COMPUTER AIDED FACTORY LAYOUT PLANNING

(CAFLAP)

Bohumil Augustin Kobliha

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ABSTRACT

This Thesis addresses Factory Layout Problems, and reviews and evaluates the available layout techniques.

Manufacturing as a system has been studied and reclassified for factory layout: space demands and spatial relationships have been considered as main principles of Factory Layout Planning. This forms a basis for the introduction of a new, more efficient Factory Layout Planning Methodology, denoted as SPACE MANAGEMENT. A new COMPUTER AIDED FACTORY LAYOUT PLANNING system is formulated as a tool for:

- preparing 3-D templates of Work Station Modules and Equipment Modules;

- drawing a requested interior of an industrial hall/bay in 3-D;

- positioning any 'objects' (spaces), via manual interactive programs in 3-D;

- automatic positioning of work stations and equipment in the bay, in 'technological' order (in 3-D), using an automatic positioning program, with a facility for: collision course finding (with objects within the bay), manual override for corrections, and finding an optimum size (width) of the bay.

The resulting layout scene can be observed from any required position and distance.

The system includes a set of auxiliary programs for Manual Feeding of lines of work stations in 'technological' order and for basic capacity calculations.

CAFLAP also opens a new way of economic evaluation of projects and alternatives.

CAFLAP is implemented in FORTRAN 77 and uses the Computer Graphics System PICASO.
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1. INTRODUCTION

The purposeful arrangement of machine tools and equipment on the shop floor is of equal importance for competitive manufacturing as machining itself. It is very well documented in history how the wealth of nations grows as their manufacturing standards improve. A very good example of this is the Republic of Venice [7]. Manufacturing was one of the pillars of the Republic's success, and was so advanced that in 1474 it led to the enactment of the first formal patent law. The "heart of the state of Venice" was the Arsenal [24]. Here was also the largest centre of production and the greatest concentration of workmen before the industrial revolution. The plans of the Arsenal, founded in 1104, were in fact an early example of planned plant layout!

'Plant Layout' and 'Factory Layout Planning' are terms (see Appendix I-1) most commonly used for labelling activities concerned with a feasible location of manufacturing or processing facilities in a suitable region, site, complex of buildings, industrial hall and finally in an industrial bay.

By definition, 'Plant Layout' is the most effective arrangement and coordination of the physical plant facilities, to allow greatest efficiency in the combination of man, materials, machines and equipment necessary for the
operation of any unit of a plant or business [1]. The activity in Factory Layout Planning could be expressed symbolically as in Fig.1.

![Activity Diagram]

Fig. 1. ACTIVITY IN FACTORY LAYOUT PLANNING RESULTS IN EFFICIENT OPERATION

As the main interest of this project is focused on mechanical engineering manufacturing, the term Factory Layout Planning [22] has been chosen. This term also clearly distinguishes activities in mechanical engineering production from chemical and other similarly specialised plants (i.e. food processing, earth products etc.), and from the design of individual equipment.

Factory Layout Planning is closely interrelated with
Mechanical Engineering, Production Engineering, Mechanical Technology, Material Handling, Management and Organisation, Industrial Psychology and Sociology, Civil Engineering, Architecture and Town Planning on one side, and with Ventilation and Heating, and Electrical Engineering etc., on the other side. The requirements and demands of these professions together with legislative measures like the Health and Safety Act, and the regulations of the Ministry of Defence, Ministry of Transport and Civil Aviation can be very restrictive. Further factors related to the protection of nature, springs and water, historic monuments, etc., have to be carefully considered, and can sometimes, even become ruling factors in Factory Layout Planning. All that is indispensable, as the construction of a new plant or modernisation and reconstruction of an older factory may have a substantial influence on the environment and on the lives of the inhabitants within a relatively large area.

In Factory Layout Planning there are usually two main types of situation to be encountered:

- The change of layout within an existing factory,

or

- A layout for a new factory on a 'green field site'.

In the first case the object is to try to utilise the existing areas in the most economical manner in order to accommodate efficient production. In the second case, the civil engineering part can be designed to fit exactly the
technological needs. These two different situations can result in a different emphasis in layout techniques. 

Other situations and complications follow from the type of manufacturing/production (single product, multi-product, parallel) and from the further division of production according to the quantity of products to be manufactured e.g. job production, batch production, flow production and mass production.

The type of production usually conditions the type of layout, i.e.:

- Process (or Functional) Layout, where the main factor for work stations arrangement is considered to be the technological process (similarity of operations, e.g. drilling machines in one area, milling machines in another area, etc., often creating departments, i.e. milling department, drilling department, etc.).

- Product (or Line) Layout, where the main factor for work stations arrangement is the product. Work stations are arranged to suit the sequences of operations (e.g. prodn. line). [1]

As a special sub-group could be considered Group Layout (Group Technology and Flexible Manufacturing Systems).
- Fixed-Position Layout,
  where the product is stationary and material,
  men and equipment are brought together
  to work on the product (ships, bridges).

The initial considerations and calculations for new layout
very often form the basis for the long-term prosperity of
the whole company. A plant must be profitable and and the
profit must be maximised, so that the plant layout
consulting engineer has to approach the task with this in
mind and take care to avoid any possible losses in future,
which may affect not only the investor, but the public as
well. Therefore the future situation must be assessed
already in the preliminary stage.

Here the layout engineer faces a dilemma. At this stage he
is not in possession of sufficient amount of data and
information of requested accuracy and depth to design a new
layout. But still, the decision making must be as precise
as possible. In some cases even the most essential
information, e.g. the volume of production, is lacking and
must be acquired by the engineer via an analysis of
statistics, typical products, indirect indicators, and
qualified guesses. The technique of Typical Products is
used when there is a lack of information regarding the
future actual products. Typical products have similar
specifications and characteristics to those of the future
planned products.

As this is a very demanding exercise, some companies and consulting engineering firms have developed up to five stages of project to avoid losses. For example, the Ford Motor Company has three 'project' stages: Programme Study, Study, and Project. (This will be discussed later in Chapter 2.)

In this complicated situation it is quite difficult to find a way to ease the work of the Factory Layout Planning Engineer. According to Francis and White [16] (published in 1974) there were some five hundred papers written on the topic.

Moor in his survey [30] in the same year (1974) analysed twenty five programs and concluded that the layout planner must still do almost all the adjustments. He considered the facility design problems to be complex and ill-structured, and as such they were handled in a variety of ways, such as: total enumeration, computerised techniques, interactive programming, heuristic programming and by intelligent machines. He also observed that a great majority of programs fell into the construction or improvement class, only five programs were found to fit into graph theory or other [30-Fig.3].

Lewis and Block [32] in 1980 noted that 'despite much
research activity there is widespread failure to use available computer programs for planning the layout of manufacturing facilities'.

According to Lewis and Block this happened for two reasons: opinion that an experienced planner can produce acceptable layout based on his own subjective judgement; and ignorance of the potential benefits of computer-aided techniques.

The writer's own experience from Ford-Dagenham, Plant Layout Department (1973-75) was similar to that of Lewis and Block, but the reasons for the failure to use computer programs are seen differently. There were serious attempts made at Ford's to use the programs available at that time, but these failed to help efficiently in practical plant layout work. The main reason could be seen in the fact that the programs were covering only a tiny portion of the planner's tasks. The manual method of templates on 'skins' (see Appendix I-12) continued in use instead, until 1987 as documented by Mike Farish [33] (See Chapter 3.).

In the second half of the seventies the number of published work titles on Factory Layout Planning seems to have dropped. However between 1980 and 1988, there were over forty new titles in the field (according to Applied Science and Technology Index, January 1980-March 1988). Contrary to Moor's survey findings and his classification [30] it seems
that some entirely new aids are now appearing combining simulation and computer graphics, for example Hollocks [25]; and interactive computer graphics, for example O’Brien and Barr [34] (See Chapter 3.).

The present work introducing Computer Aided Factory Layout Planning (CAFLAP) also uses interactive computer graphics principles. Moreover CAFLAP is pioneering some new principles of layout planning (3-D space management), which are used in combination with computer graphics in order to assist the layout engineer in a more creative way mainly in detailed layout planning.

CAFLAP offers planners a very simple, cheap and easy-to-learn-and-use practical tool for everyday layout work; a tool which would be always available for any production engineer or planner to use as and when the need occurs.
2. FACTORY LAYOUT PLANNING AND EXISTING TECHNIQUES

2.1 FACTORY LAYOUT PLANNING

According to Reed [1] a good factory layout should satisfy the following basic requirements:

- Improvement of the manufacturing process
- Improvement of Material Handling (M.H.)
- Most effective use of available area
- Improved utilisation of labour
- Improved efficiency in plant services
- Improved employee morale
- Improved production management, quality and production control
- Minimum capital investment

Main objectives of a good layout could be formulated from experience, using the above as a lead:

- effective and safe operation
- comfortable and safe access to work stations for operation and maintenance
- straight Material Flow
- work stations as close to each other as possible
- work stations positioned in inter-related positions (in straight lines or groups)
- work stations in positions requesting minimum space
in an industrial bay
and
- work stations in positions with no interference
  with other 'spaces' (see 4.2, 4.3 and 4.4).

Observing the situation in Factory Layout Planning Bestwick and Lockyer [3] conclude that "there are a number, and sometimes conflicting requirements, which should be satisfied" if "most effective arrangement and co-ordination of physical plant facilities" is to be achieved.

In the writer's view there are two different categories of basic requirements: conflicting and complementary.

Considering first the complementary criteria it can be seen that:

Firstly, improvements in the manufacturing process can be achieved if in the layout planning area provisions are made for smoother material flow and reduction of delays. This, projected on the shop floor, can be achieved by improved Material Handling (M.H.). The main generally recognised principle of M.H. is DON'T (i.e. don't move). Apple [35] and others are stressing the importance of elimination of movements. If movements cannot be eliminated they should be simplified, shortened and straightened. Any congestion should be avoided."
These M.H. principles are in agreement with the requirement for closeness of facilities as formulated by Muther [4]. The principles of closeness and reduction of movements are aimed at greater cost effectiveness.

Shorter distances between facilities result in improved utilisation of labour, not only in the M.H. area, but also in manufacturing services; e.g. faster supply of tools (this depends on accessible positioning of Tool Crib).

Secondly, closeness of sufficient facilities for health and welfare (lavatories, drinking water, sitting facilities, rest rooms, etc.) in connection with Health and Safety at Work requirements [36,57] eliminates the excessive Relaxation Allowance [51] and improves the quality of relaxation time for the labour force. These measures directly contribute to employees' contentedness, and this improves their moral. The aesthetic effect of well arranged layout also makes an all round positive contribution.

Thirdly, closeness of facilities is complementary to the requirement of the most effective use of the available (or designed) area, therefore the yield of shop floor space (t/m sq., number of products per m sq., etc.) may be increased. This positively influences capital investment which can be minimised, especially in 'green fields' projects. Size of buildings, and therefore cost of buildings, could be reduced with consequent reduction of cost of maintenance, reduction
of cost of heating, ventilation, lighting and other overheads. The resulting compact layout is more controlable and therefore supports in a better way production management functions; management control, identifying and counting of W.I.P. and products is simplified.

Fourthly, from operation management and utilisation of labour point of view, the achievement of the proper plant layout allows the most effective design of individual operations, the process and the flow.

Fifthly, the achievement of a proper facilities layout incorporating correct inspection locations in the process should positively influence quality control.

Sixthly, layout planned for ease of maintenance allows for the use of maintenance time effectively and reduces personnel requirements.

'All of the above complementary criteria show the profitable advantages of proper Factory Layout Planning.'

'Contrary to this, are conflicting combinations of criteria, which are making the task of the layout planner more difficult. The sources of conflicts occur among the needs of production technology, space requirements, space available and the overriding economic criteria.'
Firstly, a conflicting situation may arise between the requirements of an ideal technological position of work stations and the real space of an industrial hall/bay. For example, a sophisticated calculation [5,6,7,8,9] can recommend positioning work stations in a cluster to achieve the shortest possible distances between them. Theoretically this seems to be a perfect recommendation, but it could prove an unacceptable one if the width of the existing industrial bay cannot accommodate the cluster! In the same way the cluster arrangement may conflict with the spatial demands of Material Handling.

Secondly, a conflict may also arise with the width of the bay when a group or line arrangement of work stations, each of which has a different size, has to be accommodated.

Thirdly, different sizes of work stations in recommended positions may conflict with the requirements for the most economic utilisation of the shop floor area. There could also be a collision of work stations with supports/columns of maintenance steelwork etc.

Fourthly, the interrelated positions of departments, services, stores, tool cribs and the relative positions of foremen, etc., could be sources of conflict.

