	1000001000	000000										5		
71	18	01	0001100000	000100										4		
73	61	01	1011100000	000000										8		
76	11	10	1111100000	001110										8		
76	34	10	1111100000	001010										8		
76	66	10	1111100000	001000										8		
76	96	10	1111100000	001110										8		
78	23	10	1010100000	001000										6		
78	89	00	1000000001	000000										8		
81	32	10	0011100000	001010										2		
84	36	10	0010100001	110000										3		
84	52	01	0000000001	000100										4		
84	87	01	0000000001	000100										2		
84	88	01	0000000001	000100										2		
86	9	10	1101100000	001010										4		
86	15	10	1111100000	001000										4		
86	47	10	0001100000	000000										6		
86	53	10	0010000000	000000										4		
88	22	10	0111100000	111000										1		
98	73	01	0001000000	001000										3		
104	64	10	0010100000	001000										2		
104	65	10	0010100000	001000										4		
105	86	11	1000110000	000000										8		
108	90	10	1011100000	001000										7		
114	99	01	0101000000	001000										1		
116	56	10	1111100000	001000										8		
117	101	01	1000100000	001000										6		
120	91	10	0011100000	111000										8		

Res. Ref.	Prg. Ref.	C.4.1				C.4.2	
		Lauout Area	Faci.	C.D. Tables	Move Tables	Layout Design	Add. Check
		1234	1234	1234	1234	1234	
6	3	0100	0100	0100	1000	0010	1
6	3	0010	0010	0010	0000	0000	0
11	41	0100	0100	0100	0000	0000	0
14	78	0100	0100	0100	0100	0000	1
14	16	0100	0100	0100	0100	0100	0
15	13	0100	0100	0010	0100	0100	0
16	27	0010	0010	0100	0100	0010	0
18	69	0100	0000	0000	0100	0000	1
19	67	0000	0000	0000	0000	0000	0
20	26	0000	0000	0000	0000	0000	0
22	55	0010	0010	1000	1000	1000	1
23	77	0100	0100	0100	0100	0010	0
28	98	0010	0010	1000	0010	0010	1
31	20	0100	0100	0100	0100	0010	0
34	36	0000	0010	0010	0010	0010	0
37	7	0010	0010	0010	0010	0000	0
38	95	0100	0100	1000	0100	1000	0
40	45	0100	0100	0100	1000	1000	0
41	59	1000	0100	0100	1000	0010	0
42	85	0100	0100	0010	0010	0100	0
43	8	0001	0001	0001	0001	0001	0
49	94	0100	0110	1000	0110	0110	0
50	102	0000	0000	0000	0000	0000	0
51	68	0010	1000	0010	0100	0010	0
52	48	0000	0000	0000	0000	0000	0
53	74	0010	0010	0100	0010	0010	0
67	72	0010	0010	1000	0010	0010	1
69	38	1000	0100	1000	0100	1000	0
70	80	0010	0010	0000	0010	0010	0
71	18	0010	0100	0100	0010	0110	0
73	61	0010	0010	0010	0000	0000	0
76	11	0110	0110	0110	0110	0110	0
76	34	0110	0110	0000	0110	0110	1
76	66	0110	0110	0110	0110	0110	0
76	96	0110	0110	0110	0110	0110	0
78	23	1000	0100	0100	0010	1000	0
78	89	0010	0000	0100	0010	0001	0
81	32	1000	0000	0000	0000	0000	0
84	36	0100	0100	0100	0100	0100	0
84	52	0100	0100	0000	0100	0000	0
84	87	0100	0100	0000	0100	0000	0
84	88	0100	0100	0000	0100	0000	0
86	9	0010	0000	0000	0010	0000	0
86	15	0100	0100	0000	0010	0100	0
86	47	0100	0100	0000	0010	0100	0
86	53	0000	0100	0000	0100	0000	0
88	22	0000	0000	0000	0000	0000	1
98	73	0000	0000	0000	0000	1000	0
104	64	0110	0100	0100	0100	0010	0
104	65	0110	0100	0100	0100	0010	0
105	86	0100	0100	1000	0100	0100	0
108	90	0100	0100	0100	1000	0100	0
114	99	0000	0000	0000	0000	0000	0
116	56	0001	0010	0110	0110	0110	0
117	101	0100	0000	0100	0100	0000	0
120	91	0010	0010	0100	0100	0010	0

Res. Ref.	Prg. Ref.	C.5.1 Layout area 1234567	C.5.2 Facilities 1234567	C.5.3 Software Features 12345678910	C.5.4 Add. Features	C.5.5 Activity Repr'n 1234
6	3	0001000	0100000	1100000000	2	1010
6	3	0001000	0000100	1001001100	2	1000
11	41	0001000	0000100	1001000000	2	1000
14	78	0100001	1101000	0000000100	0	1110
14	16	1101100	0101100	0011100010	0	1110
15	13	0100000	0100000	1100000000	2	1110
16	27	0001100	1000100	1011001000	2	1100
18	69	0000001	1000000	1000000000	2	0100
19	67	0000000	0000000	0000000000	0	0000
20	26	0000000	0000000	0000000000	0	0000
22	55	0000000	0000100	1100101100	1	0000
23	77	1000000	0100000	0000000001	2	1111
28	98	0000100	0000100	1011001000	1	0011
31	20	0001000	0001000	1001000000	2	1000
34	36	0000100	0100000	1000001100	2	1100
37	7	0001000	0000100	1000001000	1	1100
38	95	0100000	0100000	0000000001	2	0001
40	45	0000100	0000100	1001001000	2	1000
41	59	1000000	0001000	0000000000	0	1000
42	85	0000010	0010100	0001101100	2	0100
43	8	0001000	0000100	0000000000	2	1100
49	94	0111100	1101100	1001000100	1	0100
50	102	0000000	0000000	0000000000	0	0000
51	68	0001000	0001000	1100000000	1	1110
52	48	0000001	0000001	0010000000	2	0001
53	74	0000100	0000100	1011010100	2	1101
67	72	0000100	0000100	1011001110	1	0010
69	38	0000000	0000000	0000000000	0	0000
70	80	0000100	0000100	1010000000	2	0010
71	18	0101000	0001000	1111000000	1	1000
73	61	0100100	0100000	1010001000	2	1000
76	11	0100000	0101001	1111101110	1	1101
76	34	0100000	0101000	1011101100	1	0001
76	66	0100000	0101000	1001001100	1	1100
76	96	0100000	0101000	1111001100	1	1101
78	23	0100000	0001100	0010000000	1	1000
78	89	0000000	0000001	0010000100	2	0010
81	32	0000100	0000100	1000000100	0	1100
84	36	1000000	0001000	0010001102	2	1100
84	52	0000001	1000000	0010001102	2	0010
84	87	0000001	1000000	0010000002	2	0010
84	88	0000001	1000000	0010000002	2	0010
86	9	0000100	0000100	1011100110	0	0100
86	15	1000000	0000100	1001100110	0	0100
86	47	0000100	0001000	1000000000	2	0100
86	53	0100000	0001000	0000000000	0	0100
88	22	1000000	0000100	0000110010	2	1000
98	73	0001000	1000000	1000000000	2	1010
104	64	0100000	0001000	1011001000	1	1000
104	65	0100000	0001000	1011001000	1	1000
105	86	0001000	0001000	1010001000	2	0001
108	90	0011000	0100000	1100000000	1	1100
114	99	1000000	0000100	1111111110	2	0001
116	56	0101000	0100000	1001110000	2	0110
117	101	1000000	1000000	0000000000	2	1100
120	91	1011000	0000100	1001111000	1	1010

Res. Ref.	Prg. Ref.	C.6.1			C.6.2				
		Layout Design	A Init.	B Fix	C New	D Exch-	E Shape	F Impr.	G Des.
		1234	1234	12345	12345	anges	Change	Stop.	Int.
		1234	1234	12345	12345	anges	Change	Stop.	Int.
6	3	0110	0010	1	00001	00000	2	1100	2
6	3	0010							
11	41	0010	0000	0	00000	00000	0	0000	0
14	78	0011	0000	0	00000	00000	0	0000	0
14	16	0011	0000	0	00000	0	0	0000	0
15	13	0110	1000	1	00100	10000	2	0100	1
16	27	0110	1000	1	00010	01000	2	0110	1
18	69	0100	1000	1	00001	10000	2	0001	1
19	67	0000	0000	0	00000	0	0	0000	0
20	26	0000	0000	0	00000	0	0	0000	0
22	55	1000							
23	77	0010	0000	0	00000	00000	0	0000	0
28	98	0010	0000	0	00000	00000	0	0000	0
31	20	0010	0000	0	00000	00000	0	0000	0
34	36	0111	0010	1	01000	11000	1	0001	2
37	7	0010	0000	0	00000	00000	0	0000	0
38	95	0001	0000	0	00000	00000	0	0000	0
40	45	0010	0000	0	00000	00000	0	0000	0
41	59	0010	0000	0	00000	00000	0	0000	0
42	85	0010	0000	0	00000	00000	0	0000	0
43	8	0010	0000	0	00000	00000	0	0000	0
49	94	0110	1100	1	00001	10000	2	0100	1
50	102	0000	0000	0	00000	00000	0	0000	0
51	68	0100	1000	1	00101	10000	1	0001	1
52	48	0001	0000	0	00000	00000	0	0000	0
53	74	0110	1010	1	00010	10000	2	0110	1
67	72	0100	1000	1	00010	10000	2	0010	1
69	38	0000	0000	0	00000	00000	0	0000	0
70	80	0001	0000	0	00000	00000	0	0000	0
71	18	0100	1000	1	01101	11101	1	0001	2
73	61	0010	0000	0	00000	00000	0	0000	0
76	11	0111	1000	1	00011	00010	1	0010	1
76	34	0111	1000	1	00001	00010	1	0010	1
76	66	0111	1000	1	00001	00010	1	0010	1
76	96	0111	1000	1	00011	00010	1	0010	1
78	23	0010	0000	0	00000	00000	0	0000	0
78	89	0001	0000	0	00000	00000	0	0000	0
81	32	0010	0000	0	00000	00000	0	0000	0
84	36	0101	1000	1	00110	00010	2	0010	1
84	52	0101	1000	1	00010	00010	2	0010	1
84	87	0101	1000	1	00010	00010	2	0010	1
84	88	0101	1000	1	00010	00010	2	0010	1
86	9	0110	1000	1	00010	00001	1	0110	1
86	15	0110	1000	1	00010	00001	2	0110	1
86	47	0110	1000	1	01000	00001	2	0110	1
86	53	0110	1000	2	01000	00001	2	0100	2
88	22	0100	1000	0	00010	00010	1	0010	1
98	73	0100	0100	1	01000	00000	2	0010	0
104	64	0001	0000	0	00000	00000	0	0000	0
104	65	0001	0000	0	00000	00000	0	0000	0
105	86	0001	0000	0	00000	00000	0	0000	0
108	90	0110	1110	1	00010	10000	2	1100	2
114	99	1000	0000	0	00000	00000	0	0000	0
116	56	0110	1000	1	01110	10000	2	1000	2
117	101	0001	0000	0	00000	00000	0	0000	0
120	91	0111	0000	0	00000	00000	0	0000	0



Res. Ref.	Prg. Ref.	C.6.3				C.6.4	
		A	B	C	D	A	B
		Facility Selection	Facility Location	Shape	Layout Adjust	Other Method	Produce Layout
		1234	1234				
6	3	0010	0010	1	1		
6	3	0001	0001	2	2	1	1
11	41	1010	1000	1	2	0	0
14	78	0010	0001	0	1	1	0
14	16	0000	0000	0	0	0	0
15	13	1000	1000	2	1	0	0
16	27	0001	0001	2	2	0	0
18	69	0000	0000	0	0	0	0
19	67	0000	0000	0	0	1	2
20	26	0000	0000	0	0	0	0
22	55						
23	77	0011	0010	1	2	0	0
28	98	0010	1010	2	2	0	2
31	20	0010	0001	2	2	0	0
34	36	0010	0010	1	2	0	0
37	7	0010	0010	1	1	0	0
38	95	0000	0000	0	0	1	1
40	45	1000	0001	2	1	0	0
41	59	0001	0001	1	2	0	0
42	85	1000	1000	1	1	0	0
43	8	0010	0010	1	2	0	0
49	94	1100	1100	2	1	0	0
50	102	0000	0000	0	0	0	0
51	68	0000	0000	0	0	0	0
52	48	0000	0000	0	0	0	0
53	74	1110	1010	2	1	0	0
67	72	0000	0000	0	0	0	0
70	80	0000	0000	0	0	1	2
71	18	0000	0000	0	0	0	0
73	61	0010	1010	1	1	0	1
76	11	1010	1010	1	1	1	1
76	34	1011	1001	1	1	1	1
76	66	1001	0001	1	1	1	1
76	96	1000	1000	1	1	1	1
78	23	0010	0010	1	2	0	1
78	89	0000	0000	0	0	1	2
81	32	0010	1000	1	1	0	0
84	36	0000	0000	0	0	1	2
84	52	0000	0000	0	0	1	2
84	87	0000	0000	0	0	1	2
84	88	0000	0000	0	0	1	2
86	9	1000	1000	2	1	0	0
86	15	1000	1000	2	1	1	2
86	47	1000	1000	2	2	0	0
86	53	1010	1000	2	2	1	1
88	22	1000	1000	1	1	0	0
98	73	0000	0000	0	0	0	0
104	64	0000	0000	0	0	1	1
104	65	0000	0000	0	0	1	1
105	86	0000	0000	0	0	1	2
108	90	1000	1110	2	1	0	1
114	99	0000	0000	0	0	0	0
116	56	0010	0010	2	1	0	0
117	101	0000	0000	0	0	1	2
120	91	0001	1001	1	1	0	1

Res. Ref.	Prg. Ref.	C.7.1 Layout Eval.	C.7.2				
			A Subj. Scale	B Scale Conv.	C More Tables	D Combi. Tables	E Neighbour Detection
		1234					
11	41	1000	1	1	2	0	1
14	78	0100	0	0	0	0	0
14	16	0100	0	0	0	0	0
15	13	1100	1	1	2	0	1
16	27	1100	1	1	2	0	1
18	69	0100	0	0	0	0	0
19	67	0000	0	0	0	0	0
20	26	0000	0	0	0	0	0
22	55						
23	77	1100	1	1	2	0	1
28	98	0100	0	0	0	0	0
31	20	1000	1	1	2	0	1
34	36	1110	1	1	1	1	1
37	7	1100	0	1	2	0	1
38	95	0100	0	0	0	0	0
40	45	1100	1	1	2	0	1
41	59	0001	0	0	0	0	0
42	85	0010	0	0	0	0	0
43	8	1000	1	1	2	0	1
49	94	0100	0	0	0	0	0
50	102	0000	0	0	0	0	0
51	68	1100	0	0	0	0	0
52	48	0001	0	0	0	0	0
53	74	1100	1	1	1	1	1
67	72	0110	0	0	0	0	0
69	38	0000	0	0	0	0	0
70	80	0110	0	0	0	0	0
71	18	1000	1	1	2	0	1
73	61	1110	1	0	1	1	1
76	11	1101	1	1	2	0	1
76	34	0101	0	0	0	0	0
76	66	1100	1	1	2	0	1
76	96	1100	1	1	2	0	1
78	23	1000	1	1	2	0	0
78	89	0010	0	0	0	0	0
81	32	1100	1	1	1	1	1
84	36	1100	1	1	1	1	0
84	52	1101	1	1	1	1	0
84	87	1101	1	1	1	1	0
84	88	1101	1	1	1	1	0
86	9	0110	0	0	0	0	0
86	15	0100	0	0	0	0	0
86	47	0100	0	0	0	0	0
86	53	0110	0	0	0	0	0
88	22	0101	0	0	0	0	0
98	73	1100	0	0	0	0	0
104	64	0001	0	0	0	0	0
104	65	0001	0	0	0	0	0
105	86	0101	0	0	0	0	0
108	90	1000	1	0	2	0	0
114	99	0000	0	0	0	0	0
116	56	1100	1	1	1	1	1
117	101	1100	1	1	1	1	1
120	91	1100	1	1	2	0	1

Section D (Marketing of CAFL Software)

COMPUTER AIDED FACILITIES LAYOUT (CAFL)  
INTERNATIONAL SURVEY 85-86

Ref. No.	Program/Model Title	Cost	No. of Applns	Supplier Name and Address
17	CUTFIT	\$11250	-	Christofides, N.
	INTERLAY	\$ 7500	-	Department of Management Science, Imperial College, London SW7 2BX.
22	INSITE	-	35	Cyros, L.K.
	INSITE-CAD	-	4	Office of Facilities Management Sys. MIT 77, Massachusetts Avenue, Cambridge, MA, USA 01906.
71	CAFL	\$ 20	15	Manivannan, S. 441, Link Hall, Syracuse University, Syracuse, NY, USA 13210.
78	SLPCALC	\$ 250	50	Moore Productivity Software, 1607 Greenwood Drive, Blaksbury, Virginia, 24060-5937 USA.
	TYMCALC	\$ 250	20	
	WAD	-		
114	CADAPPLE	-	15	T & W Systems, 7372 Prince Drive, Suite 106, Huntington Beach, CA, 92647 USA.
	VersaCAD	-	15	
120	SPACEPLAN	\$50000 (+Hardware)	50	ComputerVision Corp., 100 Crosby, Bedford, MA, USA

## Section E (The Use of CAFL Software)

REF_NO	E1A1	E3A1	E3A2	E3A3	E3A4	E3A5	E3A6	E3A7	E3B	E3C	E3D
6	ALPS-1		0	0900	77	08000			4	2	2
6	CRL-CAD (A)	9	999	9 9 9		99		9	5	2	2
14	CAN-Q	3	000	0 00	3	0000	70000	Y	3	1	1
14	CORELAP	3	000	0 03	5	0000	55000	Y	3	1	1
14	CRAFT	3	000	0 03	5	0000	50000	Y	3	1	1
15	CORELAP/ALDEP/CAFL	5	178	7726	77	59000	8803	77	5	1	2
19	AUTOCAD	7	0--	8--2	88	8 Y	00000		4	1	0
20	CORELAP	3	060	8855	800	44000	80000	860	2	1	1
20	CRAFT	0	040	0500	08	06000	80000	700	2	1	1
22	INSIGHT-CAD	0	999	9009	00-	99009	00000	890	5	2	2
28	UA1-UA3	7	4	3	4		6 6	44	3	1	2
29	CORELAP	7	000	8805	90	08000	4800	7	4	1	1
29	PLANET		070	0800	830	07000	86800	700	4	1	1
29	COFAD	8	060	0800	080	08000	8080	700	4	1	1
29	ALDEP	8	044	0800	800	08000	0800	8	4	1	1
29	CRAFT	7	060	0800	08	08000	90000	800	4	1	1
31	CRAFT	7	005	0705	70-	07000	6050-	70-	4	1	1
31	CORELAP	6	005	0603	04-	04000	3000-	50-	2	1	1
31	ALDEP	5	005	0806	08-	08000	8000-	80-	4	1	1
35	CRAFT	7	075	0902	09	00000	90700	930	4	1	1
36	CORELAP	5	346	6523	55	00000	2200	67	2	2	2
38	ALDEP	2	000	0000	Y0	00000	Y0000	00	1	1	1
49	CRAFT/ALDEP	5	155	8705	87	55001	8155-	84-	3	1	1
67	CRAFT	7	077	0604	70	05000	70000	440	3	1	1
67	IMPROVE	7	077	0605	60	05000	05000	540	3	1	1
67	UA1-UA3	8	088	4858	088	08000	80687	880	4	1	1
67	RELAY 1-RELAY 2B	8	088	5866	008	06000	00687	880	4	1	1
67	MS-S1 -S4	8	089	9079	080	99006	88995	990	5	1	1
70	RELAY 1,2A &2B	5	4	64			77 7		3	1	1
74	PLANET/ALDEP								4	1	0
76	CRAFT	9	007	0304	050	00000	22210	400	3	1	1
76	CORELAP	9	007	0304	40-	00000	22000	400	3	1	1
76	PLANET	9	007	0304	300	00000	22000	400	2	1	1
76	ALDEP	9	007	0304	200	00000	22000	400	2	1	1
76	COFAD	9	007	0304	040	00000	40440	400	3	1	1
76	ICEM FACILITIES	7	000	9708	003	78845	00000	090	3	1	1
90	LAYPLA		077	9805	80-	8000	00000	580	4	1	2
96	CRAFT/ALDEP	3	000	0400	77	7000	66000	45	3	1	1
103	APPLICON BRAVO!	7	899	8888	990	99999	99 84	999	5	1	1
116	INTALA	7	888	9005	98	97009	8800-	09	4	2	2
117	CRAFT/ALDEP/CORELAP	6	040	0803	77	00000	55000	85	4	1	1
117	FLAP	4	050	8000	70	55003	70000	03	3	1	1
120	SPACEPLAN	7	97	9780	9	99000	78000	90	4	1	1



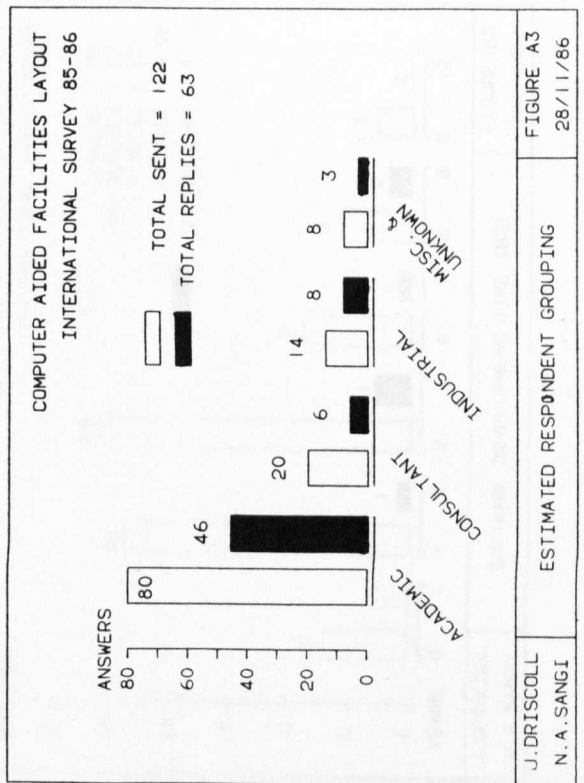
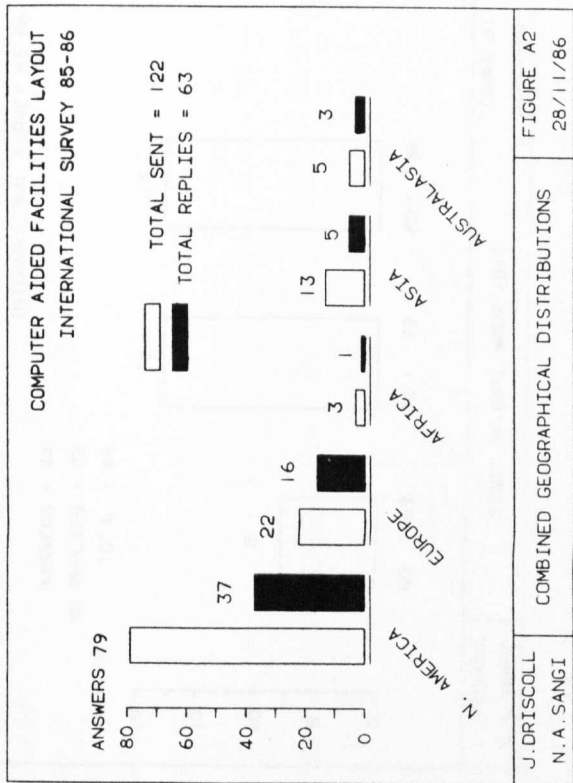
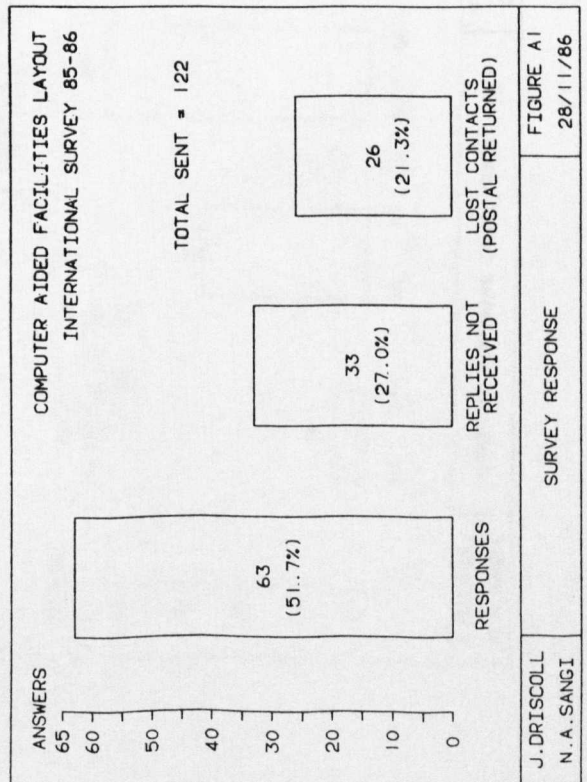
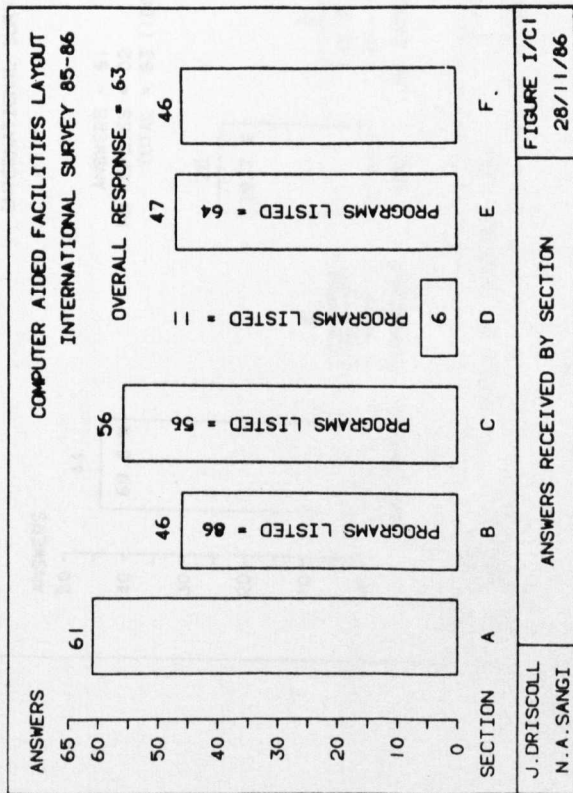
REF_NO	E1A1	E1B	E21	E22	E23	E24	E3B	E3C	E3D
14	CAN-Q/CRAFT/CORELAP	10000	355	33	5	55	3	1	1
15	ALDEP/CORELAP /CAFL	10000	331	35	7	75	5	1	2
19	AUTOCAD	10001	---	44	3	--	4	1	0
19	MCAP	10001	7-	75	7	75			
20	CORELAP/CRAFT	10010	355	33	5	75	2	1	1
22	INSIGHT-CAD	00100	9--	99	9	9-	5	2	2
28	UA1-UA3	10000	559	55	5	55	3	1	2
29	ALDEP/CORELAP/PLANET/COFAD/CRAFT	00001	555	53	5	3	4	1	1
31	ALDEP/CORELAP/CRAFT	11100	335	77	7	53	4	1	1
35	CRAFT	10000	597	57	9	53	4	1	1
36	CORELAP	10000	557	77	7	53	2	2	2
38	ALDEP	00100	999	99	5	51	1	1	1
44	CRAFT/MOMENT ARM COMPUTATION	10001							
49	CRAFT/ALDEP	10010	557	99	7	95	3	1	1
50	CRAFT/COFAD/ALDEP/PLANET/CORELAP	11011							
67	CRAFT	10000	777	73	7	55	3	1	1
67	IMPROVE	10000	777	73	7	55	3	1	1
67	MS-S1 -S4	10000	777	77	7	99	5	1	1
67	RELAY 1-RELAY 2B	10000	777	77	7	7-	4	1	1
67	UA1-UA3	10000	777	77	7	77	4	1	1
70	RELAY 1,2A &2B	10001	5	5		5	3	1	1
74	PLANET/ALDEP	11110		5	5		4	1	0
76	ALDEP/CRAFT/CORELAP/PLANET/COFAD ICEM FACILITIES	11010	351	33	5	73	2	1	1
90	LAYPLA	0000P	755	55	3	55	4	1	2
96	CRAFT/ALDEP	11001	755	35	7	77	3	1	1
103	APPLICON BRAVO!/IMAGE/EDITOR	11001	555	57	7	55	5	1	1
116	INTALA	10000	559	77	9	99	4	2	2
117	CRAFT/ALDEP/CORELAP /FLAP	01001	135	67	7	63	4	1	1
120	SPACEPLAN/ARCHADES/RMA/-MICROVECTOR	11010	---	77	7	79	4	1	1