In order to achieve the best possible results in the final layout it is essential to compromise and establish
priorities. But priorities could vary from case to case and from planner to planner.

From the point of view of overall economy, it is the distance between the interrelated places that plays the main role. It was probably for this reason that most research effort has so far been concentrated on understanding the flow of material, in an attempt to shorten the distance of travel of Work in Progress (W.I.P.) between operations. A number of methods and relationship charts, studying mostly 'from - to' material handling, have been developed. The most widely recognised method is Muther's [4] Systematic Layout Planning. He also gives priority to the closeness of facilities, combined with the importance of relationships among facilities, rated by a unique AEIOUX rating system.

These techniques improve the quality of the layout engineer's work, but have very little impact on his productivity. New ways have only been opened by the wider implementation of computers (see Chapter 3.).

As already mentioned in Chapter 1., each project is usually divided into several project stages. Reasons could be found in the necessity of approval procedures for financing the project, strategic planning, regional planning etc., as well as in technical methodology of approximation, i.e. from theoretical outline ideas of the system, to detailed complex design and installation of the "recommended system" [4, 40].
Another category in Factory Layout Planning are design phases. These are logical steps in layout design methodology and could be seen represented by some well known procedures like Muther's Systematic Layout Planning, Apple's Plant Layout Procedures or Reed's Plant Layout Procedures as summarised by Tomkins and White [39].

The distinguished reality of project stages and design phases as parallel categories is unfortunately not stressed enough in Factory Layout Planning literature. Very often they are intermixed. But for the sake of methodological clarity this should be avoided.

The distinct differences between project stages and design phases could be seen clearly from the following definition and description of project stages; which is then followed (for comparison) by design phases.

Definition of project stages:
Project stages (see Appendix 1-2) are graded steps in the preparation of project documents (i.e. reports, calculations, drawings etc.). Each step gradually goes into more depth and detail of factory layout.

In an ideal situation engineers would have the capacity, the time and the information to solve detailed problems in the early stages, as these could often influence the final economic aspects of the project.
To see more clearly the extent of the problem it is useful to describe in outline the project stages:

Stage 1.
FEASIBILITY STUDY (see Appendix I-3) defines the most economical approach to the plant layout. The production programme should be defined at this stage, sometimes with the help of typical products. The main Flow of Material, the number of machines and equipment needed, and the main areas and building(s) required should be established here, as well as manning and services. In drawings main areas and buildings are presented as block layout. A programme of all building and layout works and with the relevant economic considerations should be worked-out. Two or more alternatives are usually considered.

Stage 2.
INVESTMENT PROJECT (Appendix I-4) studies the size of the main industrial hall(s), dimensions of bays and annexes of the plant; determines the requested production programme and flow of material; designs departments in inter-related positions, but without detailed shop floor layout and the positions of work stations and equipment. In drawings the departments are often presented as more accurately specified block layout. In the case of a new factory on 'green field', a site is selected. As above, two or three alternatives are usually considered.
Stage 3.

PROJECT and WORKING DRAWINGS.

In this final project stage (Appendix I-5) all final 'capacity' calculations are made, work stations (machines and equipment) are determined and their positions are fixed in the layout of the defined building.

The project layout drawings show e.g. work stations in realistic shape, with details like anchoring bolts, and position of power supply, electrical accessories, connection to gas, water, coolant supply, etc. The Working Drawings (Appendix I-6) include all the details necessary for work stations installation and any necessary civil engineering works, e.g. if foundations are requested. The industrial halls are positioned in the general layout.

In some commercially and technically complicated cases intermediate stages are introduced, usually after the Investment Project. For example, in an 'Introductory Project' (Appendix I-7) almost everything is defined except the final and exact position of work stations inside the industrial halls. The intermediate stage is also used when the project and detailed final drawings are prepared in another country where the project is located and local subcontractors are employed. In this way the investor is saving on the cost of design work, using local draftsmen and engineers. He only hires the experts from the consulting firm or supplier who designed the previous stages of the
project. The experts, consulting engineers, supervise local staff and advise on site. This helps to secure higher employment for local people. The experts also pass on the 'know-how', which is very valuable especially for the 'Third World' countries.

Design phases (represented here by Muther's Phases of Systematic Planning [4]) are following:

Phase I
LOCATION
Determine the location of the area to be laid out.

Phase II.
GENERAL OVERALL LAYOUT
Establish the arrangement of the area to be laid out.

Phase III.
DETAILED LAYOUT PLANS
Locate each specific piece of machinery and equipment.

Phase IV.
INSTALLATION
Plan the installation, seek the approval of the plan, make the necessary physical moves.

To illustrate the difference: In Feasibility Study it is
not necessary to use all design stages. Overall layout or a block layout in drawing presentation is all that is needed. In the Investment Project the situation would be similar.

The difference in the position of 'Location' in project stages and design phases can easily be seen. Muther [4] places the 'Location' first, while the present work places the 'Location' in project stages, in Stage 2. - Investment Project.

The approach here is different for the following reason: Prior to the selection of any plot or place (location) the main capacity calculations, requirements of areas, and a block layout of facilities have to be completed. The engineer responsible for the selection of a plot must have this information in hand together with details of max.loads (bearing loads) etc., otherwise the selection of the plot cannot be carried out with full responsibility. Not furnishing the information to the engineer could be costly: completly inadequate plot could be selected, which could result in expensive alterations e.g. foundations of heavy machines and building columns might have to be supported by piles etc..

Hence project stages are influencing the activity in design phases. This is apparently the reason why Tompkins and White ([39] - Fig 1.1) are putting their Facility Location in facility planning hierarchy on a completly independent
level and position.

Further, in contemplating the design methodology and procedures only, for every layout, Muther [4] lays down three fundamentals:

- **Relationships** - the relative degree of closeness desired or required among things;
- **Space** - the amount, kind and shape or configuration of the things being laid out;
- **Adjustment** - the arrangement of things into a realistic best fit.

The above three fundamentals have a special place in CAFLAP development.

In CAFLAP, the relationships are seen in dynamic and spatial terms (see 4.2).

From the production point of view, the dynamic/activity relationships are expressed in the 'technological' positioning of work stations to suit best the Flow of Material (requirements of the most economical production).

With the help of Nugent, Wollman and Ruml's [38] ideas, 'Technological' positioning can be defined as the optimal specification of which facilities are to be adjacent in the final layout without regard to the area or shape of the
individual facilities.

The spatial demands are seen as the total amount of spaces to be accommodated in the building, which include the space needed for work stations and equipment, and some other spaces.

NOTE:
Here and in the rest of the thesis the terms 'space' and 'spaces' are used. In 3-D CAFLAP connotations (contrary to Muther's [4] spaces which are actually 2-D areas) they have been used to express the situations and spatial relationships (see 4.2).

The arrangement of work stations and equipment in the 'technological' order and realistic spatial position in an industrial bay, is the main task in Factory Layout Planning. Here also lies a source of conflicting situations and requirements, as discussed above, and more:

Firstly, the work station itself has to be designed as a safe and comfortable place allowing and supporting all functions of the machine tool or equipment, and effective work of the operator(s). The design itself carries conflicts between safety and the requirements for most effective operation.

Secondly, the requested position of work station in the real
space (building) could be in conflict with maintenance requirements.

Thirdly, the requirement for closeness of facilities could be a trigger for collision among functions, operations and maintenance of other facilities.

CAFLAP has been developed with all this in mind (see Chapter 4.).
2.2 EXISTING TECHNIQUES USED

For the study and design of Activity Relationships and the Flow of Material, a number of methods, mostly charts, have been in use (e.g. From-To charts, REL charts etc.).

On the basis of these charts, in relation to 'technological' (Appendix I-8) positioning of work stations, some computerised methods have been developed. The most important of them are discussed in Chapter 3.

From the point of view of graphical presentation of the arrangement of work stations in work shop situations the Space Relationships are the most important. Here below are outlined the main techniques for design of Space Relationships as historically developed, and as also presented even in the most recent literature ([39]-published in 1984 and [58] published in 1985).

Originally ordinary 2-D drawings were used for Factory Layout Planning. Work station after work station, position after position, had to be drawn individually. This often meant repeating similar shapes and situations, in the same way as in the days of the Venice Arsenal, or in the manner of Michelangelo Buonarroti's civil engineering layouts. There were no facilities to ease the draftsmen's work. This demanding and slow technique was improved by the use of two dimensional templates of work stations. These were either
copied (under tracing paper) into a layout, or held in position by magnetic 'operators' on a magnetic table where a drawing of the industrial hall was fixed. Where the magnetic table technique was used, a photograph of the layout was taken by an overhead camera. This process was repeated after each change, introducing alternative layouts. This technique was much faster than drawing layouts with templates under tracing paper. But all the extra equipment like cameras, special overhead stands, lighting and finally engaging a qualified photographer on the job made this method expensive. Also the extra space needed and time lost by the layout engineer involved, e.g. queuing for the magnetic table and the photography, led to this method being abandoned.

The two dimensional methods had some disadvantages especially when presented to customers or non professional top management lacking knowledge of reading drawings. Also, these methods are not able to show some of the space utilisation problems. Neither are they sufficient for collision course finding among work stations and building, maintenance steel-work, columns footings (foundations), ducts, etc.. Therefore 3-D model 'templates' were introduced.

This 3-D method, deploying wooden, plastic, or metal models, is still in use for some specialised cases, e.g. piping. This, however, is a very slow and expensive method. To
manufacture models of work stations and equipment, usually in 1:50 scale, is a straightforward job if wood or plastic materials are used. But storing and issuing them to layout engineers, as well as the manipulation of models of work stations within a 3-D model of an industrial hall is complicated. Plastic models of work stations, equipment, operators, etc., are usually subcontracted. For wooden models of industrial halls, maintenance steel-work, pipelines, etc., there have to be adjacent workshop facilities. This can be a very undesirable mixture of activities: design work vs. manufacture. According to good engineering practice, and ergonomic and synergetic rules (see 4.2), such activities should be kept separate.

When a 3-D model is finally built, photographs of the arrangement are taken in a similar manner to that needed for the magnetic table method.

With the development of plastic drawing sheets (Mylar) known as 'skins', a relatively very good technique, using 2-D templates fixed after manual positioning by double-sided sellotape, has been invented. This template on 'skins' technique, (see Appendix I-12), enables the engineer to change position of work stations several times to investigate alternatives. The templates of work stations are usually drawn in 1:50 scale on a thinner plastic tracing foil. The 'skins' have a pre-printed grid (250x250mm in 1:50 scale) to ease the positioning of templates. For
buildings, pre-printed sellotapes, indicating walls, etc., are used.

The 'skins' are reproduced in the same way as ordinary tracing paper drawings. These 'skins' remain relatively durable. However, the dust catching residue of the sellotape creates stains. Because of their relative weight and stiffness, the 'skins' are stored hanging in purpose-designed steel cases. Overall ease of manipulation of 'skins', so similar to familiar tracing paper, makes this inexpensive method of producing 2-D layout models, sometimes called 'templates and tapes', very popular. Tompkins and White ([39-published in 1984!]) stated:

"The most common method of creating layout plans for larger facilities is to use templates and tapes."

Also Konz [58] published in 1985, described this technique in great detail.

Unfortunately none of the above discussed manual methods is fast enough, and none of them assists the layout engineer in the direction of providing economic space utilisation. They do not help in the coordination of layout tasks (System - Hall, Bay, Work Station ... Mechanical, Civil, Piping, Electrical, etc.); nor do they facilitate collision course finding.
All the layout work must currently be carried out intelligently and unaided by the layout engineer. The quality of projects therefore depends on his experience, level of education and ability to consider, assess, and foresee the technological situations in a spatial context. This also requires great engineering imagination!

The methods, described above, show how inadequate are the tools which the layout engineer is using for his highly creative and, at the same time, complicated yet repetitive assignments.

Even in a new factory situation there must be a continuous re-layout and re-arrangement activity in progress [2]. The repetitiveness of layout tasks, the need for changes of layout to be carried out in the shortest possible time, and the requirement for finding the most effective arrangement by consideration of alternative layouts, have led to the development of new methods and techniques in Factory Layout Planning.
3. COMPUTER AIDED SYSTEMS PRESENTLY AVAILABLE

3.1 INTRODUCTION

In order to avoid any duplicity of research and with the view of a possible utilisation of some of the existing computer programs for CAFLAP, an extensive literature search has been undertaken. (See Chapter 10.)

One of the sources quoted is Location and Layout Planning bibliography [48] by Domschke and Drexl, in which the authors include layout planning and any relevant systems in a wide field of "location theory".