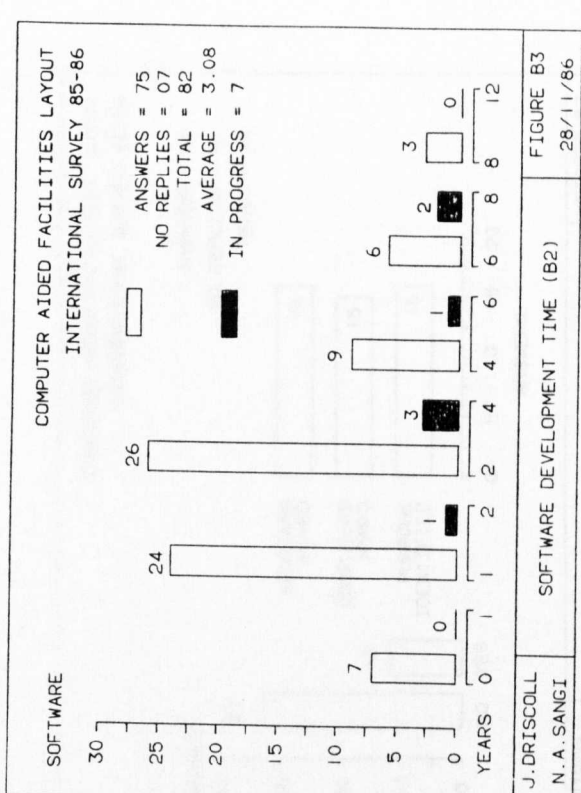
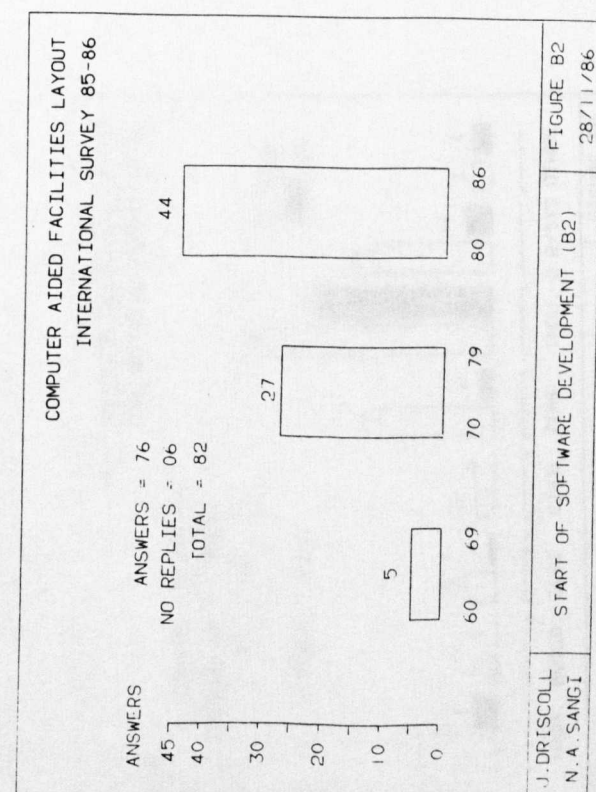
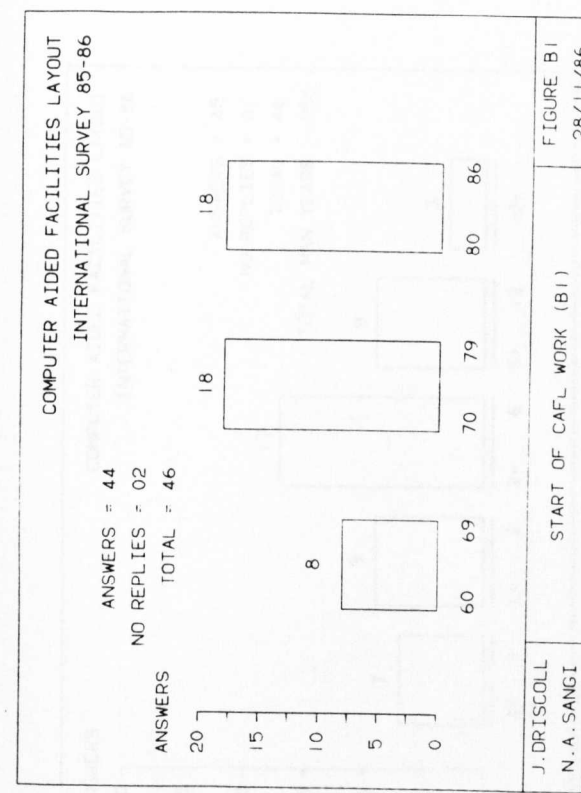
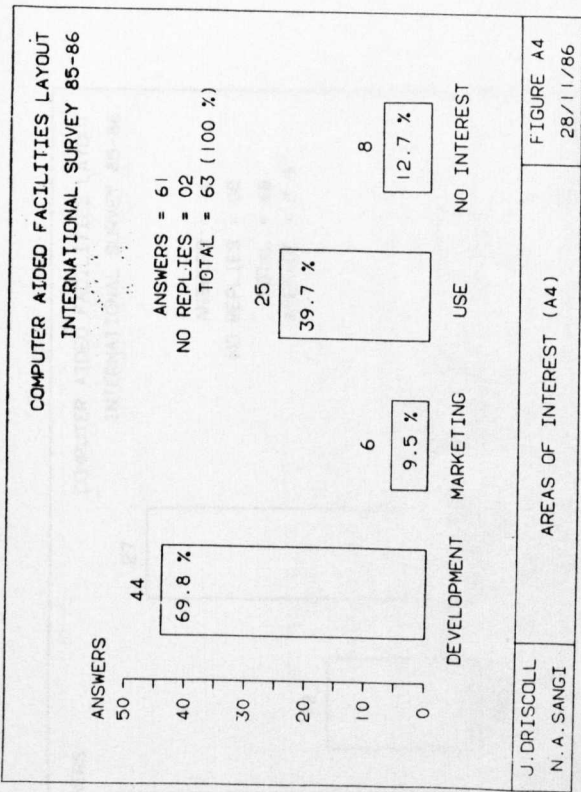
**E5**

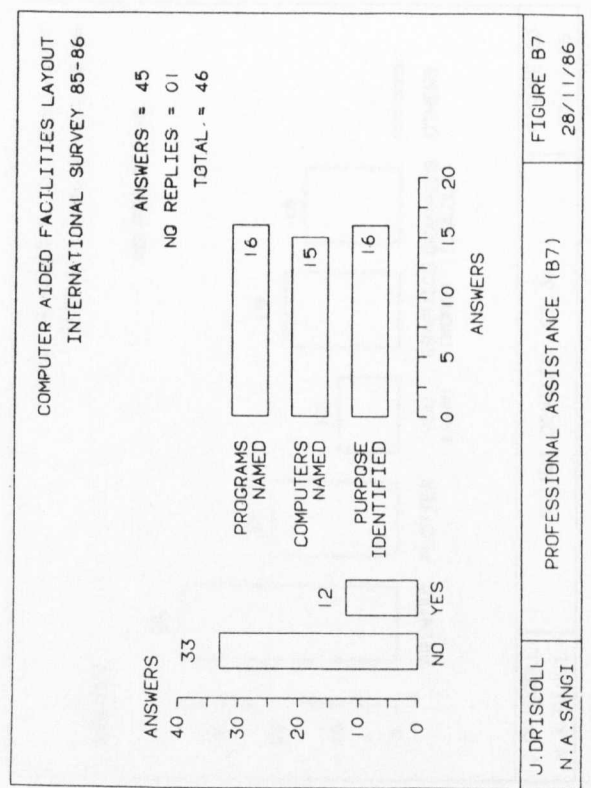
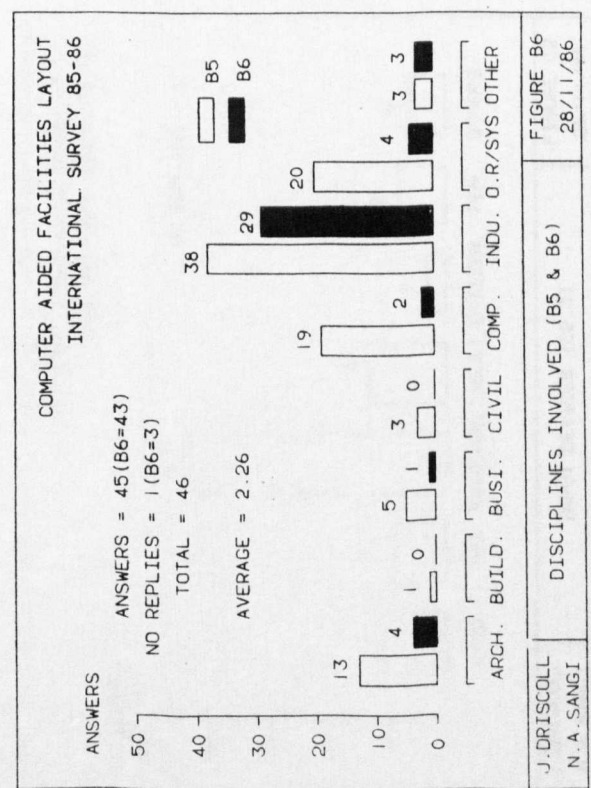
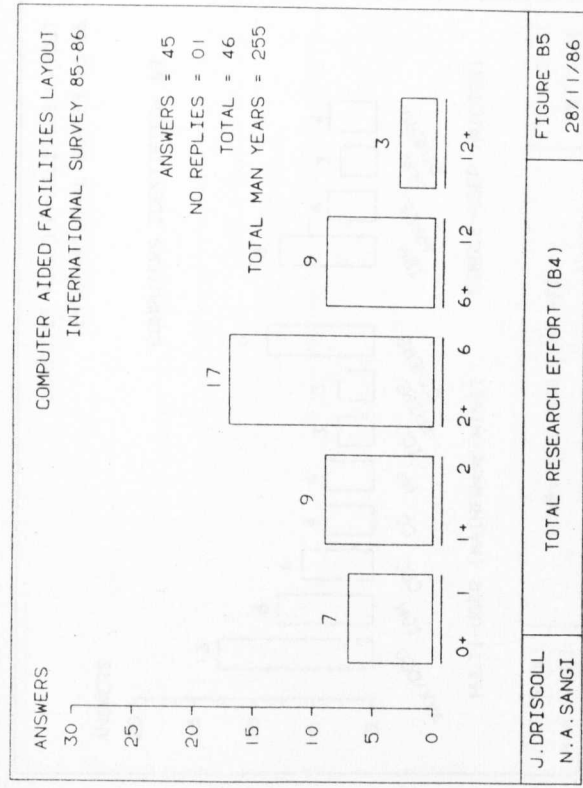
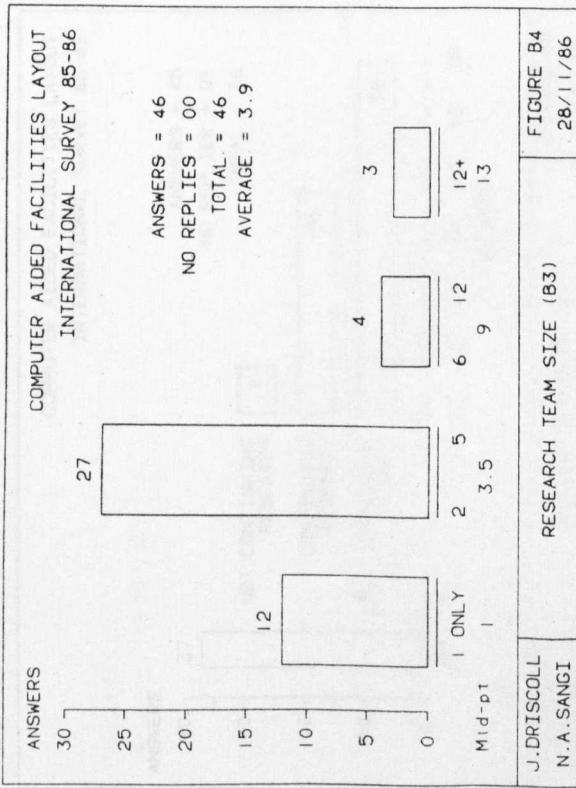
**SURVEY ILLUSTRATIONS**

## SURVEY ILLUSTRATIONS

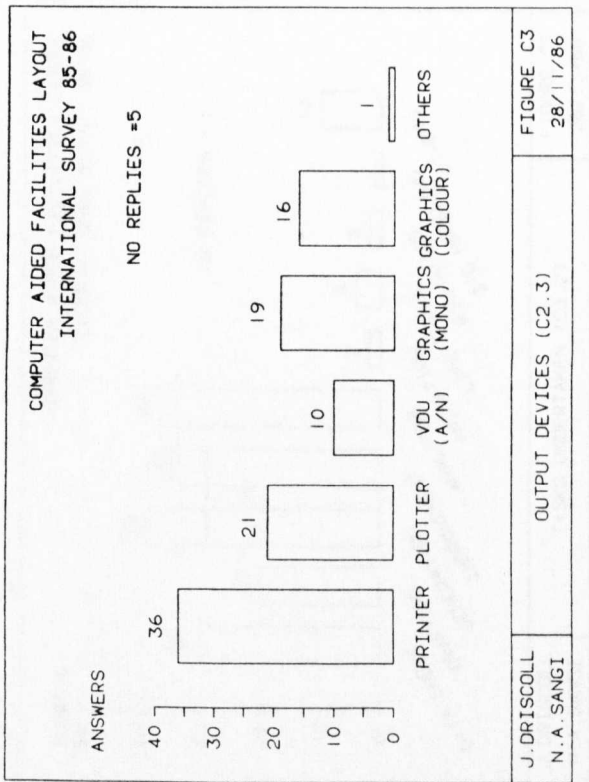
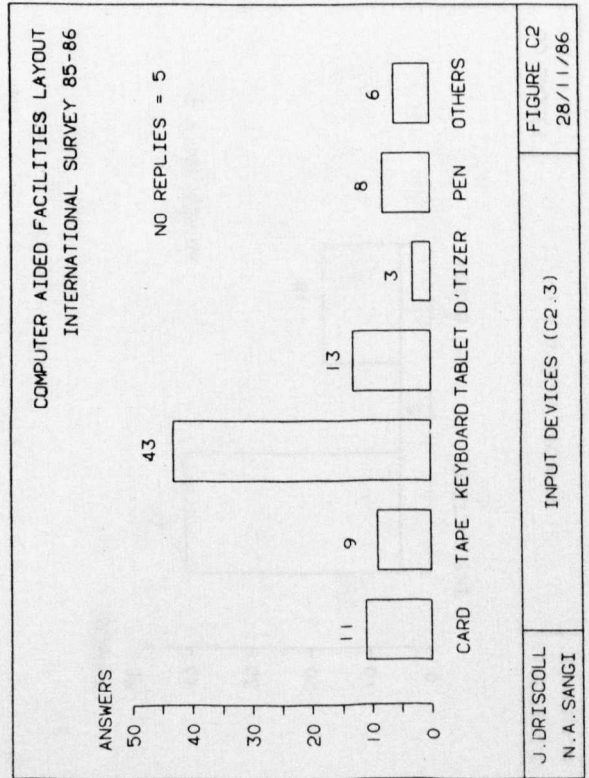
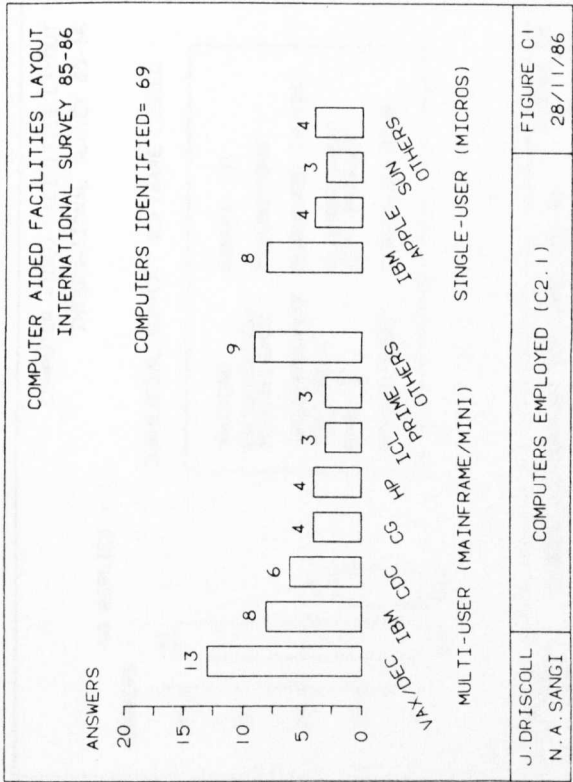
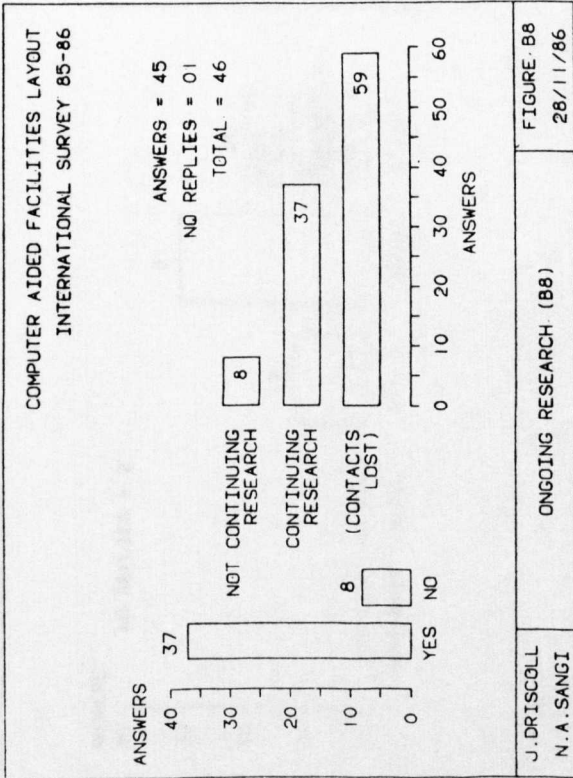
Figure	Title
I/C1	Answers Received by Section
A1	Survey Response
A2	Combined Geographical Distributions
A3	Estimated Response Groupings
A4	Areas of Interest
B1	Start of CAFL Work
B2	Start of Software Development
B3	Software Development Time
B4	Research Team Size
B5	Total Research Effort
B6	Disciplines Involved
B7	Professional Assistance
B8	Ongoing Research
C1	Computers Employed
C2	Input Devices
C3	Output Devices
C4	Computer Languages
C5	Commercial Support Software
C6	Working Mode
C7	Tasks Undertaken
C8	Advanced Technology Applications
C9	Maximum Number of Facilities
C10	Data Verification
C11	Layout Area Representation
C12	Facilities Representation
C13	Software Features
C14	Activity Representation
C15	Layout Design Procedures
C16A	Improvement Programs
C16B	Improvement Programs continuation
C16C	Improvement Programs continuation
C17A	Construction Programs
C17B	Construction Programs continuation
C18	Layout Evaluation
C19A	Closeness Desirability Models
C19B	Closeness Desirability Models continuation
C20A	Materials Movement Models
C20B	Materials Movement Models continuation
C21	Financial Appraisal
D1	Software Marketing
E1	Software in Use
E2	Software Usability Rating
E3A	Input and Execution Features
E3B	Design and Evaluation Features
E3C	Output and Graphics Features
E4	Overall User Ratings