According to them, location theory can be divided into macroeconomic and microeconomic location theories.

In macroeconomic location theories industries, economic sectors, etc., are placed 'in space'. The microeconomic location theories are further divided into plant location and plant layout theory.

Publications whose authors regard transportation cost or travel time as main location factors are described in the bibliography as transportation orientated, and of a normative (quantitative) type. This group is further divided into publications dealing with plant location and
those which deal with public facility location problems.

According to Domschke and Drexler the main objective in plant location is to minimize the sum of cost (minisum problem). In public facility location the objective is to minimize the maximum distance, time, etc., which a user of a facility has to accept (minimax problem). Within both types the factor of different distances occurs. Dealing with this there are network orientated models (where the shortest distance between two points is considered - Operation Research), and models assuming that travel takes place on a plane (all points on the plane are potential locations).

Plant layout theories try to optimize the location of facilities within a building or plant, e.g. location factors are studied.

Authors have divided publications on location and layout planning into 13 chosen subjects. (The current work would fit into the class "M"-Thesis). Future trends in the development of the microeconomic location theory are predicted by the authors as mainly concerned with the development of software tools based on computer graphics. (This is the line which CAFLAP follows.)

Nugent, Vollmann and Ruml [38] are considering "the optimal specification of which facilities are to be adjacent in the final layout without regard to the area or shape of the
individual facilities", as most important step in the complete layout process.

With the expansion of the use of computers, many attempts have been made to find the algorithms for the most suitable 'technological' positioning of work stations, related to each other in the sense of the most economic flow of material. Relationship charts of activity areas (based on the flow of material and service departments) have created the basis for a number of computerised methods in Factory Layout Planning.

According to Tompkins and White [39], techniques for computer aided layout may be classified by the method of recording flow among departments and by the method of generating the layout. The flow may be expressed as a quantitative record in a FROM-TO chart, or as a qualitative one recorded in an activity relationship chart.

The method of generating layout may vary from computerised algorithm developing block layout, presented by symbolically marked squares, to computer graphic presentation of detailed facilities in 3-D.

Moore in his international survey [30] in 1974 is using Wollmann's [41] classification of computer programs for facilities design as either 'construction' type or 'improvement' type. According to him the construction
algorithms build or construct a solution from raw data; the improvement algorithms require a feasible solution as part of the input.

In Moore's survey eighteen programs are classified by authors as construction type, seven as improvement type, but five are not classified either way. (As Moore's classification fits better for block plan plant layout algorithms, it is less suitable for classification of other systems. If Moore's approach should be applied to CAFLAP it would fit in his class 'Others', although this class was originally created for a different purpose.)

Below are reviewed and evaluated some classical types of methods/programs from the past, which are still quoted in recent literature. Tompkins and White in 1984 [39] are actually presenting CRAFT, COFAD, PLANET, CORELAP AND ALDEP. Their selection is identical with programs chosen in Computer Aided Layout: A User's Guide [57], which quotes them as "techniques already proven to be usable to the facility designer". Konz in 1985 [58] also finds it useful to include in his book CRAFT, COFAD, CORELAP, ALDEP AND PLANET.

These classical types of program are followed by new tendencies and ways in tackling Factory Layout Planning problems.
3.2 COMPUTER AIDED SYSTEMS

Many programs and commercial software packages currently in the field are approaching plant layout as a pure operation management problem of 'sequencing' the departments or work stations, in order to receive a final block layout with shortest possible distances between the interrelated facilities. As described in the following, many of them are building on the original ideas of Armour-Buffa [5,6], Lee-Moore [8] or Apple-Deisenroth [9].

3.2.1 CRAFT

In 1962 G.C.Armour and E.S.Buffa presented their work "A Heuristic Algorithm and Simulation Approach to Relative Location of Facilities" which resulted in CRAFT (Computerised Relative Allocation of Facilities Technique - 1964), a typical improvement type program for block plan plant layout [5,6,7]. The program was developed for process (functional) layout. This method is based on the algorithm to minimise Material Handling (M.H.) costs incurred among all departments. M.H. cost is defined as the product of flow, distance, and unit distance travel cost, which are the main input data. An initial layout has to be given and must consist of a group of unit squares to represent each department. The procedure first determines the centroids of departments. Then CRAFT evaluates the given layout, calculating the rectilinear distances between the
departments and stores it in a distance matrix. Then M.H. cost is calculated as product of data from FROM-TO chart (flow), distance matrix and move cost matrix.

Production departments are identified by assigned capital letters. CRAFT next considers departmental interchanges and evaluates what the effect will be if locations are interchanged. The program switches the positions of the departments to achieve, through an approximation process, maximum economy in Material Handling. M.H. costs are compared. The process continues until no more improvement can be made by pairwise exchanges. Only departments with common borders or of the same area are considered for exchanges of locations.

On final computer prints the inter-related positions of departments are marked by lines, composed of the assigned capital letters, delimiting the areas of individual departments. CRAFT program does not guarantee that the layout with lowest M.H. cost will be found unless all possible interchanges are considered.

Some assumptions made in the CRAFT algorithm could be viewed critically. Francis and White [16] commented that:
Firstly, the use of centroid locations in measuring distances, might not be realistic for some practical applications. This way some unusual layout designs could be obtained, resulting in crooked aisles.
Secondly, the assumption that M.H. costs are significant,
known and linear in distance travelled. In the real layout this could sometimes be of small significance.

The comments on problematic assumptions are important for the user. He should see CRAFT as a conceptual tool for the design of block layout in some early stages of projects or search phase of design.

Nugent, Vollmann and Ruml in 1967 [38] compared CRAFT with newly developed similar programs H63 and HC63-66. They compared the goodness of the solutions reached and computational efficiency. The results obtained by the authors show that CRAFT runs more slowly than HC63-66; the latter produces solutions of slightly higher quality. Despite some positive results achieved by programs H63 an HC63-66, none of them were quoted in literature studied and failed to appear even in Moor's survey [30].

In spite of the above criticism Francis and White in 1974 [16] finally have a word of praise for CRAFT:

"Although there are other improvement algorithms, in general none have been shown to be superior to CRAFT in layout design."

3.2.2 COFAD

From the family of similar improvement programs, at least COFAD should be mentioned here. Developed by Tompkins and
Reed [43], COFAD -Computer Facility Design- is basically a modification of CRAFT.

COFAD allows the use of move cost for a variety of M.H. systems, i.e., each alternative layout is also considered from the point of view of the M.H. method to be selected.

Input requirements are the same as for CRAFT, expanded by the cost of M.H. system, and a percentage of utilization of M.H. equipment per move. COFAD enables the selection of the least-cost layout and in parallel the selection of M.H. method with minimal cost of M.H. equipment.

The program starts with procedures identical to CRAFT, i.e., improving the initial layout. Then the cost of each move with M.H. method alternatives is determined. Flow (FROM-TO chart data) is constant. Next comes determination of a minimal cost M.H. system which is followed by a search for M.H. equipment whose utilization is good.

In the next phase reduction in total cost is sought. If in the COFAD process no reduction of total cost can be achieved, the program is terminated or flow volume inputs are changed. This is done for following reasons: to confirm that the found solution is a steady-state solution, and to check the sensitivity of design to the flow data. If the steady-state is not confirmed, COFAD is restarted with a new apportioning of cost of M.H. system to individual
moves. This loop continues until the requested (steady-state) solution is obtained.

The assumptions inherited from CRAFT (as discussed above in this connection) are inevitably sources of the same critical comments. Here the situation is made even more complicated by the variety of M.H. methods considered, and their costs due to the variation of market prices. Another complication arises in connection with the collection of data regarding the realistic percentage of utilization of equipment, which is always difficult to establish.

Further programs of a similar type in the improvement class quoted by Moore [30] are: GRASP, KONUVER, LAYADAPT, OFFICE, PREP and The Terminal Sampling Procedure. In 1978 Tompkins and Moore [57] are adding to this list another two: COSFAD and SET.

3.2.3 CORELAP

As a classical example of construction type program [30] could be seen the digital computer program CORELAP [8]. CORELAP—Computarised Relationship Layout Planning—was developed by R.C.Lee and J.M.Moore in 1967 to design block plan plant layout economically. It is a job shop orientated procedure.
In comparison with CRAFT, which is using flow consideration for its procedures, CORELAP procedures are based on activity relationships (originally suggested by Apple[10]). Activity relationship (REL) charts are using A, E, I, O, U, X, rating convention [4, 10].

For input the following data are required:
- the number of departments (N)
- the data from REL chart
- the area requirements for each of the departments
- the ratio of maximum length of the building to width.

The heuristic algorithm starts with areas having the greatest sum of relationships. The departments with the highest total closeness rating (TCR) is placed in the centre of layout matrix. The program then interactively adds other areas, one at a time, in such a way as to maximize the attainment of the desired relationship. The final output is in the form of layout matrix. On the print of the final layout, whole areas of departments appear covered by identifying numbers, each representing the unit square it occupies. The areas which are available but not occupied are marked up by zeros. Layouts designed by CORELAP are often of an irregular shape. To fit a conventional shape of a building, this has to be adjusted manually.

Similarly to CRAFT, CORELAP should be considered as a conceptual tool for the design of block layout in some early
project stages or research phase of design.

3.2.4 PLANET

Another construction type program often quoted in literature is PLANET - Plant Layout Analysis and Evaluation Technique-developed by J.M.Apple and M.P.Deisenroth in 1972 [9,7,39]. PLANET was also developed for design of block layout.

For input the following data are required:
- material flow data (i.e.entries from the FROM-TO chart)
- move cost matrix
- distance matrix

PLANET uses three alternative methods for specifying material flow data. In the design procedure three different layout construction algorithms are used.

The three methods of specifying material flow data are following:

The first one specifies product sequence by department for each part, together with cost per move per unit of distance for each part. The cost is often input as unity, because it may not be determined. PLANET then develops a flow-between cost chart, which indicates the cost of movement between pairs of departments. This is then used in the construction algorithm.
The second method inputs material data directly from FROM-TO chart, which is then converted to a flow-between cost chart.

The third method of inputting flow data is that using a penalty matrix. The penalty input between two departments is an indicator of the importance of closeness of the departments. The matrix can also indicate the difficulty and relative frequency of material movements between departments, or indicate the relationship data. A placement priority scale 1 to 9 is used (9 is the lowest priority). The layout is not predetermined.

The three construction algorithms used in PLANET are best described as follows:

Method A selects departments according to flow-between costs, starting with pairs of highest priority group with the highest flow-between costs. The next department to be selected is that from the highest priority group and with the highest flow-between cost with any department already placed. In this fashion the procedure continues until there is no department left unplaced within the layout.

Method B starts in a similar way to that of A, but the next department to enter is chosen from the highest priority group and has the highest sum of flow-between costs with all selected departments. This continues until no department is left unpositioned.
Method C starts with the department in the highest priority group that has the highest sum of flow-between cost with all other departments. As the next entry, method C selects the department in the highest priority group that has the highest sum of flow-between cost among all other departments. The procedure continues until no department is left unpositioned.

The layout routine always starts with the two top selected departments placed in the centre of the layout. Any following department is placed in a manner which will minimize the M.H. cost, using a trial-and-error method.

PLANET often generates layouts that do not suit a uniform building shape, so deficiencies are similar to those of CORELAP. Layout must be manually adjusted but this cannot be evaluated by PLANET as feedback. PLANET can be considered as another conceptual technique for initial stages of projects or search phase of design.

3.2.5 ALDEP

ALDEP - automated layout design program - was presented by Seehof and Evans in 1967 [54]. As classified by Tompkins and Moore [57] this is another construction type routine.

First the authors studied the attributes which condition a better layout. They suggested a scoring technique, and used
a matrix of weighting factors which indicated a desirable 
closeness of departments. The layout score is the summation 
of the preference values for the adjacent departments. No 
details of preference values (factors), or scoring 
techniques have been published by the authors. However, 
Tompkins and Moore [57] used in their assessment of ALDEP 

The main input data are:
- number of departments and their square footage,
- relative departments location preference,
- layout of the building (building dimensions, etc).

ALDEP creates a random layout and scores it. This is 
repeated several thousand times to reach the best scores. 
Compared with CORELAP, ALDEP produces many layouts and rates 
them leaving the selection of the best alternative to the 
user; while CORELAP attempts to produce one best layout. 
Block layouts are produced by a plotter. Selection and 
adjustments for the final layout are done manually. ALDEP 
can be only used for block plan layouts with predetermined 
aisles, stairs and other amenities. ALDEP cannot be 
utilised for a detailed layout or 'technological' 
positioning of work stations, and therefore cannot be used 
as an entry programme for CAFLAP.

It is worth quoting that, in 1979, Rosenblatt suggested a 
new algorithm [60] which, as he claims, could be used with
ALDEP. He uses a combined quantitative and qualitative (subjective) approach to the plant layout problem. His supposition is that quantitative and qualitative approaches are formulated as a quadratic assignment problem. Both have the same feasible region, therefore the two methods can be combined. His multi-objective formulation, minimizing total flow cost and maximizing total closeness rating, is made possible by the introduction of weight assigned to the total cost flow and total rating score. Rosenblatt suggests a graphical solution to find the 'best' layout. The 'best' layout lies on the intersection of a line, established by the weights, with a point on a 'discrete efficient frontier', given by positions of efficient layouts in the graph.

Moore in 1974 [30] quotes in this class of programs (using construction algorithms) another 16 programs. They are: CASS, COLO2, COMP2, COMSBUL, DOMINO, GENOPT, IMAGE, KONUVER, LAYADAPT, LAYOPT, LSP, MUSTLAP2, PLAN, SISTLAP AND SUMI. In 1978 Tompkins and Moore [57] added another two: Hiller-Conners and RMA Compl.

A number of further programs based on the above mentioned classical types have been developed. Some authors tried to eliminate the disadvantages mentioned above, some tried to develop the system in a more universal way or to extend their use into other areas.
Examples of the latter intentions are MODULAP and SPACECRAFT.

3.2.6 MODULAP

Real situations, influenced for example by transport routes, were not considered previously. The development of new more practical methods was then begun, e.g. MODULAP [11].

MODULAP, contrary to CRAFT or CORELAP, measures the real distances alongside the transport routes. However, it still cannot guarantee the positioning of all the departments along the transport routes, and the layout engineer has to define the required additional routes intelligently. MODULAP first designs an ideal layout and then, in a second round, converts the ideal layout into a feasible alternative. Similarly as all the above quoted methods, MODULAP is also more suitable for block layout and the positioning of departments, rather than for the more detailed positioning of work stations.

3.2.7 SPACECRAFT

SPACECRAFT was developed in 1982 by Roger V. Johnson [44]. It is a construction type program based partly on CRAFT method. Johnson is trying to minimize the total variable cost of movements (M.H.) between facilities in multi-floor
buildings.

The aim of the program is to locate the departments in a feasible way, and the total time of journeys on N floors is minimized. Johnson considers the volume or number of journeys from department 'i' to department 'j' as constant, but the time of a journey will depend on the location of departments 'i' and 'j'. The main difference between the multi-floor problem and the single-floor problem is, according to him, the nonlinearity of transportation times.

For input, SPACECRAFT requires:
- building size data (number of floors, number of floor types, number of columns, rows of modules and definition of floor types),
- travel times between each pair of floors, for each inter-floor access route,
- travel times between each pair of modules within each floor type,
- travel times between each module on a particular floor type and each access point,
- department information (number of departments, a code number of departments, department titles, volume of movements between each pair of departments),
- Initial layout and its restrictions and any requirements, or restrictions of any department.

SPACECRAFT, in a procedure very similar to CRAFT but with
the difference caused by the nonlinearity of transportation times between floors, produces:
- table of movement times between each pair of floors,
- table of movement times between each pair of modules on each floor type,
- table of movement times between each module and each vertical movement point on each floor type,
- table of volume of movement per period between each pair of departments,
- table of single journey movement times between each pair of departments,
- table of single journey movement times between each pair of departments which have a nonzero volume of movements,
- table of the dollar cost of a single journey between each pair of departments which have a nonzero volume of movements,
- table of total per period movement time between each pair of departments,
- table of dollar cost of the total per period movement time between each pair of departments,
- summary of total per period time and cost of movements originating from each department,
- location data listed for each department,
- location data listed for each floor,
- layout grid of the building.

The graphical presentation of layout designed by SPACECRAFT is similar to that of CRAFT. But the positions of
departments are indicated by symbolic numbers instead of the letters used for CRAFT. The numbers are printed in a grid given by column numbers, module row numbers, and floor numbers. This grid feature could be seen as an improvement on CRAFT and the method can, similarly to CRAFT, be used for the development of block layouts. However, SPACECRAFT cannot guarantee an optimal solution. A poor layout will result in higher utilization of elevators.

This method was commented upon by Jacobs in 1984 [45]. He compares SPACECRAFT to a program known as CRAFT-3D developed already in 1975 [46]. Jacobs considers the programs as very similar, with the following difference. SPACECRAFT considers all the travelling distances parallel to the department edge, not diagonally, while CRAFT-3D calculates with rectilinear distances measured between department centroids.

In spite of their discussion of space and 3-D programs, SPACECRAFT and CRAFT-3D are both actually only solving 2-D layouts on different floor levels.

In comparison with CAFLAP (see Chapter 4.) they are actually only 2-D and symbolic in presentation. They also have no facility for 'space management', automatic positioning in 3-D space with collision course finding, etc.. This comment is also true for CRAFT, COFAD, CORELAP, PLANET and MODULAP programs.
SHAPE - Selection of material handling equipment and area placement evaluation program [47], was presented by Hassan, Hogg and Smith in 1986. The aims of Shape resemble those of CORELAP (3.2.3) or PLANET (3.2.4). The intention was to develop a functional layout with minimum interdepartmental movement costs. SHAPE tried to find the 'best arrangement and configuration of departments' [47]. This was considered in terms of a real area shape.

SHAPE used warehousing methods for locating a new single item in existing stores. This was a new approach to plant layout design. SHAPE divides the layout into a mesh consisting of numbered unit squares (1 to N). Constraints are:
- Departments (n) are occupying a number (compact collection) of unit squares (Ai),
- Each unit square in the mesh is to be occupied by only one department.

SHAPE allocates the unit squares for each department and tries to minimize interdepartmental movement costs. In a similar way to CRAFT and PLANET, SHAPE uses a quantitative departmental relationship (FROM-TO chart), with the difference that each flow value is classified as major or minor and is defined by the user. SHAPE determines the order in which departments enter the layout according to the
sum of the major flow values. The first selected department is placed in the centre of mesh. The rest of departments are placed around according to their flow values. Departments with the largest flow values are near the centre; those with decreasing values are placed in the direction towards the perimeter.

Similarly to CRAFT, centroids of departments are established and the rectilinear distances between the centroids are used. The movement cost here is the product of average distance and flow between placed departments. The placement procedure is similar to PLANET and is extended by a process orientating departments in the layout according to the minimum movement cost. The process allows the shape of departments to be changed by influencing objective functions of the model; i.e. the flow-distance product controls the selection of unit squares and therefore changes the shape of the departments. In the final layout every department is of an optimum shape, while the least movement costs between departments are secured.

In spite of the authors' original claim about SHAPE dealing with "selection of material handling equipment..." no selection is discussed in the paper presented [47]. SHAPE is also compared in the paper with PLANET and CRAFT, but if selection of M.H. equipment is considered it should rather be compared with COPAD (3.2.2). The comparison with PLANET, provided by authors in detail, shows SHAPE's advantage of up
to 23% reduction in movement cost.

The final layout is presented as a 2-D layout matrix of unit squares. Each unit square represents a particular area of the department, coded by a number. Thus SHAPE can be used, similarly to the previously described programs, as a conceptual technique for the initial stages of project or search phase of design.

Unlike CAFLAP and in company with the other programs discussed here it also has no facility for 3-D presentation, no facility for detailed layout or collision course finding, etc.. Because of its otherwise unique ability of changing the layout shape it can be used for block layout, but is not suitable for 'technological' positioning of individual work stations and therefore cannot be used as an entry program for CAFLAP.

The disadvantages of SHAPE for practical layout are similar to CORELAP, PLANET and CRAFT. Unusual layout designs can sometimes be generated by SHAPE and the resulting crooked aisles cause difficulties in practical M.H. Moreover, placement of the work stations in the detailed layout may prove to be difficult, if not impossible, because of the changed shape of departments.

SHAPE should be seen as a most recent attempt to improve the existing line of heuristic construction algorithms based on
the classic ideas of Lee and Moore in the sixties.

3.2.9 RUGR

In parallel with the construction and improvement types of programs, Moore introduced, in his survey [30], another class of programs: graph theory [50]. A classical representative of these types of program is RUGR, already presented by Krejcirik in 1969 [12]. Using the graph theory Krejcirik tried to consider the plant layout problems within the limits of an existing building and given areas. His RU-Program is designed for finding the optimum arrangement of spaces which lie alongside a corridor. He was partly inspired by Armour-Buffa's CRAFT program but, contrary to this program, his arrangement of spaces (e.g. departments) follows a direct line, distributing them evenly within the building, without any waste of space available.

Krejcirik's RG-Program is intended to find mutually related locations of spaces on one plane, while the RR-Program is designed for the minimization of total area of the layout, in order to achieve the most economic size of the building. RUGR is suitable for 2-D plant layout block plans.

Seppänien and Moore in 1975 [53] reviewed the graph theory. They found that it is not always possible to represent the plant layout situation as a planar graph. String processing algorithms, using Novelty Luggage problem method, were
suggested as an alternative approach. But this method has not been further developed and implemented using a computer.

3.2.10 MATHANDL

Very important techniques for the 'technological' positioning of work stations have been developed by the University of Strathclyde.

Program MATHANDL [13] introduces a new technique of arranging work stations into lines instead of clusters, as it is in CRAFT and CORELAP, and removes the shop floor limitations which are inherent in these methods. To achieve this, Numerical Taxonomy, a computerised approach to biological classification has been adopted to develop a computerised algorithm. However, the developed program is at present not available for multiple machine departments. The method of numerical taxonomy was further studied by Carrie [51]. He also observed [55] that the technique of numerical taxonomy provided an analytical procedure similar to the intuitive one of the plant layout engineer. For the Layout of Multi-Product Lines [14], he has proposed a computer method of preparing alternative line layout designs. The method considers work flow and work load and proposes a three stage procedure:

1. Construction of a 'complex' line which contains enough work stations at appropriate positions to allow every part to be processed without back-tracking;
2) Identification of those machines which do not have an economic work load, and eliminate them by re-routing the operations planned to be performed on them to other machines in the line. This is done in an interactive manner producing several possible designs;

3) Comparison of the alternative designs by computer simulation.

The simulation model was written using the GPSS package [26].

3.2.11 PLANTAPT

PLANTAPT - a prototype integrated package for layout planning analysis- was presented by Carrie in 1977 [54]. This general purpose package is intended for medium size plant layout and group technology applications. PLANTAPT's file system holds following data:
- for a number of independent projects,
- on component parts,
- on plant resources, machines or processes;

it is designed to:
- permit variations in the data,
- permit max. flexibility in the data layout in input documents,
- store and retrieve results of application programs.

PLANTAPT's application programs are designed for:
- specifying the component parts to be examined,
- specifying the machines to be considered in the analysis,
- analysing group technology code numbers (Opitz),
- analysing the operations carried out on parts,
- developing the layout of group flow lines and rationalising operation sequences,
- analysing material flow or activity relationships for planning overall layout or detailed layout.

PLANTAPT programs first analyse the situation and then, in a grouping operation, design parts groups, and corresponding groups of machines. If no grouping is necessary, each item becomes a group of one. A facility for operation sequences is provided. If a multiple-product flow line is being considered, machines for the flow line are selected by a specialised program.

Integral parts of PLANTAPT are programs called TRAVEL and LAYOUT. TRAVEL computerises relationship data, while LAYOUT develops a maximal planar subgraph (the theoretical ideal layout) from which a practical plant layout can be designed.

A graphical extension of PLANTAPT was described by Carrie in 1980 [55]. He used PLANTEC, an interactive package for plant layout, developed by National Engineering Laboratory [56]. PLANTEC stores and supplies 2-D shapes of buildings and machine templates. Coordinates of the shapes, relative to a convenient origin, are measured and filed. This can
also be done by digitising the shapes. Similarly, positions of machines in the layout are given by coordinates and scale factors can be given. The layout is presented on VDU and manually adjusted according to engineer's discretion. When the layout reflects the theoretical ideal layout best, the engineer can instruct the computer to provide a large size plot of the layout drawing.

Utilisation of Strathclyde's techniques MATHANDL and PLANTAPT is suggested for the benefit of CAFLAP (section 4.3).

3.2.12 A large-scale spatial allocation problem

A large-scale spatial allocation problem was formulated in 1980 by Liggett [61]. He used a quadratic assignment approach combined with a 'partitioning scheme'. This very interesting method allows the efficient solution of layout problems, positioning up to 1000 departments, shortening the computing time substantionally. The 'partitioning' approach solves a layout at a set of nested levels. The highest level (master partitioning problem) assigns activity modules to subsets of locations. These are grouped into zones or 'partitions'. The method used for selecting the assignments in levels considers the immediate costs of assignments (activities to locations) and the restrictions imposed on possible choices for future assignments. Probability theory is used to predict which assignment would most likely
lead to an optimum solution, and therefore which is the most suitable as a possible future choice.