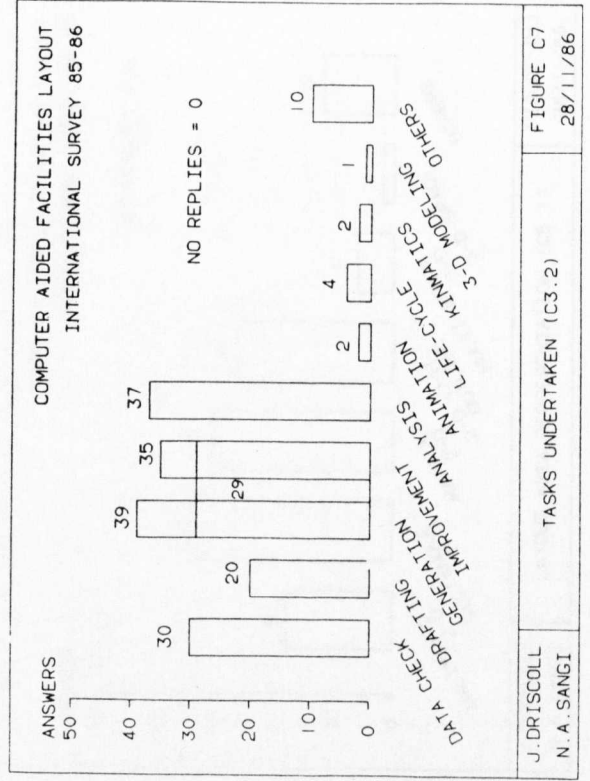
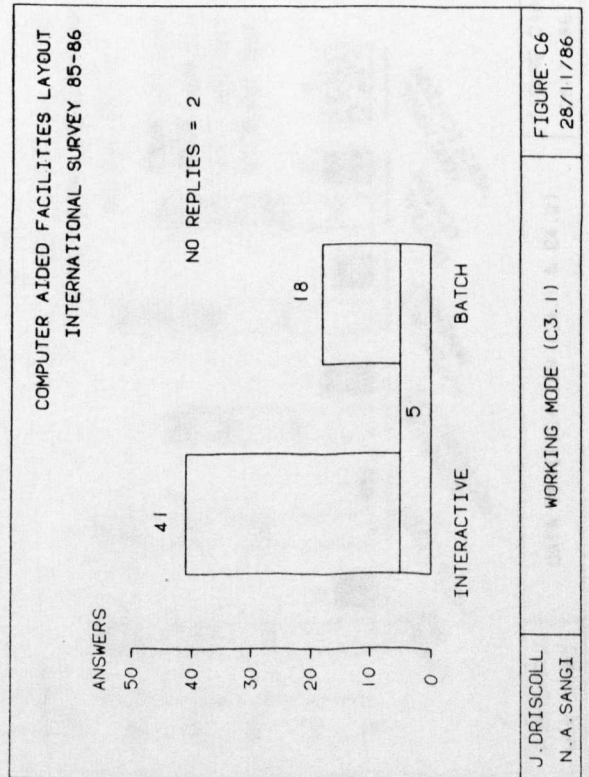
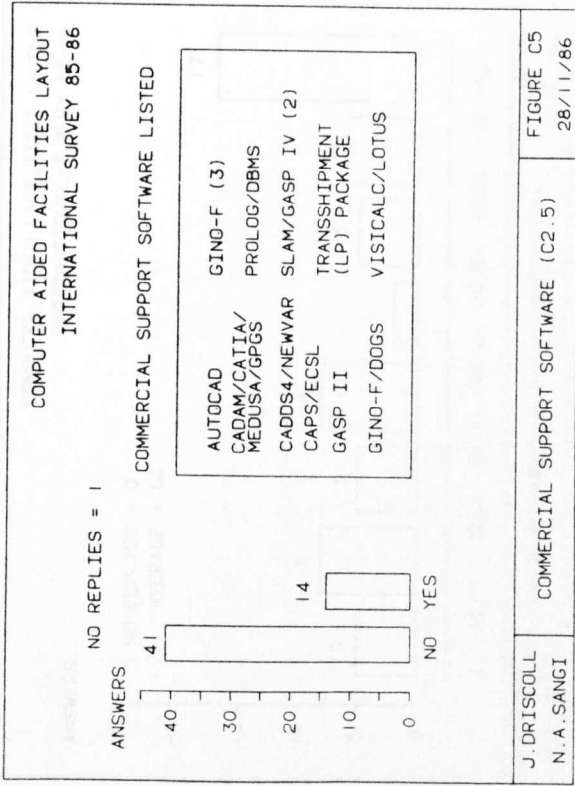
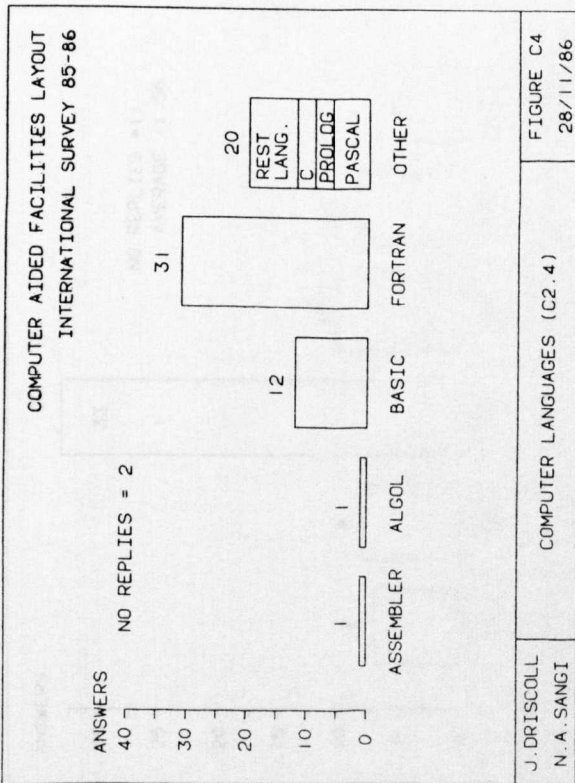




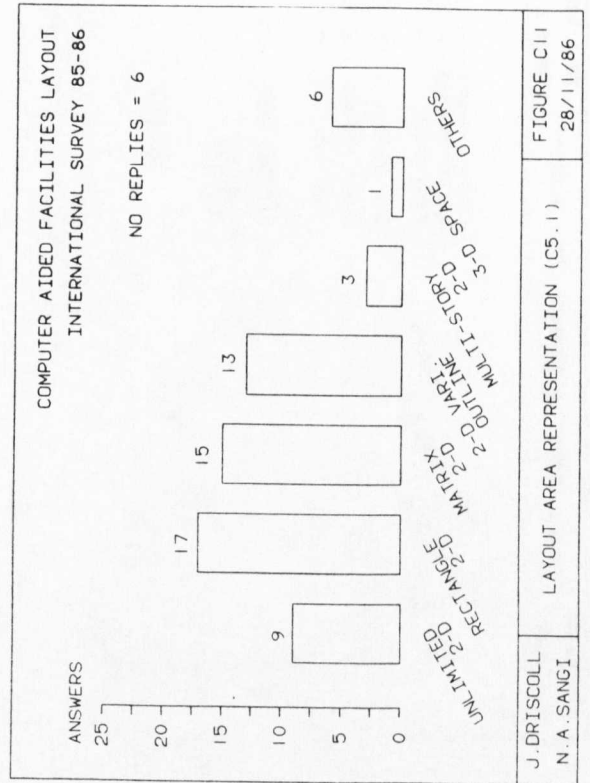
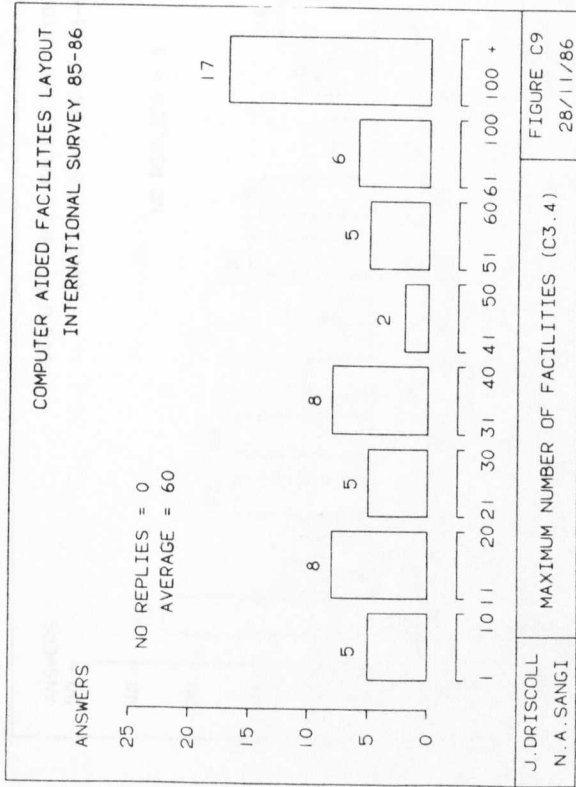
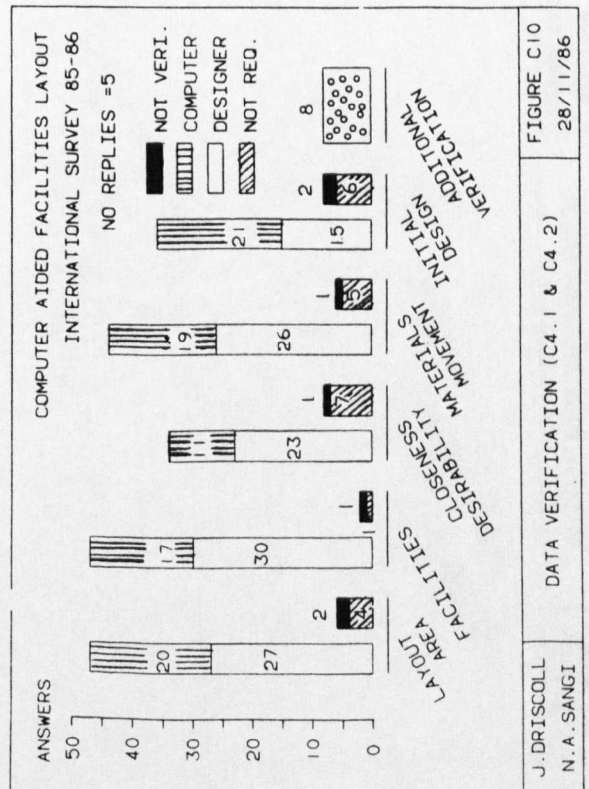
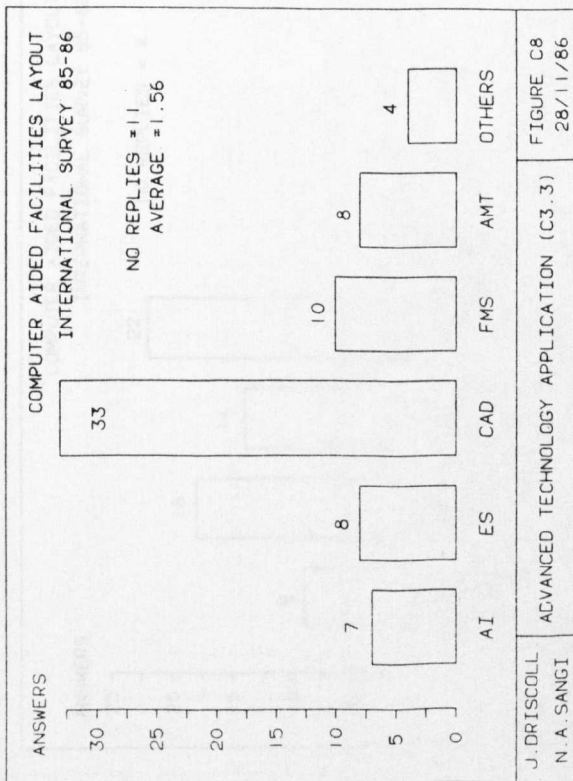