This partitioning method is said to be very effective and computer time saving. It is appropriate for architectural space allocation but unfortunately it leads to irregular shapes of departments, and on a much higher scale than in CRAFT (which is the program used by Liggett for comparison). The method is therefore much less suitable for mechanical engineering application.

3.2.13 INLAYT, S-ZAKY (an interactive approach)

An interactive approach to construction and improvement procedures was described by O'Brien and Barr in 1980 [34]. They tried to overcome some problems which are inherent in the above quoted procedures, by introducing the user's participation in the selection process. Program INLAYT is designed for the construction of initial layout for a new factory, or improvements in an existing one. The improvement procedure, based on program S-ZAKY, is asking the user to evaluate the 2-D layout on VDU.

INLAYT analyses the flow of material between facilities and suggests to the user groups of facilities and priorities to select for positioning. The user then has to position the facilities in the layout manually. The procedure disregards the actual areas required, and is concerned with relative
location only. INLAYT does not produce the final layout, it only provides the initial input to the improvement procedure S-ZAKY.

Input data into program INLAYT are following:
- The number of facilities, their names and identification numbers.
- The spatial array of building or site.
- The weighted flow of material between facilities.
- A flow factor (a control variable specified by the user).

The order of departments is produced by the program and stored in a matrix organised according to maximum values of weighted flows. Facilities are assigned to a space location grid by the light pen.

The improvement procedure S-ZAKY must start from an initial layout. This can be produced by INLAYT, or the existing layout or any other proposal can be used.

Input data required:
- The name of each facility.
- The area of each facility.
- The relative location of all facilities.
- Details of fixed facilities.
- The coordinate positions of all machinery.
- The coordinate position of material set-down and pick-up.
- The orientation of set-down and pick-up with each facility.
- Estimates of cost of relocating each facility.
- The cost of investment capital.
- The lifespan of the programme being considered.
- Control variables.

The authors claim that the improvement algorithm S-ZAKY is superior to other available algorithms. The main reason is that they interchange three pairs of facilities instead of two, as CRAFT and other programs do.

The 2-D layout is presented on the screen together with the total M.H. cost. Material flow pattern between set-down and pick-up can be superimposed on the layout. Series of questions are asked regarding further procedures required. In the case of exchanging facilities the program will reposition aisles. The rearrangement of facilities is left to the experience of the user, who can move facilities (2-D templates) manually by the light pen. The improvement layout is assessed by computer. The procedure continues until no more improvement can be achieved. Total M.H. cost which is the prime factor in this procedure is compared with the cost of physical repositioning of facilities. The ratio of these costs indicates the economy achieved by the changes. If no requested economic effect is achieved, the relayout procedures could be resumed and the process is repeated. The procedure can handle up to 100 facilities but all areas must be rectangular, and the system of aisles must be rectilinear, which is a substantial limitation.
The INLAYT-S-ZAKY method has certainly brought a new approach to factory layout planning. Unfortunately there does not seem to be any independent assessment of the method yet published. There are also limitations similar to other comparable methods e.g. the inaccuracy of the input data on M.H. cost, installation costs, etc.

Kaltnekar in 1980 [62] considers three groups of criteria for layout decision making: limiting, mutually influencing, and marginal conditions. These criteria dictate approaches and Kaltnekar reminds the reader that most of the literature mainly considers the relationship between layout and material flow while other factors are ignored. To balance this he suggests it appropriate to study the above three groups of criteria:

Limiting conditions are those which cannot be changed (i.e. market, sources, etc.).

Mutually influencing conditions are those which can be changed (i.e. M.H., flexibility of layout, outside transport, building construction, conditions for the employees, the mutual influence of different parts of production system, etc.).

Marginal conditions are all conditions surrounding the production system (i.e. the social order, disposable workforce, financial possibilities etc.).

Because of the large number of different influencing
factors, the criterion of minimization of particular functions or their costs is used. Kaltnekar's critical observation that every method offered optimizes a model, and not the real state, is a crucial one. His improving algorithm only emphasizes that the result is still far from a satisfactory solution.

Prof. Lockyer [21] in 1981, when assessing the existing computer aided layout planning systems, is quoted as saying that:

"...computer programs may assist the planning function by avoiding an oversight and this is a common experience when using computers, in that the preparation of input data enforces a discipline which is often useful. It is the author's experience that layouts are currently, in fact, prepared entirely manually, and his belief that the use of the computer in this area will, for many years, be extremely limited."

In this rather unsatisfactory situation, new attempts to ease the layout engineer's work were made, especially in the area of simulation and systems using computer graphics.

3.2.14 SEE WHY (FORSIGHT)

In 1984 B.H. Hollocks [25] suggested a new approach to plant layout problems through computer simulation. His
program FORSSIGHT experiments on 'real world' layout situations. The engineer may change the layout situations and the program finds out the influences of the options, before any decisions (changes, purchase of equipment etc.) are made.

The method was originally developed at British Steel for reflecting a course of activity on physical mimic displays. The computer simulation run was valuable for giving a fuller understanding of the behaviour of mimic displays in specific circumstances. It is claimed [25] that the FORSSIGHT program "enables an accurate computer model of real world production plant to be constructed quickly and easily". It gives production statistical results and can produce an animated view of the model in operation. FORSSIGHT also enables the user to change operating parameters and to observe the results. Departments or work stations are presented as 2-D blocks (as is usual in mimic diagrams), but without any real shop floor area or space considerations. FORSSIGHT has recently been renamed SEE WHY: it is a good package for the study of cost effective production flow.

3.2.15 UA1, UA2, UA3

From the range of other simulation programs it is worth mentioning programs presented by Driscoll and Sayers in 1985 [68]. The authors have studied a dynamic facility relayout, and developed three new programs:
Program UA1 undertakes data validation. For static layout design program UA2 is used, while UA3 is designed for changeover simulation. The programs have the facility for evaluating alternatives on a financial basis.

Static 2-D layout (in UA2) is determined by coordinates of the building outline; facilities are represented by rectangular or circular shapes/areas. Facilities (workcentres) are grouped into sets and the placement of facilities is done manually. The relayout starts with the existing layout, the new arrangement, and with the support of M.H. information. The changeover simulation model (UA3) operates subject to a number of assumptions which define the changeover situation, e.g.: specified life-span, times of relocation, limits on the number of relocated workcentres, limits on relocation moves (within a period), etc.. There are three types of changeover:

- instant changeover (at time zero)
- slow changeover (with intermediate layouts)
- changeover while stopping production for early benefit from the new layout.

UA3 evaluates the changeover, on the basis of M.H. costs and workcentres relocation costs. M.H. distances are calculated as straight-lines, where no traffic routes exist, or as the shortest distances around the traffic system. In comparison with CRAFT and PLANET, UA3 considers not only the cost of journeys but also extra costs i.e. M.H. fixed
costs, consisting of pick-up and set-down costs. A priority rating expressing the order of potential gain from changeover is used. Program UA3 prints details of M.H. costs throughout the simulation.

The authors are fully aware of the vulnerability of M.H. criteria if considered in isolation. The dynamic facility layout draws a comparison between M.H. cost and the rate of profit from production in the new changeover situation on, on the one hand, and the cost of the relocation of facilities, on the other hand: this produces a better picture of the changeover.

The simulation model is designed as an aid for decision making regarding changes of layout, rather than as a tool for actual detailed workshop layout.

In the class of major and expensive simulation packages programs MAP and CDAS were introduced.

3.2.16 MAP

MAP -Manufacturing Automation Protocol, was developed by General Motors in cooperation with Boeing, and introduced in 1986 by Baer [69]. The system is able to handle 3-D CAD data, NC tool paths, robots, automatic guided vehicle instructions and shop traffic instructions. The MAP package can be integrated with CAD/CAM system. According to Baer,
the MAP system is very expensive and currently beyond the means of medium and small-sized companies. MAP enables communication and control of the shop floor. Operations in this particular application include loading, cleaning, soldering and stacking. Using MEDUSA CADD software, the system was used to draw the cell configuration, but the levels of manual/automatic drawing or any specialized factory layout facilities are not documented.

MAP is clearly orientated as a large scale process control system, including MRPII (material requisitioning) programs. Therefore any comparison with CAFLAP, which is a special purpose, plant layout orientated system, can hardly be made.

3.2.17 CDAS

Immediately after MAP, Rockwell's Configuration Design Analysis and Simulation Environment System (CDAS) was introduced by Tice [70]. It was primarily designed for the simulation of future human or robotic on-orbit servicing procedures during space flight. Low fidelity computer graphic visual simulation was used. All positions and motions of objects were calculated ahead of time and could be recalled in 3-D presentation, frame by frame. Tice claims that CDAS can be used for:

- designing spacecraft, tool and cradle hardware,
- analyzing remote manipulator system
- checking effectiveness and feasibility of design
-simulating design, redesign, feasibility and efficiency operations.

At the present time, CDAS has no collision detector.

Grant and Weiner [71] evaluated ten Animated Simulation Systems in worldwide use. This included the "See Why" system already described in paragraph 3.2.14. The systems evaluated were:

AutoGram, BEAM, Cinema, Modelmaster, PCmodel, RTCS, See Why, SimFactory, Simple 1 and TESS.

The features compared are:
-simulation model building system
-animation graphics
-operational consideration

The model building system is most important both for the model builder and for the user. Five of the above systems are special purpose with manufacturing orientation and five are general purpose systems. All but one system uses 2-D animation graphics. Only AutoGram uses 3-D and the graphics display allows observation of the designed system from different perspectives. AutoGram allows the creation of layout from drawings, via a digitiser. The other systems offer mouse driven menus of characters or shapes.
The listing of these features reveals that none of the simulation systems are similar to CAFLAP.

The Buyer's Guide to CAD systems [72] was studied and it shows that although different CAD system offer various and sometimes very sophisticated facilities, none of them is similar in operation or presentation to CAFLAP (see also Chapter 4.2.).

3.2.18 GRASP

Another interesting package recently developed is GRASP [29]. This is a practical tool for the visualisation and study of relative positions of work stations with respect to robotics and movements of parts in 3-D Computer graphics. GRASP was designed predominantly for:

1) Programming robots;

2) Process purposes (showing what the robot is doing and finding movement paths. A Clash detector menu can indicate, by flashing, the clash of parts or equipment);

3) Robot purchase.

The system is orientated on Flexible Manufacturing Systems (FMS) and on relatively small areas or spaces of
manufacturing cells. At present it has no facility for labelling the work stations with tag numbers and dimensions, although this may be a feature of a new program GRASP 6.1 which is now being developed. GRASP is certainly a very powerful system and could in future be expanded into other specific areas.

Parallel to the above mentioned new approaches, research still continues in the field of 'technological' positioning of facilities (considering mainly flow factors and desirability rating). This can be seen documented by the works of Foulds, Giffin and Cameron in 1984 [63, 64 and 65] and Foulds, Giffin and Evans in 1985 [66].

The last word in block layout design is apparently the study of Evans, Wilhelm and Karwowski [31] presented in 1987. Instead of the previously mentioned techniques, they suggest the use of the theory of fuzzy sets. The authors consider flow rates and REL charts as vague concepts, yet the inexact data could be handled with the use of fuzzy methodology in a mathematically strict way.

However, Herroelen and Van Gils, in 1985 [67], in a similar manner to Kaltnekar [62], critically examined the main stream of research following the ideas of flow dominance. Assessing the stream of studies following the concept of CRAFT, they come to the following conclusion:

"Using flow complexity measures to decide on the
particular layout configuration to be installed...
...is a mere neglect of the many complexities involved in designing a plant layout and materials handling system..."
"...the layout complexity issue is in desperate need of further research..."

All the above references show methodical differences in approach to solving layout problems and a genuine effort to find a way of facilitating the industrial/layout engineer's work. Despite all this effort, Lockyer's claim [21] that the layouts still have to be designed entirely manually, persists. The Writer believes that this failure to find a better method was not only caused by the fact that in Factory Layout Planning "there are a number, and sometimes conflicting requirements" (as claimed by Lockyer [3]) or by methodology of approach, but also by the state of computer science. As in many other engineering fields, it is the recent development of the techniques in computer graphics that is generally opening new horizons. In this particular work it is these techniques which have made CAFLAP possible!
4. COMPUTER AIDED FACTORY LAYOUT PLANNING

4.1 ENUNCIATION OF THE PROBLEM

Factory Layout Planning "is at best an imprecise craft" and "layout planning never developed into a clear procedure" stated Muther ([57-Preface], [4]). Nugeent [38] and others see its combinatorial nature. "Factors influencing layout are numerous" says Kaltnekar [62]. Order, product, production programme, production planning, production, manufacturing systems, cost of product, and capital investment are just the main factors influencing Factory Layout Planning (Fig.2.) to be quoted.