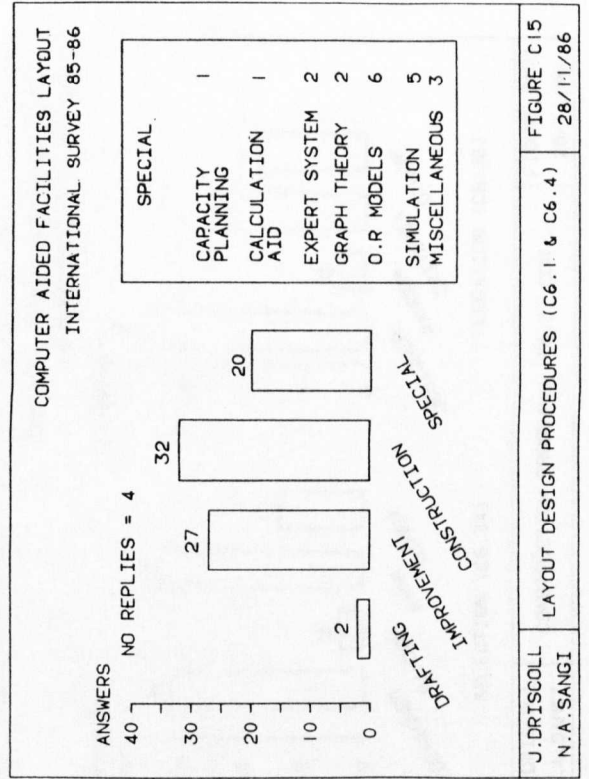
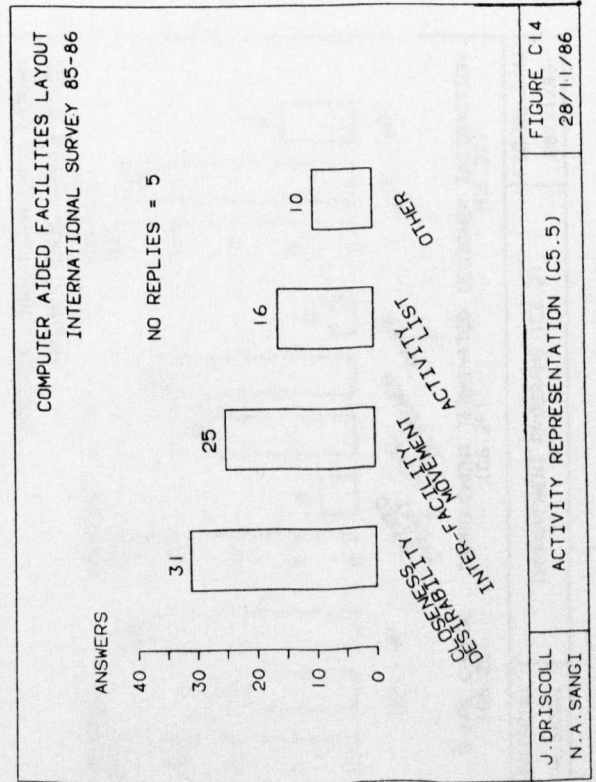
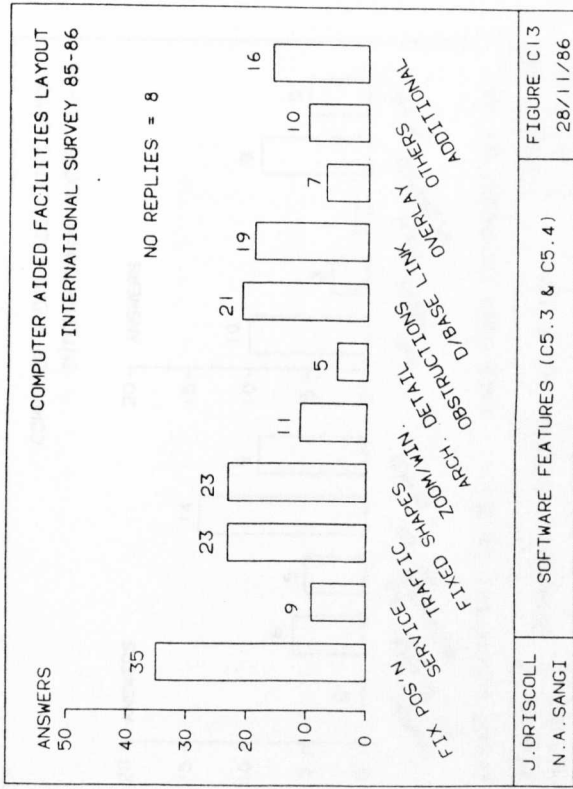
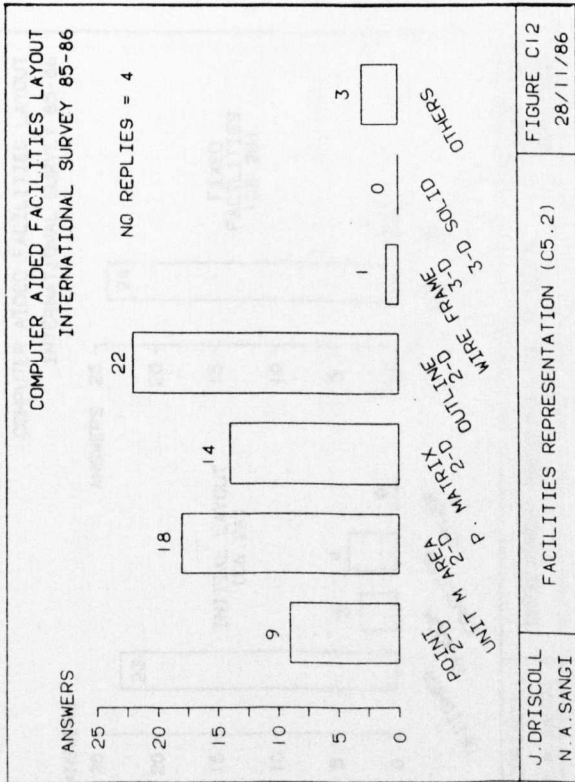


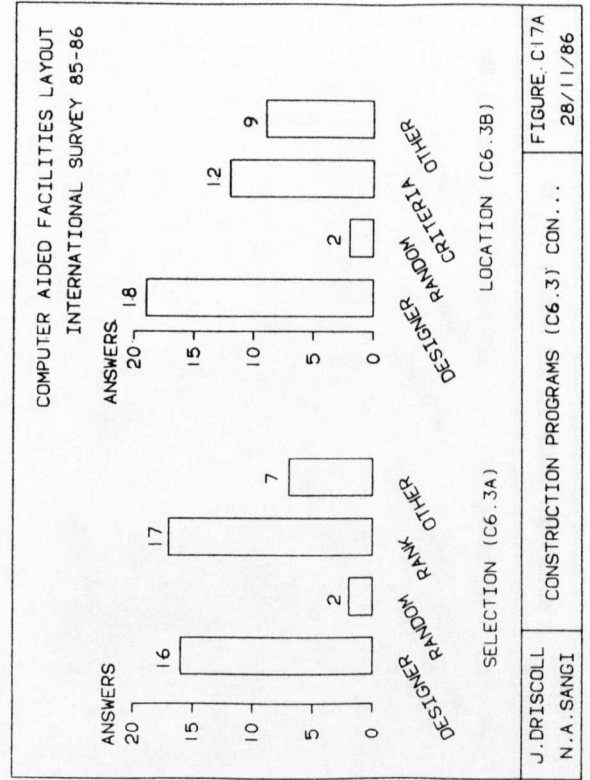
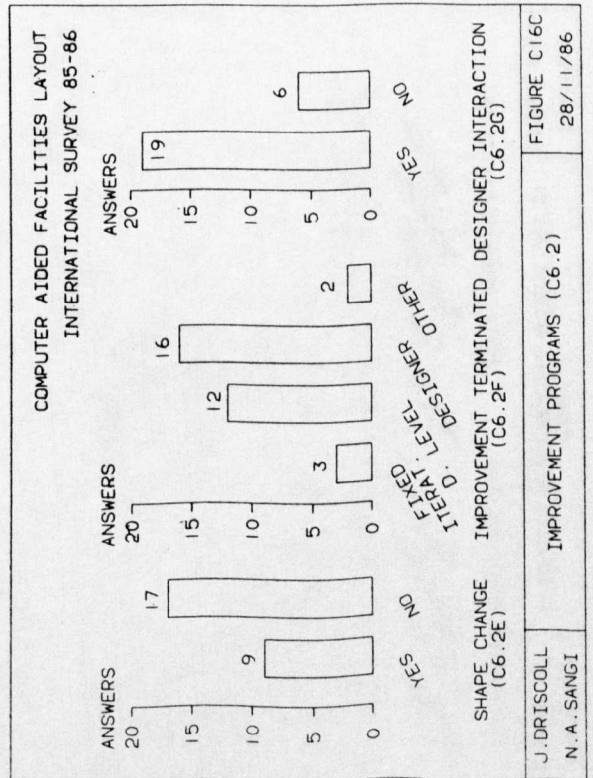
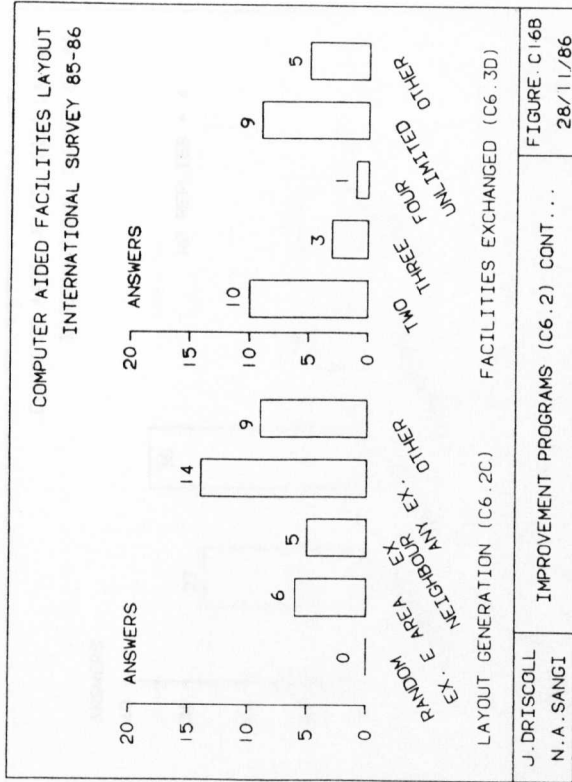
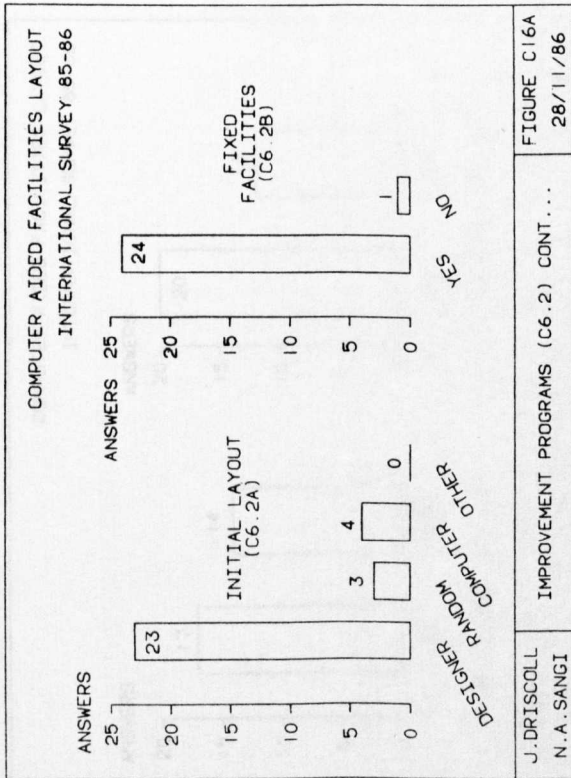


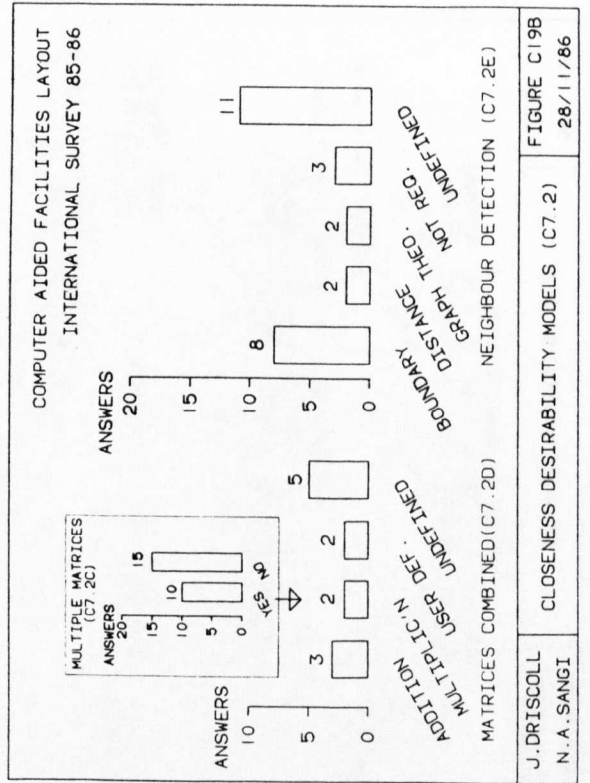
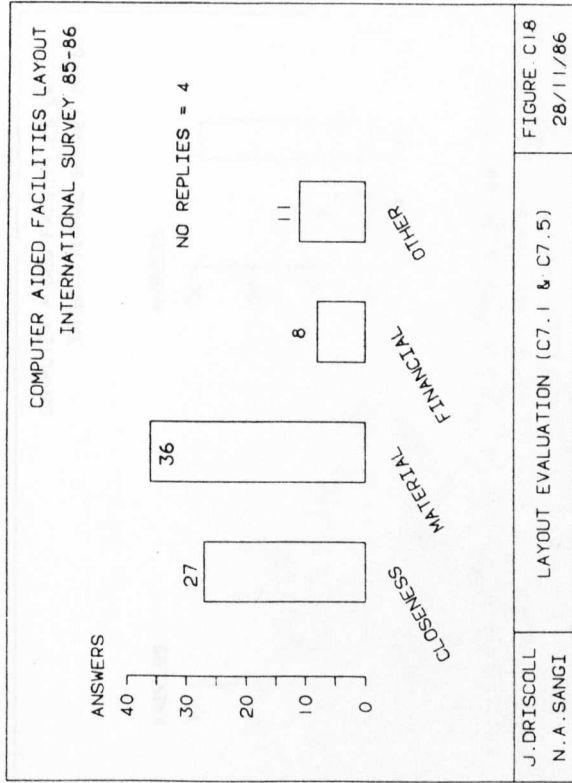
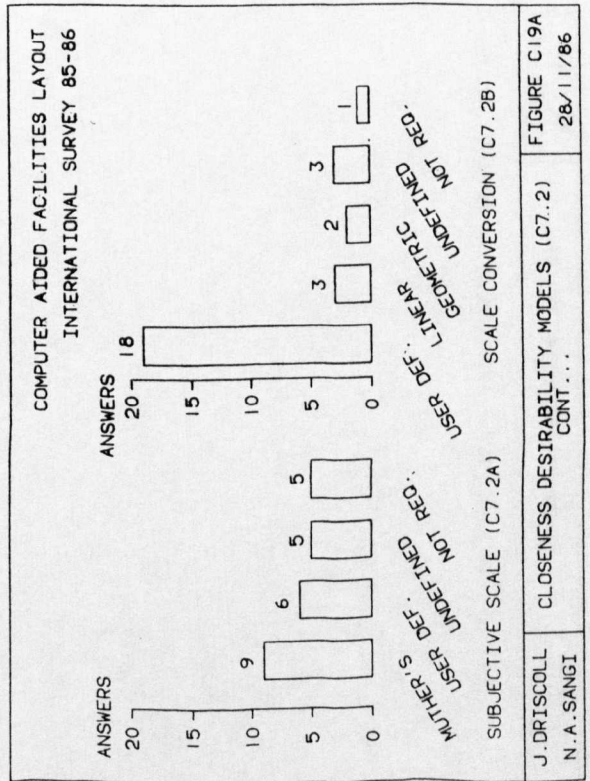
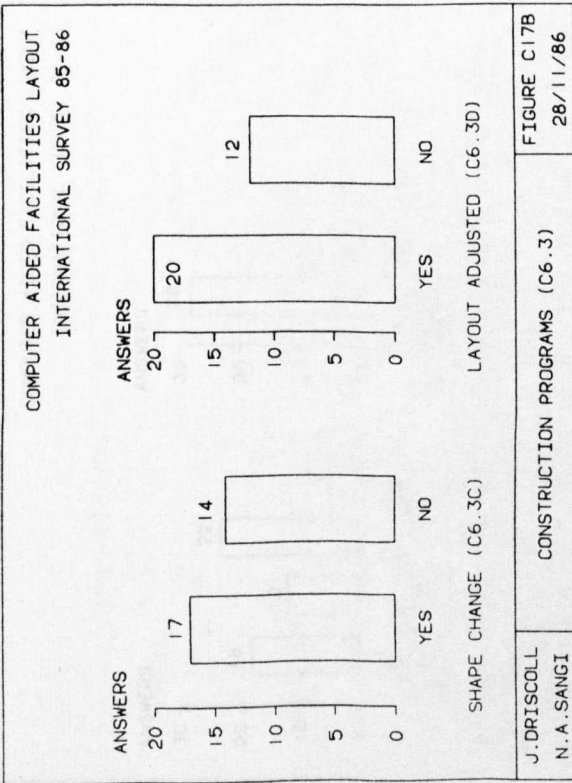