Only with all the digested knowledge of what Factory Layout Planning involves (see Chapter 1,2 and 3) is it possible to select the area of layout planning which is suitable for methodological improvements with the use of computers. Hence the area of space demands and space relationship has been selected as the main topic for this Thesis. Contrary to all the above mentioned packages, CAFLAP solves SPACE RELATIONSHIP AND SPACE REQUIREMNT problems.
Main factors influencing Factory Layout Planning

CHANGE OF:
MANUFACTURING CAPACITY
NUMBER OF MACHINES (etc.) and SPACE needed
FLOW OF MATERIAL
POSITION OF MACHINES - RELATIONSHIPS
SIZE OF BUILDING - total SPACE

FACTORY LAYOUT

Fig. 2. MAIN FACTORS INFLUENCING FACTORY LAYOUT PLANNING
CAFLAP consideres the relative positions of 'spaces' (Manufacturing Space, Product Space...see section 4.2) conditioned by the technological requirements and demands of optimum utilisation of building space (Civil Engineering Space).

To fulfil the task, the following particular areas and steps are considered:

a) Manufacturing, as a system, is re-defined for the purpose of Computer Aided Factory Layout Planning in dynamic and spatial terms.

b) The definition of a Work Station Module as a new 3-D 'template' for the use in computer graphics is established. (A Specimen of a Work Station Card which can also be used for the purposes of a complete computer aided Production/Industrial/Project Engineering control and planning system, is developed.) Material Handling studies, regarding space and its 'filling' are pursued.

c) A specific computer graphics system, PICASO (see section 4.4), is selected.

d) The principle of a 'continuous industrial bay' and 'Product Space Zone', as an aid for layout planning, is defined.
e) Programs for the design of individual Work Station Modules, Buildings, and for Manual Positioning of Work Station Modules are written.

f) A program for the manipulation of the whole scene to allow the user to observe the layout from a required position is written.

g) The development of the system into an automatic positioning system, considering mainly the interdependence/interaction of spaces, is contemplated: programs using a combination of automatic and manual positioning are developed.

h) The criteria for the automatic collision course finding of work stations with building elements are established.

The end product is an automated tool, assisting engineers to design/optimise the layout, in terms of most economic space utilisation, while maintaining 'technological' positioning.

Alongside the main layout problems it was also found essential to consider:

- Production Management conditions (see 4.2).

- Material Handling problems influencing the Layout and
the size of the Industrial Bay (see 4.2).

- Retrieving work stations for a suggested production line from a chronological list. This happens after the 'technological' position of work station has been determined.

- Capacity calculation for Feasibility Study and Investment Project (e.g. number of work stations needed etc.).

The CAFLAP system was originally aimed at layout and re-layout of a medium-size engineering company with batch type production and with a maximum product weight 60kN.

4.2 SYSTEM MANUFACTURING

In the last decade manufacturing has ceased to be observed as a pure mechanical technology problem. The increase in overall production output is no longer considered to be purely a matter of the introduction of more advanced machining or other technological methods. Studies of machine break-down, for example, have led to a new approach to maintenance. Similarly, concern about the human factor failure in fulfilling the requested tasks accurately and in the shortest possible time and consequently, studies of the
relationship between workers and their environment, have brought about the development of a new discipline: i.e. Human Factor Engineering, or Ergonomics. Attempts to optimise the operator's output have resulted in the development of the subject of Synergetics.

**Maintenance:**

To avoid excessive wear and tear and break-down of machines a system of 'Planned Maintenance' has been developed. The principles of planned or preventive maintenance have been known for many years, but were formulated methodically in the sixties in the studies of the Ministry of Technology [73]. Since then the interest in Planned Maintenance has been growing steadily: the works of Clifton [74], Heintzelman [75] and Patton [76] are of note.

Planned Maintenance creates conditions for diminishing the losses resulting from machines down-time. In an attempt to minimise the maintenance demands and costs, a new discipline in machine design, 'Design for Maintenance', has been developed.

Planned Maintenance is defined as an activity including all necessary works on, and services of, work stations (machines), organised in pre-planned time cycles, to maintain them in good working order.

Maintenance requirements are also described in many factory
management books e.g. Lockyer's 'Factory and Production Management' [21]. It should be said that maintenance practice and maintenance cycles vary from industry to industry, and with the type of machinery installed. However, there is an underlying general pattern of planned cycles of improvement and of preventive and corrective maintenance, as formulated by Patton [76].

Larger time scale cycles (years) usually contain provision for:

- Preventive Maintenance (Appendix I-9) (greasing, cleaning, adjusting, repairs taking less than 3 hours, etc.);
- Major Overhaul (complete inspection, parts replacement, renovations);
- Safety Inspections (elimination of safety hazards);
- Modification and Modernisation (alteration of present machines for more demanding functions, e.g. gearing); and
- Emergency Repairs to keep equipment operative (taking more than 3 hours).

From the above mentioned types of maintenance services, Preventive Maintenance is the most important for CAFLAP. It is itself organised within smaller cycles (day or week):

during shifts - oiling, greasing, adjusting;
between shifts - inspection, adjusting, oiling;
during night shift (24 hrs interval) - cleaning, small repairs taking less than 3 hrs, etc.
As the services are performed in the area of the work station, they create demands on Maintenance Space. In the past, when importance of Planned Maintenance was not widely recognised, the space needed for maintenance was often overlooked or neglected at the design stage. Losses resulting from this were evident. It is important to note that in the CAFLAP system developed here, the provision for Maintenance Space is embodied.

Design for Maintenance means giving the necessary support to all the functions of the machine. For example, an easy access to all oiling, greasing and inspection points must be guaranteed. Assembly procedures/provisions should serve easy replacement of parts and for all other maintenance purposes. Energy supply lines (pipes, cables), should be designed in such a way as to avoid crossing problems during maintenance. Lubrication and cooling should always be on the opposite side of the operator's post. Where possible, maintenance free material (e.g. plastic, sintered bronzes) should be used. Swarfing (cleaning of machine tools from all scrap of machining process) should be designed for most ease of removal [22].

Both Design for Maintenance and Planned Maintenance are determining factors influencing the demands on space around any work station. This, denoted in CAFLAP as MAINTENANCE SPACE, is further discussed in paragraph 4.2.1.1 and 4.5.1.
Human Factor Engineering - Ergonomics:

Human Factor Engineering is a branch of technology that helps to design machines, operations, and environment to match human ability and limitations. Human Factor Engineering is a term used mainly in the USA [82]. The term Ergonomics is used mainly in Europe [21,81] and the definition is slightly different from that of Human Factor Engineering. Ergonomics is seen as scientific study of the relationships between man and his work environment. The first studies in what is now called Ergonomics, started as early as in World War Two. Explanations were sought as to why bombs and bullets often missed their targets, planes crashed and friendly ships were sunk without apparent reason: it was discovered that a human factor had frequently to be blamed. After the war research continued in manufacturing industry where the reasons for a high percentage of faulty products were studied. Again the human factor was found responsible. The main sources of problems were:

- Monotony of work (especially on assembly lines);
- Fatigue from heavy tasks;
- Badly designed machine tools, equipment and instruments;
- Badly designed work station layout;
- Influence of shortcomings in the immediate environment (Lighting, Noise, Ventilation, Heating, etc.).

From the above factors it can be seen that the design of Work Station Layout is very relevant to CAFLAP, and especially to the design of a Work Station Module - Man
Space (see 4.2.1.3).

The physical factors of Work Station Layout, which have a dominating influence on the operation are:
- maximum physical comfort of the operator;
- good view, enabling the operator to see all phases of the manufacturing process;
- good access to all important parts of work station;
- a reduction of physical strain to a minimum.

Mental factors of Work Station Layout, which are of equal importance to physical ones from the control point of view, are:
- operator should be able to exercise control easily and with accuracy;
- sources of mental strain that distract the operator's attention from making judgements and decisions needed for the job should be eliminated;
- stress from lack of space or unsafe working practices should be prevented.

These ergonomic factors are determining the demands on space in which the operator is working. This, denoted in CAFLAP as MAN SPACE, is discussed further in paragraph 4.2.1.3.

Synergetics:
Synergetics is a relatively new science which is studying sets of effects of work environment on operators [27,28].
It is trying to establish the best configuration and combination of sets of elements and their influences, to achieve optimum performance. From the Synergetics point of view, CAFLAP is trying to find the best arrangement of work stations in detail layout (see 4.3).

A study of all the above aspects has, in the present CAFLAP work, led to a new appreciation of dynamic and spatial relationships within a manufacturing system, and to their reconsideration for the purposes of CAFLAP. But, before the system is analysed in detail, the shop floor situation, as it is recognised in today's factories, has to be summed up.

A classical Plant Layout (shop floor space) usually comprises the following Areas:

a) Manufacturing Area
b) Manufacturing Services Area
c) Non-Manufacturing Area
d) Stock Area
e) Aisles Area
f) Unrehabilitated Area

Other areas include:
1. Administration Offices
2. Employee Facilities
3. Factory Offices
CAFLAP could, of course, consider the layout of all areas, but because the Manufacturing Area is the most important (sometimes it occupies over 50% of all other areas), the present work is concentrated on this area.

As from the point of view of system approach, complex problems can be seen more clearly, this methodology has been used in the following classification.

4.2.1 SYSTEMS

A manufacturing system expressed in dynamic organisation terms for the purposes of CAFLAP [see Fig.3.] can be classified [15] as follows:

A) Higher Systems - region, state, continent, world.. etc.


Systems, within the wider system, are:

a) System Management and Administration:

- Management control level (Personnel, Purchasing, Financial, Sales, Marketing, Prodn. control,
Prodn. planning, Industrial eng., etc.);

b) System Research and Development, Drawing Office;

c) System Services:

- Health and Safety, Catering, Maintenance, Stores, Swarfing, Scrap control, Plant and Building Services, Power, Energy Supply etc.;

Fig. 3

MANUFACTURING SYSTEM EXPRESSED IN DYNAMIC ORGANISATION TERMS
d) System Manufacturing:

Here Sub-systems can be distinguished:

- Manufacturing (incl. Work Stations, Swarfing, Manufacturing (Auxiliary) Services etc.)
- Man (Operators, Fitters etc.)
- Material (incl. Material Handling, Intermediate Stores etc.)

The above dynamic organisation systems have to be physically accommodated (in spatial terms) and it is obvious that the systems and sub-systems would have their own specific requirements on physical properties of buildings (floors, areas, spaces).

Hence the Wider System, expressed in spatial terms {Fig.4.}, will comprise:

a. Offices (System Management and Administration, Drawing Office, R+D)
b. Special Areas (System Services, Laboratories, etc.)
c. Shop Floor/Space (Layout)
which has to accommodate the system Manufacturing and its sub-systems:
A) Higher systems are region, state, continent, world

B) Wider system is plant, factory (area, plot, ind. estate)

- a. Offices (system management and administration, drawing office, R&D)
- b. Special areas (system services, laboratories, etc)
- c. Shop floor/Space (layout)
  sub-systems:
  - manufacturing space
  - man space
  - product space
  - manufacturing services space (tool crib, grinding etc).

Fig. 4.

Manufacuring system expressed in spatial terms.
- Manufacturing Space
- Product Space
- Man Space
- Manufacturing Services (Appendix I-10) Space
  (Tool Crib, Cutter Grinders etc.)
- Services (Appendix I-11) Space (Power, Water etc.)

The design of offices and similar areas is usually the domain of architects. The industrial or layout engineer furnishes them with information relevant to administration and production requirements, for example, the number of staff to be accommodated, the office equipment needed, etc. Special areas are usually designed through co-operation between architects and engineers. In respect of manufacturing areas it is the factory layout engineer who is principally involved. Architects or other professionals also try to exercise their influence in these areas, but such approaches must be considered as secondary because they cannot guarantee technologically orientated, cost effective production.

It is the intention here to highlight the special features of manufacturing areas from a Factory Layout Planning point of view, and a discussion of the spaces of main concern
4.2.1.1 MANUFACTURING SPACE

Manufacturing Space is defined as the whole space where product manufacturing is performed, i.e. it is the space occupied by:

- Work Stations (incl. accessories), Work Centres including assembly, inspection, painting etc.

- Operational Space (space for all movements of work station parts, essential for smooth production flow e.g. robotics, and movements of Material or Work in Progress (W.I.P.) within the work station).

- Work station Maintenance and Repair Space.

The smallest, self-contained unit of Manufacturing Space is a WORK STATION MODULE which is a sum total of all three spaces and includes Man Space (see below). It is simulated as a 3-D computer drawn template (see Fig.5.). See also program 'WSBUILDR.FOR', Chapter 4.5.1, and Appendix II.

The WORK STATION MODULE is also part of the Work Station Card containing manufacturing and other information regarding the work station (Appendix III, Drawing No. 1, sheets 1 to 6).
Fig. 5.

WORK STATION MODULE
4.2.1.2 PRODUCT SPACE

Product Space is defined as the space occupied by the Flow of Material, W.I.P., Product, Swarf and Scrap. It includes the space needed for Material Handling equipment and Intermediate Stores.
NOTE: For machine interfaces (deployment of robots etc.) Product Space ends from the very moment when/where the W.I.P. is attached to the work station. A moving work station is considered as a special case of Manufacturing Space.

4.2.1.3 MAN SPACE

Man space is defined as the space necessary for operator(s), fitter(s), etc. to perform all the duties regarding the manufacturing process, and is designed in accordance with the ergonomic principles.

4.2.1.4 MANUFACTURING SERVICES (AUXILIARY) SPACE

Manufacturing services (Auxiliary) space is defined as that space required to accommodate machine services, e.g. Tool Crib, Cutter Grinders, Tool Salvage etc.

4.2.1.5 SERVICES SPACE

Services Space comprises ducts, enclosures, cable trays,
etc., and/or maintenance steelwork accommodating supply lines of gasses, power, technological water, coolant, oils etc. for manufacturing purposes.

4.2.1.6 SHOP FLOOR "BREATHING SPACE"

Shop floor "Breathing Space" is the space where NONE of the above spaces are included. (It could be empty). In practice a space like this is usually kept as reserve to accommodate small changes in layout, and expansion. It is usually utilized as additional intermediate store.

It should be noted that all the 'technological' spaces are considered above as well as below zero floor level according to specific situation and needs.

Foundations of work stations, equipment, etc., are considered as being part of the spaces (sub-systems) to which the work stations, equipment, etc., belong (e.g. foundation for a production milling machine is considered in the sub-system Manufacturing Space).

4.2.1.7 BUILDING - CIVIL ENGINEERING SPACE

Building - Civil Engineering Space is defined as the space physically accommodating all 'technological' spaces (Manufacturing Space, Product Space, Man . Space,
Manufacturing Services Space, Services Space, and Breathing Space), and is providing a suitable environment.

The space includes:

- Foundations of buildings (columns etc.)
- Floors, Staircases, Platforms, Pits, Ramps etc.
- Columns
- Storm and sewerage water ducts
- Drinking water piping
- Walls, Barriers, Doors, Windows
- Roof structure
- Any unspecified structural supports, stiffeners, etc.
- Heating and Ventilation, and
- Lighting.

4.2.2 PRODUCTION PROGRAMME

The reasons for wishing to change the layout of a factory such as market forces, orders and production capacity requirements were considered, but are not part of this study. It is assumed only that the Production Programme has been determined that and a new layout has been requested.

The Production Programme basically conditions the type of production (technology, operations, types of machines, and equipment), and this directly influences the type of layout (as quoted in Introduction, Chapter 1.).
4.2.2.1 INFLUENCES OF PRODUCTION PROGRAMME ON DESIGN OF MANUFACTURING SPACE

In Chapter 3. were discussed some computer aided systems which also consider Production Programmes. They sometimes use very sophisticated methods to arrive at a very simple, and usually the only possible, solution: i.e., positioning work stations 'technologically' in an order/line, which is at the same time an economic optimum.

It is also the practical layout strategy (see 4.3) of positioning work stations in a real industrial bay that dictates [13] the order of work stations. This could be, in an overwhelming number of cases, only a physical line of interrelated work stations.

Once a 'technological' position of work stations is computed (by any of the suitable systems mentioned in Chapter 3.), or intelligently established, the actual layout may be designed with CAFLAP system in a straightforward manner. CAFLAP system operations start from the very moment when a 'technological' order of work stations is established, and this data is fed into the system. It can be said that the type of Production Programme, or even type of layout, has no bearing on the design of manufacturing space by CAFLAP system. Neither can it influence the performance of CAFLAP itself.
4.2.2.2 INFLUENCES OF PRODUCTION PROGRAMME
ON DESIGN OF PRODUCT SPACE

The Production Programme cannot be considered in isolation and the influences of Production Management techniques (state of organisation) must also be considered. Together they create needs for size of aisles, stores, intermediate stores and Product Space next to work stations.

When designing the size of aisles, the basic unit to be considered is the Unit Load (expressed in dimensions, widthxlengthxheight, and in volume/hr or weight/hr). Unit Load is defined as an optimum load in Material Handling (M.H.) to satisfy all principles of standardization; or simply as "a unit to be moved or handled at one time" as suggested by Tompkins and White [39].

For the purposes of deriving the computer graphics expression, the basic equations from Hydrodynamics was considered:

\[ \omega = \frac{Q}{F} \]

where \( \omega \) = speed of movements of Unit Loads (m/hr)
\( Q \) = Volume of Unit Loads manufactured per unit of time (cu.m/hr)
\( F \) = sectional area available for transport (sq.m)
\[ F = w \cdot f \]

and

\[ f = \frac{Q}{\omega \cdot w} \]

- \( w = \) Aisle width (m)
- \( f = \) "filling" of the Bay (m)
- is height of the Aisle utilised for M.H., (indicates the density of M.H.).

It has to be said that the above considerations only serve as an auxiliary guide because the real movement of material in batch production is in paces. However, such equations help to define the optimum dimensions of transport aisles when translated into computer graphic histograms.

Further the value 'f' (filling) can:

a) Indicate any slowdown in M.H. area, or production area and, once the optimum value is established, any deviation could be monitored, i.e. it could be used as a tool for the Production Control Department;

b) Show what speed of movements in Product Space is required; how many M.H. vehicles, fork-lift trucks, or what sort of M.H. means of transport are needed.

Computer Program 'M100.FOR' was contemplated to provide
In order to design the size of Product Space at work stations, the following basic systems have to be considered: Two Bin system, Just-in-Time system (KANBAN) and Base Stock control [77,78,79,80]. For any of these systems presentation of Product Space creates special problems, and these are dealt with in section 4.3 Layout Strategy.

The product mix and size of batches can influence Product Space (see 4.2.1.2) considerably, but only if the batches are very small. This has, of course, to be considered in conjunction with M.H. cycle and unit loads.

A unit load (Ul) has requirement for space (Us); the total time required for machining of a batch is Tb, and the duration time of a regular M.H. cycle is Tmh.

If a unit load is equal to one batch, and time Tb is N times smaller than M.H. cycle (Tmh),

\[ Tmh = Tb \times N \quad (or \, Tmh = \frac{N}{1} \times Tb) \]

then Product Space (Ps) -space next to work station available for unit loads waiting for machining or transport- must be increased N times.

\[ Ps = N \times Us \quad (or \, Ps = \frac{N}{1} \times Us) \]
Or, vice versa, material handling cycle must be shortened (which would increase M.H. costs).

The above consideration is of general validity, including the increasingly popular Just-in-Time system (JIT).

If the JIT (KANBAN) system in production control is used, each Kanban (Shop sign, card) represents a unit load -or container load, according to Burbidge [77]. Apart from identifying the contents of a material container, Kanban is used to order a replacement supply when a container is issued. Kanban practically defines the size of a batch. The number of Kanbans issued indicates the number of batches (unit loads) in the process, and determines the size of the base stock. In other words: the more Kanbans, the larger the base stock. This leads to demands for increased Production Space generally.

It must be concluded that, apart from style of production management, the Product Space is influenced mainly by the type of M.H. equipment.

Other product spaces, Stores and Intermediate Stores should be designed intelligently, but could be incorporated into automatic layout system as individual modules.
Overall Conclusion:

Insufficient Product Space generally results in difficulties, especially in the following areas:
- shop floor management/production management
- material handling (clumsy and slow M.H., bad access)
- safety

Excessive Product Space results in an overall increase of shop floor/ space and this creates waste in the following spheres:
- material handling costs (bigger distances),
- ventilation and heating costs,
- lighting costs,
- maintenance costs, and
- larger capital investment costs.

The above indicates that the design of an optimum Product Space is quite a difficult task considering the variability of factors involved. It is made even more complicated by the requirements of computer graphic presentation and this leads to the development of a novelty idea: the concept of a PRODUCT SPACE ZONE (see the following section 4.3).
4.3 LAYOUT STRATEGY

One of the objectives of CAFLAP project is to shorten the time of the traditional layout approximation process (as described in Chapter 2.), while maintaining the principles of a good factory layout. This can only be done by preparing the detail layout first; skipping the two initial project stages: Feasibility Study and Investment Project (see Fig. 6.).
4.3.1 CAPACITY CALCULATION

It is assumed that the number and types of work stations needed will be extracted from Route Sheets (or Job Cards), and the 'technological' positions of work stations will be established (as mentioned in Chapter 3.). The number of machine tools (M/C) can also be calculated via program 'M100.FOR'.

4.3.2 DETAIL LAYOUT

Experience has shown that the actual layout can be prepared effectively only when it is started in the direction of the Flow of Material, and in the 'technological' order of a line of work stations involved.

In Fig. 7., Layouts a) to g) are presented as typical detail layouts of regularly arranged work stations in Industrial Bays.
Fig. 7.

TYPICAL DETAIL LAYOUTS OF REGULARLY ARRANGED WORK STATIONS

(Plan views)
Types a) and b) are considered ideal:
- to satisfy the criteria of a good layout,
  and
- to provide maximum comfort for the operator (create a set of environmental configurations in order to optimise his performance - all ergonomic principles are maintained).

For the above reasons these two types have been selected to be used for automatic positioning in CAFLAP system developed here. The main steps in detailed layout are shown in a system chart {Fig. 8}.

STEP 1.
The list of work stations is determined and individual Work Station Modules are drawn and filed. The basic width of the industrial bay and the width of the Product Space Zone are determined intelligently according to the width of an average size Work Station Module and the width of Unit Load {see Fig.9}.
STEP 1. Basic data

- Industrial bay is drawn (Program 'CIVES.FOR')
- List of work stations is determined (Programs 'MFEED.FOR' and 'WSVITO.FOR')
- Individual Work Station Modules are drawn and stored (Programs 'WNSBUILDER.FOR' and 'WSBUILD.ALL.FOR')

STEP 2. Automatic positioning (Program 'POSCLASH5.FOR')

First work station is positioned manually (POSCLASH5.FOR has its own manual positioning mode)

STEP 3. Manual positioning (Programs 'IYTWSFILE.FOR' and 'IYTVAAXO.FOR')

Individual work stations are called in arbitrary order and positioned manually in any place. (Entry from 6 is not necessary)

- Text work station position follows in 'technological' order
- Collision course detector checks the position, and signals and identifies clash.

- Is there the next work st. in the file?
  - yes: Is the position O.K.?
    - yes: The developed layout can be printed
    - no: Do you wish to see the scene of the clash?
      - yes: The developed layout can be observed in any perspective (Program 'DISPLAY.FOR')
      - no: Situation is presented in detail

- Repositioning of the clashing and any following work station is done in the manual mode.

- When the manual override is ceased the automatic positioning can be resumed.

- Final layout is presented and can be printed

Fig. 8. CAFLAP SYSTEM SIMPLIFIED SYSTEM CHART
Fig. 9.

DESIGN OF AN INDUSTRIAL BAY

(3-D representation, viewed from above)
The PRODUCT SPACE ZONE is defined as a 'hard shoulder' type area; a continuous strip of space running alongside aisles, which is designed:

a) to serve for storage of material, W.I.P. and products (Unit Loads, pallets etc. [39,83]) next to work station, and

b) as a 'boarder' for automatic positioning mode in CAFLAP.

The width is determined by the width of Unit Load. The Product Space Zone can accommodate all the different demands (i.e., Two-bin, Just-in-time, and Base-Stock Control) on Product Space resulting from the above mentioned systems. The only space loss is limited to the width of the Man-Space, allowing a safe passage for the operator.

If the automatic positioning mode was considered in isolation from the rest of the CAFLAP system, it could be classified according to Moore [30] as an improvement type procedure because it starts with a predetermined industrial bay.

STEP 2.
The first work station is positioned manually in a requested place/section of the industrial hall either at a right angle to the aisle or obliquely to it (see Fig.6. a) and b)).
STEP 3.