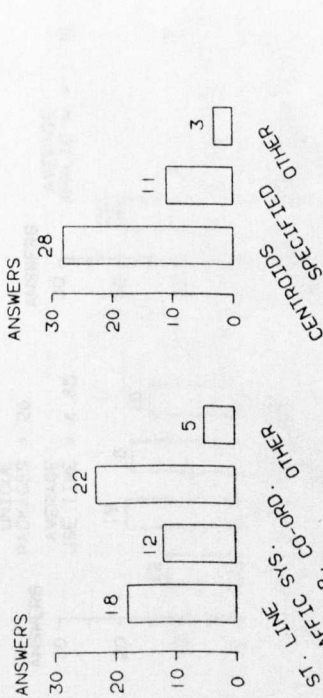








COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86



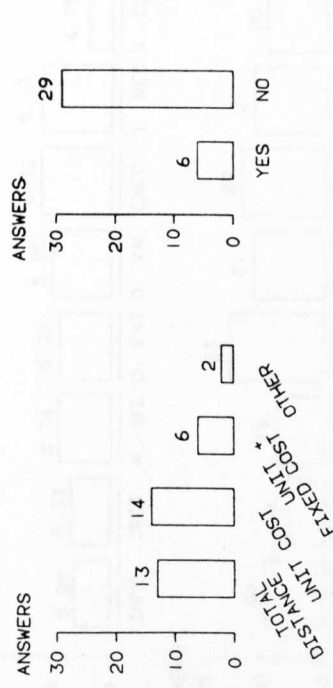
DISTANCE CALCULATION (C7.3A) START/FINISH POINTS (C7.3B)

J. DRISCOLL  
N. A. SANGI

MATERIAL MOVEMENT MODELS (C7.3) CONT...

FIGURE C20A  
28/11/86

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86



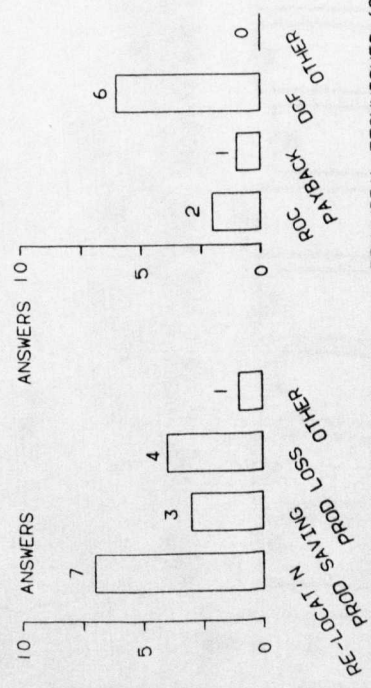
DISTANCE CONVERSION (C7.3C) M H SYSTEM SELECTION (C7.3D)

J. DRISCOLL  
N. A. SANGI

MATERIAL MOVEMENT MODELS (C7.3)

FIGURE C20B  
28/11/86

COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86



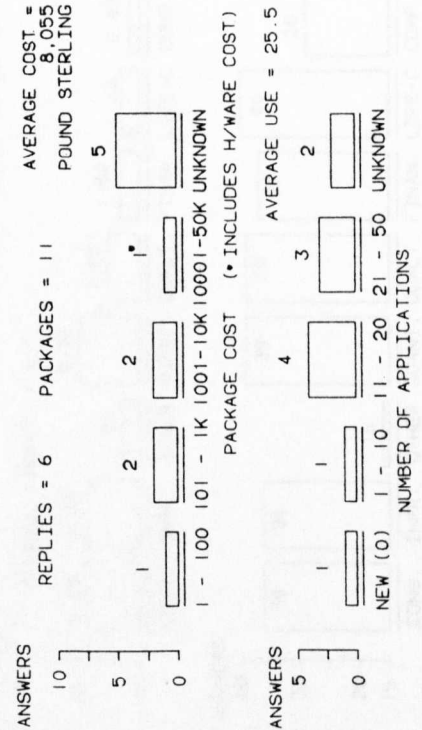
ADDITIONAL COSTS (C7.4A) FINANCIAL TECHNIQUES (C7.4B)

J. DRISCOLL  
N. A. SANGI

FINANCIAL APPRAISAL (C7.4)

FIGURE C21  
28/11/86

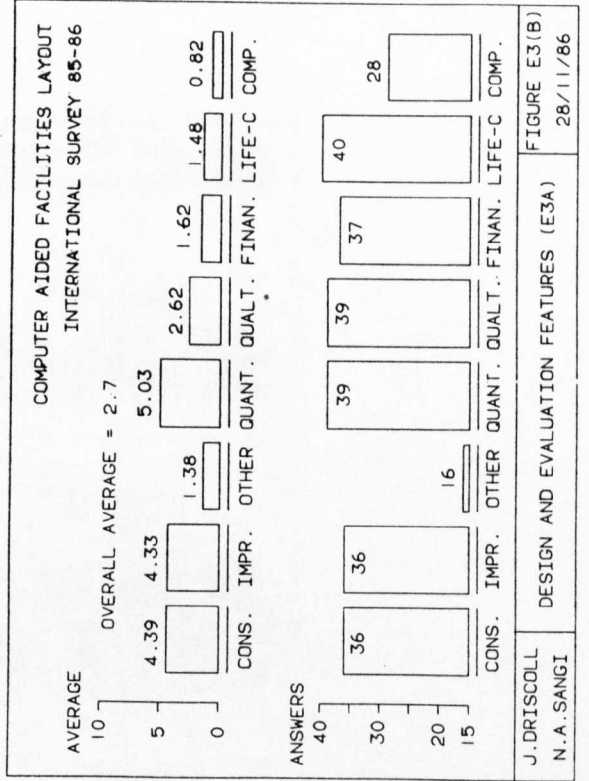
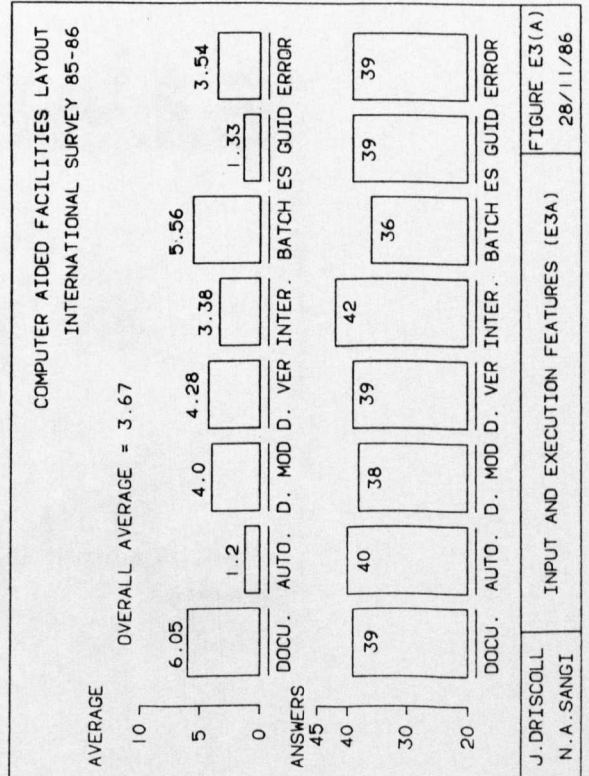
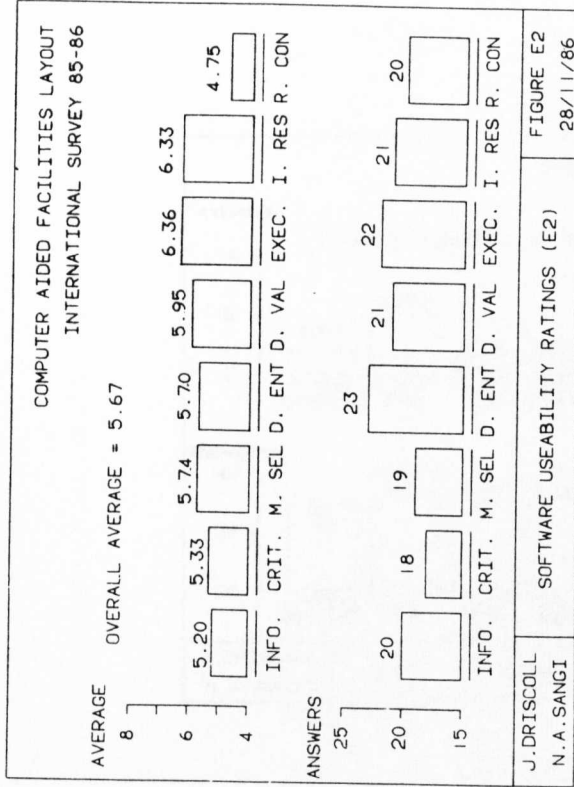
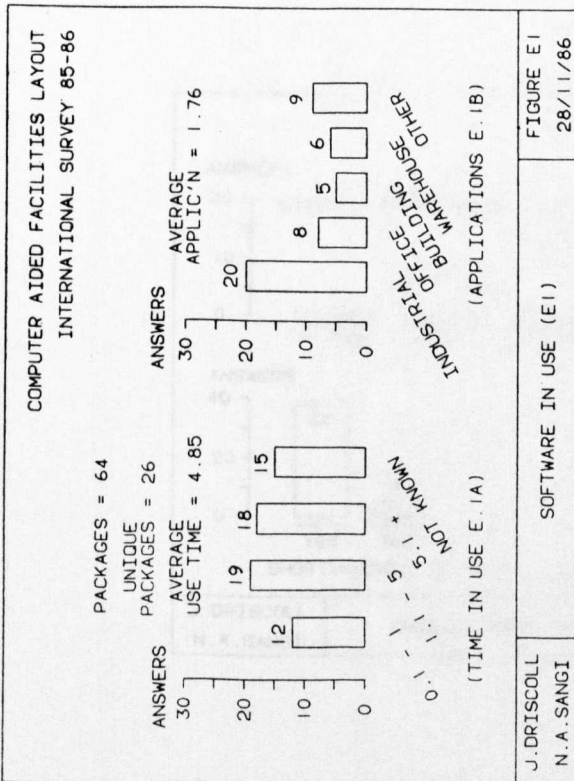
COMPUTER AIDED FACILITIES LAYOUT  
INTERNATIONAL SURVEY 85-86

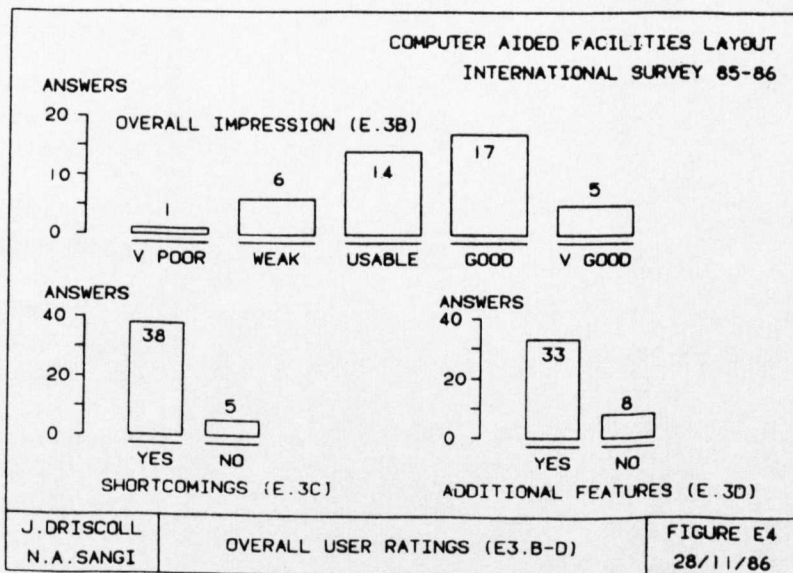
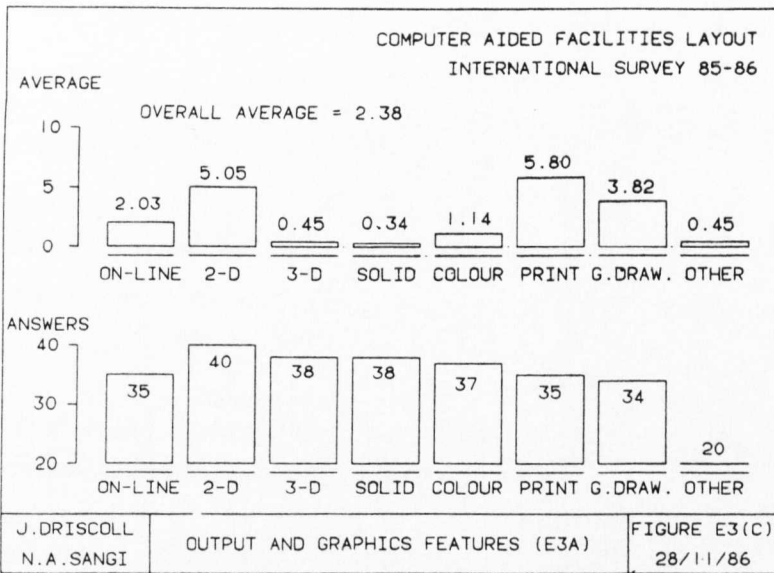


SOFTWARE MARKETING (D1)

J. DRISCOLL  
N. A. SANGI

FIGURE D1  
28/11/86





## REFERENCES



## REFERENCES

1. Abdul-Magid, E.E., "Alternative Plant Relay Layout Policies in Batch Manufacture," University of Liverpool, Ph.D Thesis, 1980.
2. Afentakis, P., "A Model for Layout Design in FMS," Working Paper #85-007, Department of Industrial Engineering and Operations Research, Syracuse University, Syracuse, 1985, pp.1-24.
3. Anonymous, "Facilities Planners Debate CAD Use Issue," Industrial Engineering, Vol. 15, No. 3, 1983, p. 60.
4. Apple, J.M., "Plant Layout and Material Handling," 3rd. ed., John Wiley & Sons, New York, 1977.
5. Apple, J.M., Deisenroth, M.P., "A Computerized Plant Layout Analysis and Evaluation Technique (PLANET)," Proceedings of the 23rd AIIE Annual Conference, 1972, pp.121-127.
6. Armour, G.C., and Buffa, E.S., "A Heuristic Algorithm and Simulation Approach to Relative Locations of Facilities," Management Science, Vol. 9, No. 2, 1963, pp.294-309.
7. Bonney, M.C., and Green, J.L., "Graphical Simulation and Off-line Programming for Robot Workcells and AMT Systems," Proceedings of the 9th International Conference on Production Research, Cincinnati, Vol. 2, Aug. 17-20 1987, pp.2542-2550.
8. Carrie, A.S., "Computer-aided Layout Planning - The Way Ahead," International Journal of Production Research, Vol. 18, No. 3., pp.283-294.
9. Choi, R., "Automatic Preparation of Layout Diagrams," Aston University, Birmingham, B.Sc. Project, 1975.
10. Collier, L.M., "Use of the Computer in Facilities Planning: Yes," Industrial Engineering, Vol. 15, No. 3, Mar. 1983, pp.50-58 (excluding p. 51).
11. Driscoll, J., "Layout of Workcentres in a Job Shop Situation," Aston University, Ph.D. Thesis, 1975.
12. Driscoll, J., Sangi, N.A., "Design of Manufacturing Systems Using CAD Software," 8th European Operation Research Conference, Lisbon, Sept. 16-19, 1986, pp.1-15.
13. Driscoll, J. Sangi, N.A., "The Development of Computer Aided Facilities Layout (CAFL) Systems International Survey 1985-86 : Survey Report and Results," Department of Industrial Studies, The University of Liverpool, England, 1986, pp. 1-119.

14. Driscoll, J., and Sangi, N.A., "An International Survey of Computer Aided Facilities Layout - The Development and Application of Software," Proceedings of the 9th International Conference on Production Research, Cincinnati, Vol. 2, Aug. 17-20 1987, pp.1811-1820.
15. Driscoll, J., and Sangi, N.A., "An International Survey of Computer Aided Facilities Layout - Analysis of Software," Proceedings of the 9th International Conference on Production Research, Cincinnati, Vol. 2, Aug. 17-20 1987, pp.1821-1831.
16. El-Rayah, T.E., Hollier, R.H., "A Review of Plant Design Techniques," International Journal of Production Research, Vol. 8, No. 3, 1970, pp.263-279.
17. Filley, R.D., "CAD for Facilities Planning : Survey Identifies Software, Systems Most Useful to IEs," Industrial Engineering, Mar. 1983, pp.67-80.
18. Filley, R.D., "A Survey of Software for Facilities Planning & Design," Industrial Engineering, May 1984, pp.71-79.
19. Fisher, E.L., Nof, S.Y., "FADES: Knowledge-Based Facility Design," Proceedings of the Annual International Industrial Engineering Conference, Institute of Industrial Engineers, 1984, pp.74-83.
20. Footlik, R.B., "Use of the Computer in Facilities Planning: No," Industrial Engineering, Vol. 15, No.3, Mar. 1983, pp.51-65 (excluding pp. 54-56).
21. Foundyller, C.M., and Jenkins, B.L., ed., "CAD-CAM, CAE : Survey Review and Buyers' Guide," Daratech, Cambridge, 1986, pp. 1710.11-1710.13 and 1720.10-1720.11. (ISBN 0-938484-22-2)
22. Francis, R.L. and White, J.A., "Facility Layout and Location : An Analytical Approach," Prentice Hall, New Jersey, 1974.
23. Goetsch, D.L., "CAD Applications : Architectural," 1st. ed., Delmar, New York, 1986, pp.9-13.
24. Grech, L.L., "Computer-Aided Facilities Design," Proceedings of the Fall Industrial Engineering Conference, 1982, pp.120-122.
25. Groover, M.P. and Zimmers, E.W. (Jr.), "CAD/CAM Computer-Aided Design and Manufacturing," Prentice Hall, New Jersey, 1984, pp. 56-64.
26. Hales, H.L., "Computer Aided Facilities Planning : A Brief Survey of Current Practice," The Numerical Control Society, Annual Technical Conference, 1979, pp.181-184.
27. Hanley, T.E., "Application of CAD to Plant Layout at Land Rover," The International Journal of Advanced Manufacturing Technology, Vol. 1, No. 3, 1986, pp.35-42.

28. Heisterberg, R.J., "New Tools for Computer Aided Facilities Layout and Design," Proceedings of the AIIE Spring Annual Conference, 1978, pp.107-120.
29. Hitchings, G.G., "Control, Redundancy and Change in Layout Systems," Transactions, AIIE, Vol. 2, No. 3, September 1970, pp. 253-262.
30. Inglis, S., Medland, A.J., Carnall, C.A., "A Comparison of Modes for Using CAD," Computer Aided Design, Vol. 17, No. 5, 1985, pp.230-234.
31. Kalvaitis, R., "Computerized Plant Layout System," Society of Automotive Engineers, 1981, pp.1-4.
32. Lee, R.C., and Moore, J.M., "CORELAP - Computerized Relationship Layout Planning," Industrial Engineering, Vol. 18, No. 3, 1967, pp.195-200.
33. Levary, R.R., Kalchik, S., "Facilities Layout - A Survey of Solution Procedures," Computer & Industrial Engineering, Vol. 9, No. 2, 1985, pp.141-148.
34. Lilley, M.T., "Computer Based Design and Simulation for Manufacturing Facilities," University of Liverpool, Ph.D Thesis, 1985.
35. Majchrzak, A., et al., "Human Aspects of Computer-aided Design," 1st. ed., Taylor & Francis, London, 1987, pp. 1-7.
36. Malde, A.J., Bafna, K.M., "Facilities Design Using a CAD System," Proceedings of the International Industrial Engineering Conference, AIIE, 1986, pp.118-123.
37. McGetrick, M.H. and Hitchings, G.G., "The Application of Graphical Techniques in Facilities Layout Planning," Proceedings of the 9th International Conference on Production Research, Cincinnati, Vol. 2, August 17-20, 1987, pp. 2436-2443.
38. Montreuil, B., "Domesticating CRAFT, CORELAP, PLANET et al.," IE News Facilities Planning & Design, Vol.19, No.2, Fall 1984, pp.1-4.
39. Moore, J.M., "Computer Aided Facilities Design : An International Survey," International Journal of Production Research, Vol. 12, No. 1, 1974, pp.21-44.
40. Moore, J.M., "Computer Aided Facilities Design: Help, Hoax or Hex?," Proceedings of the AIIE Systems Engineering Conference, 1976, pp.99-101.
41. Moore, J.M., "Who Uses Computers for Layout Planning," Proceedings of the International Conference on production Research, 1978, pp.829-843.
42. Muther, R., "Systematic Layout Planning," Cahners Books, 1961.

43. Muther, R., Phillips, E.J., "Facility Planners Cite Clear Objectives and Proper Input Data as Main Success Factors," Industrial Engineering, Vol. 17, No. 2, 1983, pp.44-48.
44. Nicol, L.M., Hollier, R.H., "Plant Layout in Practice," Material Flow, Vol.2, No. 1, 1983, pp.177-188.
45. Nof, S.Y., "An Expert System for Planning and Replanning of Programmable Facilities," International Journal of Production Research, Vol. 22, No. 5, 1984, pp.895-904.
46. Raker, D., and Rice, H., " Inside AutoCAD," 3rd ed., New Riders, Thousands Oaks (California), 1987, pp. 291-311.
47. Rosenblatt, M.J., "The Dynamics of Plant Layout," Department of Industrial Engineering and Engineering Management, Stanford University, Stanford, California, 1984, pp.1-22.
48. Sangi, N., Driscoll, J., "Applying an Enhanced CAD System in the Layout of Advanced Manufacturing Systems," Proceedings of the 2nd ASME International Computers in Engineering Conference, New York, Vol. 4, 9-13 Aug. 1987, pp. 141-147.
49. Seehaf, J.M., and Evans, W.O., "Automated Facility Layout Programs," Journal of Industrial Engineering, Vol. 18, No. 12, 1967, pp. 690-695.
50. Shigley, J.E., "Mechanical Engineering Design," McGraw-Hill, New York, 3rd edition, 1977, pp. 3-8.
51. Simpson, D., "Macro Geometry : CADCD, CADET, CADMACGM -the Basics," CADAM User Exchange -CUE (Europe) Meeting, Sept. 1983, pp. 50-53.
52. Teicholz, E., ed., "CAD/CAM Handbook," 1st. Ed., McGraw-Hill, New York, 1986, p. 8.23.
53. Tompkins, J.A. and Moore, J.M., "Computer Aided Layout: A User's Guide," AIIE, Norcross, 1977.
54. Tompkins, J.A., Reed, R., "An Applied Model for the Facilities Design Problem," International Journal of Production Research, Vol. 14, No. 5., 1976, pp.583-595.
55. Tompkins, J.A. and White, J.A., "Facilities Planning," John Wiley, New York, 1984.
56. Whitehead, B., Eldars, M.Z., "An Approach to the Optimum Layout of Single Story Buildings," Architectural Journal, Vol. 17, No.6, June 1964, pp. 1373-1380.

## **BIBLIOGRAPHY**

## BIBLIOGRAPHY

- Abdel-Barr, S.E.Z., Koura, M.M., "Computer Aided Plant Relayout," 23rd Machine Tool Design Research Conf., UMIST, Sept. 1982, pp.439-443.
- Agraa, O.M., Whitehead, B., "Nuisance Restrictions in the Planning of Single-Storey Layouts," Build. Sci., Vol. 2, 1968, pp.291-302.
- Aish, R., Van Vuren, J., Walmsley, M., "Integrated CAD Development for Building Services Engineering," Computer-aided Design, Vol. 17, No. 4, 1985, pp.179-190.
- Al-Banna, S., and Spillers, W.R., "An Interactive Computer Graphics Space Allocation System," Proc. 9th AGM:IEEE Des. Autom. Workshop, June 1972, pp. 229-237.
- Anonymous, "Databases in Perspective", Computer Aided Design, Vol. 11, No. 3, pp.117-118.
- Ardavan, N., Enscoe, E., Emory, J.R., "Computerized Facility Layout with Graph Theory," Computer Industrial Engineering, Vol. 5, No. 3, 1981, pp.183-193.
- Arndt, G., "Survey and Some Basic Considerations of the Layout of Flexible Manufacturing Systems," Proceedings of International Conference on Manufacturing Engineering, 1980, pp.303-308.
- Awane, H., Miyakawa, S., Tanaka, N., "Computer Aided Planning of a Fully Automated Assembly System for Tape Recorder Mechanisms," Internal Paper, Hitachi Limited, PERL, Yokohama, Japan., 1983, pp.1-9.
- Baugh, W.H., "Anatomy of Plant Layout Planning," Proceedings of Conference, Am. Inst. of Plant Eng., 1976, pp.3/1-3/42.
- Bazaraa, M.S., "Computerized Layout Design : A Branch and Bound Approach," AIIE Transactions, Vol. 7, No. 4, 1975, pp.432-438.
- Benzin, R.W., "Total Systems Concept in the Factory of the Future," Proceedings of Annual International Industrial Engineering Conference, Institute of Industrial Engineers, 1985, pp.460-470.
- Bernier, L.J.D., Cullinane, T.P., Phillips, D.T., "An Approach to Facilities Modernization," Proceedings of Annual Industrial Engineering Conference, Institute of Industrial Engineers, 1983, pp.251-256.
- Bhatt, R.V., Fisher, E.L., "Information Retrieval Architectures for Expert System/DBMS Communication," Proceedings of Annual International Industrial Engineering Conference, Institute of Industrial Engineers, 1985, pp.315-320.
- Bilgehan, G., Ibrahim, N., "Detailed Layout Planning for Jobbing and Batch Manufacture," International Conference on Production Research, 1981, pp.233-240.

Bindschedler, A.E., Moore, J.M., "Optimal Location of New Machines in Existing Plant Layouts," Journal of Industrial Engineering, Vol. 12, No. 1, 1961, pp.41-48.

Blair, E.L., Miller, S., "An Interactive Approach to Facilities Design using Microcomputers," Comput. & Indus. Engng, Vol. 9, No. 1, 1985, pp.91-102.

Blank, L., Carrasco, H., "The Economics of New Technology : System Design and Development Methodology," Proceedings of Annual International Industrial Engineering Conference, Institute of Industrial Engineers, 1985, pp.161-168.

Block, T.E., "On the Complexity of Facilities Layout Problems," Management Science, Vol. 25, No. 3, 1979, pp.281-285.

Block, T.E., "Fate - A New Construction Algorithm for Facilities Layout," J. of Engg. Prod., Vol. 2, No. 2, 1978, pp.111-126.

Block, T.E., "PLOP Plant Layout Optimisation Procedure," Journal of Engineering Production, Vol. 3, 1979, pp.71-93.

Block, T.E., "Approach to Effective Layout Planning," International Conference on Manufacturing Engineering, 1980, pp.309-314.

Brown, M., "Marketplace Trends as Growth tops 50 per cent," Computer-aided Design, Vol. 17, No. 2, 1985, pp.94-96.

Buffa, E.S., Armour, G.C., Vollmann, T.E., "Allocating Facilities with CRAFT," Harvard Business Review, Vol. 42, No. 36, 1964, pp.39-48.

Carrie, A.S., "Numerical Taxonomy Applied to Group Technology and Plant Layout," Int. J. Prod. Res. Vol. 11, No. 4, 1973, pp.399-416.

Chakravarty, A.K., Shtub, A., "An Integrated Layout for Group Technology with in-process Inventory Costs," Int. J. Prod. Res., Vol. 22, No. 3, 1984, pp.431-442.

Chan, H.M., Milner, D.A., "Layout Planning for Efficient Batch Manufacture," 6th International Conference on production Research, 1981, pp.185-191.

Cornell, T.R., "Systems Integration is a Mandatory Component in Achieving an Optimum Systems Environment," Proceedings of Annual Industrial Engineering Conference, Institute of Industrial Engineers, 1983, pp.38-46.

Cummings, G.F., "Simulation Model to Compare Group Technology and Functional Layout," Summer Computer Simulation Conference Washington, 1980, pp.626-630.

Cytryn, A., Parsons, W.H., "Planning ADES A System for Computer-assisted Space Planning," Interior Design, 1977, pp.190-197.

Davies, D.G., "Ergonomic Factors in Plant Design and Layout and their Contribution to production," PEMEC 80 Fact. Management and Maintenance Eng. Conf., 1980, pp.8.4.1-8.4.7.

Deshchenko, A.I., et al., "Method for Selecting the Optimum Operational Layout for Assembly Equipment," Soviet Engineering Research, Vol. 3, No. 11, pp.32-37.

Di Gansi, D., "Design Approach for an Advanced Factory Management System," Numerical Control Society Annual Meeting & Conference, 1980, pp.148-159.

Donaghey, C.E., "A Department Location System for Micro-Computers," Proceedings of International Industrial Engineering Conference, Institute of Industrial Engineers, 1986, pp.113-117.

Drezner, Z., "DISCON : A New Method for the Layout Problem," Operations Research, Vol. 28, No. 6., 1980, pp.1375-1384.

Driscoll, J., Abdul-Magid, E.E.E., "Assessing the Potential Loss of Production Capacity During Batch production Plant Layout Changes," Adv. Eng. Software, Vol. 6, No. 1, 1984, pp.14-21.

Driscoll, J., Lilly, M., "A Graph Theory application in the Redesign of Production Layouts," Proceedings of European Conference on Operations Research, 1985, pp.1-16.

Driscoll, J., Sawyer, J.H.F., "A Computer Model for Investigating the Relayout of Batch Production Areas," Int. J. Prod. Res., Vol. 23, No. 4, 1985, pp.783-794.

Dutta, K.N., Sahu, S., "Some studies on Distribution Parameters for Facilities Design Problems," Int. J. Prod. Res., Vol. 19, No. 6, 1981, pp.725-736.

Dutta, K.N., Sahu, S., "A Multigoal Heuristic for Facilities Design Problems : MUGHAL," Int. J. Prod. Res., Vol. 20, No. 2, 1982, pp.147-154.

Edwards, H.K., "Computer Graphics : Vital New Facilities Design Tool," Industrial Engineering Journal, Vol. 15, No. 9, September 1980, pp.32-34.

Eshchenko, V.G., "Layout Program Package Written in High-Level Language," Programming Methods, Plenum Publishing Corporation, 1984, pp.70-73.

Fargher, J.S.W., "Using the Modular Approach for Development of Computer Integrated Manufacturing Systems," Proceedings of International industrial Engineering Conference, 1986, pp.175-186.

Fisher, E.L., "Expert Systems Can Lay Groundwork for Intelligent CIM Decision Making," Industrial Engineering Journal, March 1985, pp.78-83.

Footlik, R.B., "Retrofit Layout Master Plan Helps Smooth Transition, Minimize Surprises," Industrial Engineering Journal, Vol. 17, No. 4, April 1983, pp.86-92.

Fortenberry, J.C., Cox, J.F., "Multiple Criteria Approach to the Facilities Layout Problem," Int. J. Prod. Res., 1985, Vol. 23, No. 4, pp.773-782.



Foulds, L.R., Robinson, D.F., "Graph Theoretic heuristics for the Plant Layout Problem," Int. J. Prod. Res., 1978, Vol. 16, No. 1, pp.27-37.

Foulds, L.R., Gibbons, P.B., Giffin, J.W., "Facilities Layout Adjacency Determination : An Experimental Comparison of Three Graph Theoretic Heuristics," Operations Research, Vol. 33, No. 5, September - October 1985, pp.1091-1093.

Foulds, L.R., Giffin, J.W., "A Graph-Theoretic heuristic for Minimizing Total Transport Cost in Facilities Layout," Int. J. Prod. Res., 1985, Vol. 23, No. 6, pp.1247-1257.

Gallagher, C.C., "The History of Batch Production and Functional Factory Layout," CME, April 1980, pp.73-77.

Ganascia, J.G., "Using an Expert System in Merging Qualitative and Quantitative Data Analysis," Int. J. Man-Machine Studies, 1984, 20, pp.319-330.

Gantz, S.P., Pettit, R.B., "Plant Layout Efficiency," Modern Materials Handling, Vol. 9, No. 1, 1953, pp.65-76.

Gaston, G.K., "Facility Layout Optimizes Space, Minimizes Costs," Industrial Engineering Journal, Vol. 18, No. 5, May 1984, pp.22-28.

Gibson, D.F., Sattoriva, G.A., "An Interactive Graphics System for Warehouse Layouts," Proceedings - AIIE Spring Annual Conference, 1978 pp.121-126.

Gonzalez, J.C., Williams, M.H., Aitchison, I.E., "Evaluation of the Effectiveness of Prolog for a CAD Application," IEEE Computer Graphics, March 1984, Vol. 4, No. 3, pp.67-75.

Graves, R.J., Richardson, J.I., White, J.A., "Computer Aided Warehouse Layout : A Case Study," Proceedings - AIIE Spring Annual Conference, 1978, pp.143-147.

Greco, A., "The Analysis and Design of Plant layout Systems and Economics," Creative Manufacturing Engineering Programs, Society of Manufacturing Engineers, 1975, pp.1-13.

Hammouche, A., Webster, D.B., "Evaluation of an Application of Graph Theory to the Layout Problem," Int. J. Prod. Res., 1985, Vol. 23, No. 5, pp.987-1000.

Heisterberg, R., Phillips, D.T., "How Facilities Design Affects the Manufacturing Engineer," SME/MHI Conference, December 1977, pp.1-11.

Hicks, P.E., Cowan, T.E., "CRAFT-M for Layout Rearrangement," Industrial Engineering Journal, May 1976.

Holland, J.R., "Factory Area Networks - the Key to Successful Factory Automation Strategies," Autofact Europe Conference, 1983, pp.31-51.

Hosni, Y.A., "Multi-Purpose System for Plant Layout Design," Computer Industrial Eng., 1978, Vol. 2, No. 1, pp.41-54.

Hosni, Y.A., Atkins, T.S., "Facilities Planning Using Microcomputers," Proceedings of Annual Industrial Engineering Conference, 1983, Institute of Industrial Engineers, pp.55-61.

Husband, T.M., "Robots, CAM and O.R.," Journal of the Operational Research Society, Vol. 34, No. 4, pp.303-307.

Hutchinson, G.K., Holland, J.R., "Economic Value of Flexible Automation," Journal of Manufacturing Systems 1982, Vol. 1, No. 2, pp.215-228.

Hutchinson G.K., "The Design of an Automated Material Handling System for a job Shop," Computers in Industry, 1983, Vol. 4, No. 2, pp.139-145.

James, G.S., "Cell Layout Utilizing the CIM Data Base," Proceedings of Annual International Industrial Engineering Conference, Institute of Industrial Engineers, 1985, pp.239-246.

Jaraiedi, M., Byrd, J., "Design of Quality Assurance Programs for Data Base Management Systems," Proceedings of International Industrial Engineering Conference, Institute of Industrial Engineers, 1986 pp.83-88.

Johnson, R.V., "Spacecraft for Multi-Floor Layout Planning," The Institute of Management Sciences, Vol. 28, No. 4, 1982, pp.407-417.

Kahyaoglus, D.J.D., "CAD Machine Location Program for Job Shop Departmental Layouts," Proceedings of Spring Annual Conference and World Productivity Congress, 1981, pp.174-177.

Kaltnekar, Z., "Some Algorithms for Decision-Making about Layout of Production Systems," Int. J. Prod. Res. 1980, Vol. 18, No. 4, pp.467-478.

Khalil, T.M., "Facilities Relative Allocation Technique (FRAT)," Int. J. Prod. Res., 1973, Vol. 11, No. 2, pp.183-194.

Khator, S., Moodie, C., "A Microcomputer Program to Assist in Plant Layout," Industrial Engineering Journal, Vol. 17, No. 3, March 1983, pp.20-23.

Kooy, E.D., Peterson, D.L., "Use of the Computer in Warehouse Layout and Space Planning," AIEE, 22nd Inst. Conf. & Conf. Boston, Mass., 1971, pp. 131-138.

Kunii, T.L., Kunii, H.S., "Architecture of a Virtual Graphic Database System for Interactive CAD," Computer-aided Design, Vol. 11, No. 3, 1979, pp.132-135.

Lam, K.P., "Hierarchical Method for Large Scale Two Dimensional Layout," Journal of Mechanical Transactions, ASME, Vol. 105, No. 2, 1983, pp.242-248.

Lichtefeld, R.A., Ward, T.L., Wilhelm, M.R., "Solving Multifacility Location Problems to Minimize Material Handling Costs," Proceedings of Annual Industrial Engineering Conference, Institute of Industrial Engineers, 1983, pp.276-279.

- Macgregor Smith, J., "Queuing Networks and Facility Planning," Building and Environment, Vol. 17, No. 1, 1982, pp.33-45.
- Malakooti, B., D'Souza, G., "An Interactive Approach for Computer Aided Facility Layout Selection (CAFLAS)," Proceedings of Annual International Industrial Engineering Conference, Institute of Industrial Engineers, 1984, pp.206-212.
- Malakooti, B., Tsurushima, A., "Some Experiments with Computer Aided Facility Layout Selection," Proceedings of International Industrial Engineering Conference, Institute of Industrial Engineers, 1986, pp.124-129.
- Martinelli, G., "Plant Layout for Maximum Efficiency," Metallurgia (SWIE), Vol. 46, No. 2., 1979, pp.92-95.
- Miller, R.F., "Quantitative Approaches to Facilities Planning and the Planning of Manufacturing Processes," Journal of Industrial Engineering, Vol. 18, No. 1, 1967, pp.10-13.
- Mize, J.H., Seifert, D.J., "CIM - A Global View of the Factory," Proceedings of Annual International Industrial Engineering Conference, Institute of Industrial Engineers, 1985, pp.173-177.
- Montreuil, B., Ramudhin, A., "Globalist vs. Hierarchical Strategies for Large Scale Facilities Layout," Research Memorandum No. 86-13, Dept. of Industrial Engineering, Purdue University, 1986.
- Montreuil, B., Nof, S.Y., "Approaches for Logical vs. Physical Design of Intelligent Production Facilities," Research Memorandum No. 87-5, Dept. of Industrial Engineering, Purdue University, 1987.
- Montreuil, B., Banerjee, P., "Object Knowledge Environment for Manufacturing Systems Layout Design," Proceedings of IEEE Comp. Int. Conference, 1987, pp.1-4.
- Moore, G.C., Revelle, C., "The Hierarchical Service Location Problem," Management Science, Vol. 28, No. 7, 1982, pp.775-780.
- Moore, J.M., "The Zone of Compromise for Evaluating Layout Arrangements," Int. J. Prod. Res., Vol. 18, No. 1, 1980, pp.1-10.
- Moore, J.M., "Long Range Space Planning," Proceedings of 6th International Conference on production Research, 1981, pp.303-307.
- Moore, J.M., "Facilities Design and Management with SLPCALC," Proc. 7th Int. Conf. on Prod. Res., 1983, pp.738-744.
- Murthy, T.S., Arora, J.S., "A Survey of Database Management in Engineering," Adv. Eng. Software, Vol. 7, No. 3, 1985, pp.126-132.
- Nakai, S., Yoshimoto, K., "A Study on Facilities Location with Tie Set," Bulletin of the JSME, Vol. 23, No. 182, 1980, pp.1396-1401.
- Nathan, D.L., Sokol, D.Z., Kent, H.K., "A Decision Support System for Factory Analysis," Proceedings of International Industrial Engineering Conference, Institute of Industrial Engineers, 1986, pp.288-294.

- Nof, S.Y., "A Methodology for Computer-Aided Facility Planning," Int. J. Prod. Res., Vol. 18, No. 6, 1980, pp.699-722.
- Nof, S.Y., "An Expert System for Planning and Replanning of Programmable Facilities," Int. J. Prod. Res., Vol. 22, No. 5, 1984, pp.895-904.
- Ntuen, C.A., "Computerized Decision Rules : User's Interface Problems," Proceedings of International Industrial Engineering Conference, 1985, pp.89-94.
- O'Brien, C., Abdel Barr, S.E.Z., "An Interactive Approach to Computer Aided Facility Layout," Int. J. Prod. Res., Vol. 18, No. 2, 1980, pp.201-211.
- O'Brien, C., Felton, T.C., "Computerised Procedures to Assist the Planning Engineer in the Input and Evaluation of Facility Layout Problems," Proceedings of 6th International Conference on Production Research, 1981, pp.319-323.
- O'Brien, C., Skok, M.J., "Development of a User-Oriented Computer Aided Plant Layout and Facilities Design System," Proceedings 7th International Conference on Production Research, 1983, pp.745-751.
- Oksala, T., "The Language of Formal Architecture," Environment and Planning B, Vol. 6, 1979, pp.269-278.
- Rabideau, G.F., Luk, R.H., "Monte Carlo Algorithm for Workplace Optimisation and Layout Planning WOLAP," Human Factor Society 19th Annual Meeting, 1975, pp.187-192.
- Rushton, A.S., Williams, J.M., "The Cost of Materials Handling to the Economy Part 1," Material Flow, Vol. 1, No. 2 1982, pp.3-11.
- Rushton, A.S., Williams, J.M., "The cost of Materials Handling to the Economy Part 2," Material Flow, 1982, Vol. 1, No. 2 pp.101-197.
- Sahu, S., Sahu, K.C., "On the Estimation of Parameters for Distributions Associated with the Facilities Design Problem," Int. J. Prod. Res., Vol. 17, No. 2, 1979, pp.137-142.
- Scott, D.C., "Facilities and Manufacturing Planning using Integrated Computerized Technologies," Proceedings of CASA/SME Autofact 5 Conference, 1983, pp.433-447.
- Scriabin, M., Vergin, R.C., "Comparison of Computer Algorithms and Visual Based Methods for Plant Layout," Management Science, Vol. 22, No. 2, 1975, pp.172-181.
- Sekhon, G.S., "Dynamic Programming Interpretation of Construction-type Plant Layout Algorithms and Some Results," Computer-aided Design, Vol. 14, No. 3, 1982, pp.141-144.
- Seppanen, J., Moore, J.M., "Facilities Planning with Graph Theory," Management Science, Vol. 17, No. 4, 1970, pp.B242-B253.

Seppanen, J.J., Moore, J.M., "String Processing Algorithms for Plant Layout Problems," Int. J. Prod. Res., Vol. 13, No. 3, 1975, pp.239-254.

Sim, R.M., "Recent Developments in Computer-aided Design and Engineering," CAD International Directory, 1986, pp.11-15.

Steudel, H.J., "Job-shop Layout Analysis via Computer Simulation," Int. J. Prod. Res., Vol. 19, No. 1, 1981, pp.59-67.

Taraman, S.R., "A Relational Data Model for a Manufacturing Database," Proceedings of Annual International Industrial Engineering Conference, Institute of Industrial Engineers, 1985, pp.195-293.

Tommelein, I.D. et al., "Sightplan : A Blackboard Expert System for Construction Site Layout," Proceedings of IFIP WG5.2 Working Conference Expert Systems in Computer-Aided Design, 1987, pp.1-2.

Tommelein, I.D., Levitt, R.E., Hayes-Roth, B., "Using Expert Systems for the Layout of Temporary Facilities on Construction Sites," Proceedings of CIB W-65 Symposium, 1987, pp.1-3.

Venugopal, S., Mohanty, R.P., "A Multigoal Analytic Formulation for Plant Layout Problems," Journal Inst. Eng. India, Vol. 63, No. ME2, 1982, pp.48-56.

Vollmann, T.E., Nugent, C.E., Zartler, R.L., "A Computerized Model for Office Layout," Journal of Industrial Engineering, Vol. 19, No. 7, 1968, pp.321-327.

Waghodekar, P.H., Sahu, S., "Machine-component Cell Formation in Group Technology : MACE," Int. J. Prod. Res., Vol. 22, No. 6, 1984, pp.937-948.

Webster, D.B., Tyberghein, M.B., "Measuring Flexibility of Job-Shop Layout," Int. J. Prod. Res., Vol. 18, No. 1, 1980.

Zirkel, P.R., "Extensions of the M-CRAFT Facility Layout Design Program through Operational Constraints," Proceedings of AIIE System Engineering Conference, 1975, pp.303-305.

Zisk, B.L., "Flexibility is Key to Automated Material Transport System for Manufacturing Cells," Journal of Industrial Engineering, Vol. 15, No. 11, 1983, pp.58-62.

Zoller, K., Adendorff, K., "Layout Planning by Computer Simulation," AIIE Transactions, Vol. 4, No. 2, 1972, pp.116-125.