The rest of the layout development follows according to the mode selected (see section 4.5.4). If a collision course is indicated, a facility for manual positioning (manual override) is used in order to reposition one or more work stations as necessary to avoid the collision. If then requested, the automatic positioning mode can be resumed.

This method can also be used to find the optimum width of an industrial bay (see Fig.10.), i.e. if the work station is found to be colliding with the 'border' (Product Space Zone, aisle, walls etc.) it is repositioned into an oblique position. This, intelligently assessed, could lead to an even narrower bay design, especially if work stations are long and 'slim' (e.g. a turret lathe).

![Diagram](Fig. 10, FINDING THE OPTIMUM WIDTH OF INDUSTRIAL BAY)
The value of this procedure for a 'green field' layout design is obvious.

A narrow industrial bay is much more cost effective than a wide span industrial bay, which is not only expensive to build (initial high capital investment), but also to maintain. The larger span bay requires a higher roof structure which also increases the volume of air to be ventilated and heated: a further consideration for costs. The construction height of the building cannot be fully utilised technologically. If cranes are used, it is again the larger span of the bay that dictates higher cost of cranes and may influence their performance.

In a practical layout, there are two types of work station formations: regular and irregular (see Fig.4). CAFLAP system has been developed to accommodate both: for the irregular formation case the manual positioning mode of CAFLAP may be used, while the automatic mode serves in the case of regular positioning.

4.3.3. OVERALL LAYOUT OF INDUSTRIAL HALL

CAFLAP can be used as a tool for design of an industrial hall of any shape. The following describes a typical case. A flow chart in Fig. 11. shows the methodical steps in layout design of an industrial hall. For typical production
line flow patterns see Fig. 13.

1. A 'Continuous longitudinal bay' is designed, regardless the shape and size of the existing or newly designed industrial hall (program POSCLASH5.FOR). Total length of the bay 'L' is obtained.

2. If the hall length 'H1' (e.g. depending on the size of the plot available) is n-times shorter than 'L', then 'L' is cut in 'n' bay sections.

3. The shape of the flow pattern is chosen (U-shape, S-shape, parallel).

4. The bay sections are fitted into the hall, following the chosen flow pattern.

5. The bay sections are checked against the corresponding civil engineering space. The layout is revised and adjusted if necessary. (POSCLASH5.FOR)

6. Improved layout is printed.

7. Alternative designs of the industrial hall (changing the flow patterns and detailed layout) follow.

8. Alternative designs are evaluated using the ratio of spaces, and minimum space needed is sought.

Fig. 11. MAIN STEPS IN THE DESIGN OF INDUSTRIAL HALL-OVERALL LAYOUT
A detail layout of 'technologically' self-contained sections (i.e., an interdependent line or group of work stations), is continued in a straight 'continuous' line. This also satisfies Muther's [4] layout fundamentals (see Fig. 12). A 'continuous longitudinal bay' is thus designed (corresponding to Fig. 13. a).

The principle of a 'continuous industrial bay' is an aid for layout planning using automatic positioning mode (see section 4.5.4). It provides for fluent positioning of work stations in the bay.

The continuous bay is designed in its total length regardless the length of the industrial hall. The hall usually accommodates more than one bay (see Fig. 13.d). The work stations may be positioned on both sides of the aisle.

When the length of the industrial hall 'H1' is shorter than the length of the continuous industrial bay 'L' and a U-shape or S-shape Flow Pattern is used (see Fig. 13. b), the total length of longitudinal bay has to be cut (while 'technologically' self-contained sections are maintained), into lengths which can be accommodated in the industrial hall.

When a Parallel Lines Flow Pattern (see Fig. 13. c) is used, individual lengths have to be cut accordingly.
RELATIONSHIP
degree of closeness desired among M/Cs

OP01 → OP02 → OP03 → OP04 → operations

SPACE
configuration

ideal position of work stations

ADJUSTMENT
realistic best fit

realistic position of work stations

Fig. 12. 'CONTINUOUS' LINE SATISFIES LAYOUT FUNDAMENTALS
Fig. 13. FLOW PATTERN FOR PRODUCTION LINES
4.4 LAYOUT USING INTERACTIVE COMPUTER GRAPHICS

In the preparatory stage of this project it was essential to select an existing commercial software system suitable for the purposes of CAFLAP methodology. The selection was influenced by CAFLAP demands for a computer graphics system and also by several other factors, which are summarised as follows:

The system should have a facility for a simple design of all objects/spaces in 3-D. This refers especially to the design of Work Station Modules and to the Civil Engineering Space with all its elements.

The system should have a facility for marking the designed objects with identification or tag numbers.

The system should have a suitable potential for the development of facilities for manual and automatic positioning of 3-D objects and collision course finding. Kinetic function ability is essential for the positioning of Work Station Modules in the Civil Engineering Space and for Collision Course Finding. It is also important for the observation of the developed scene.

The obvious choice available was a CAD drafting system, for example MEDUSA (in possession of Middlesex Polytechnic).
The system was tested and part of the Project was investigated with the participation of some engineering undergraduates.

In spite of the fact that MEDUSA offers an excellent drafting facility, it was realised that modification of the system for the purposes of CAFLAP would be far too complicated (if not impossible). Therefore the development using this system had to be dropped.

Another system in operation at Middlesex Polytechnic is PICASO (PIcture Computer Algorithm Subroutine Orientated) developed by Dr. John Vince [93, 94]. It is a FORTRAN-based computer graphics system, designed to ease the interface between programmer and graphical problem areas. PICASO subroutines may be incorporated into any FORTRAN or PASCAL based programs. It offers a comprehensive library of 2-D shapes and 3-D objects which may be manipulated through a wealth of manipulating algorithms. The system's conceptual space allows the user, through the 'observer', projection mode and projection space (using system commands), to observe and manipulate any designed scene. For shapes and object analysis the system is equipped with some thirty six analysis commands. For shapes and objects presentation there are over thirty drawing commands. Drawings generated by PICASO are normally drawn on high resolution VDU and could also be plotted upon any suitable plotter. Since PICASO was apparently developed for
visual arts, it has a variety of built-in features to suit that purpose. Because of its versatility, it offers considerable potential for creative use even to engineers. It also has a capacity for modification and for further development. These are the reasons why PICASO was adopted for use in CAFLAP work.

The hardware used was originally Prime 550 computer which was replaced by VAX/VMS VERSION V4.5 computer system. Terminals used were Applied Digital Data System, Model ADDS-Regent 25; Insight Terminals Ltd., Model vdt-1; and printer EPSON FX-80.

4.5 PROGRAMS AND THEIR SOLUTIONS

The CAFLAP programs developed here were compiled in FORTRAN 77. The major reason for using FORTRAN was because the research project exploited the PICASO computer graphics library, which was implemented in FORTRAN 77. Although PICASO can be treated as a library of subroutines and functions, and therefore is accessible to other languages such as: PASCAL and C, it was decided to implement all programs in FORTRAN as the CAFLAP system needed to modify some of the original code of PICASO. Maintaining this language consistency only involved the Writer in learning one language. Furthermore, Middlesex Polytechnic - where the research was undertaken - had used FORTRAN as its primary scientific/mathematical language and was able to
provide a reliable software support service.

Although FORTRAN has played a very important part in the development of scientific/mathematical software, and is still used to implement original code for some companies, the language in favour at the moment is C. It offers a more rigorous programming environment with strengths in: data structures, structured programming, interaction with UNIX and reduced program development times.

CAFLAP could be implemented in C, and also in other languages such as PASCAL, or BASIC, but would require modification to exploit the benefits offered by PICASO. If CAFLAP was to be made independent of PICASO, it would require substantial support in the area of computer graphics.

Developing any program requiring computer graphics facilities presents problem to the programmer, mainly because of the variety of graphic specification available for workstations. To help overcome these implementation problems some computer graphics standards have now been developed, e.g. GKS, GKS-3D and PHIGS. None of these systems were available to the Writer during his work; nor was it possible to have access to sophisticated colour graphics workstations that would have had an impact upon CAFLAP's interface.
CAFLAP was developed as a vehicle to explore the Writer's ideas in developing strategies for automatic factory layout, and in this respect it was successful. To be considered now as the basis for a commercial system, it has in future to be rewritten specifically to meet the demands of any particular commercial environment.

The development of layouts, using computer graphics, generally followed the steps outlined in the Layout Strategy (Chapter 4.3).

In order to maintain an efficient programming technique [96] the main programs have been kept short (i.e. not more than 100 lines), and the subroutines have been mostly built-in, in a tree-like hierarchy. The input data are manipulated via COMMON areas, subroutine arguments, external files and an interactive terminal, for the convenience of the user, in some cases in conjunction with a printer. Each program is internally documented by comments in natural language, for the benefit of the user or another programmer. The comments are divided into two categories: Macro Introductory Comments and Micro Continuous Comments.

The Macro Introductory Comments describe the general qualities of the program:

- name of the program;
- the purpose for which the program was built;
- if the program is long and complicated, there is a
short description of previously written sub-programs of which it consists or with which it co-operates;
- size of the program, i.e. for which number of work stations it is designed;
- program output.

The Micro Continuous Comments are those relating to the main operations, and these help to clarify and expand the significance of the FORTRAN written code.

The layouts of programs produced here have purposely been kept simple for easy reading and understanding. Great care has also been given to Statement Numbering so as to keep them in an ascending numerical order sequence, which is easy to follow. The resultant layout, and especially the included comments, thus make the programs largely self-explanatory.

The programs were developed as an integral and major part of this work but, because of their large physical volume, it was not considered appropriate to include them here. They are instead described in the following sections and included, in their entirety, as Appendix II.

4.5.1 WORK STATION MODULE BUILDER

Work Station Modules are built by the program 'WSBUILDER.FOR'. A 3-D template is built-up from a
hand-drawn sketch of the Work Station Module. The sketch includes Maintenance Space, Operational Space, Man Space, and work station (i.e. the machine tool itself including accessories), maintaining recommendations from manufacturers and all ergonomic principles. The steps in Work Station Modules design via the interactive program are following:

- requested objects (boxes, cylindrical parts, anchoring bolts, operator(s), Tag Number etc.) are selected according to a pre-printed code;
- instructions are given in the program regarding size and position requirements;
- the engineer feeds in requested dimensions and positions of the objects, starting from the origin \((x=0,y=0,z=0)\);
- this process continues, object after object, until a complete Work Station Module is built;
- the work station is then filed under a unique Tag No. for future reference/recall, and the procedure is ended.

'Drawing' of the next work station can follow.

Any Work Station Module picture may be recalled by program 'WSRECALL.FOR'.

NOTE:
Information for the hand-made sketches of Work Station Modules is usually taken from the machine tool
manufacturer's drawings, foundation plans and manuals (including installation and maintenance recommendations and instructions).

Some well established manufacturers of machine tools helpfully supply, with their installation manuals, pre-printed simplified 2-D templates of their machine, on the basis of which the sketch of the Work Station Module could be prepared. The original intention was to identify Man-Space, Maintenance Space and Operational Space in the drawing by hatching. But this was found impossible in a 3-D representation because hatching would obscure the picture. Therefore the Spaces are drawn inside the 'largest volume' of Work Station Module [Fig. 5.], without any further identification (hatching or tinting).

4.5.2 BUILDING (CIVIL ENG. SPACE) DESIGN PROGRAM

For the purpose of designing an Industrial Bay interior, Program 'CIVES3.POR' has been compiled. A fully-detailed 3-D image of an industrial bay may be built from PICASO objects (presently only Boxes are used).

The method is following:

Individual civil engineering elements and 'borders' (i.e. Product Space Zones, aisles, etc.), are input. The 3-D image is shown on a VDU and individual elements can be changed, replaced, or added until the simulation of the bay interior is completed.
NOTE:
In case the layout is being planned in an existing building, the Civil Engineering Space will be built exactly according to the civil engineering drawings available. The writer's experience is that even well established old factories often possess unreliable civil engineering information, so that, an industrial hall survey may have to be taken and new reliable drawings produced.

4.5.3 MANUAL POSITIONING PROGRAMS

For the manual positioning of Work Station Modules (largest volumes only) in the bay, or for the positioning of departments, bays in the hall and halls in a plot, a program 'IYTVAXOO.FOR', using a joystick, has been compiled. Examples of drawings prepared by this program are shown in Appendix III, Drwgs Nos. 02. and 03.

Any objects, represented here by boxes, can be entered into a list and marked individually by Tag Nos. or any other identification (e.g. name of a department). They are then positioned against the background of a grid representing the requested area.

For manual positioning of work stations only, program 'IYTWSFILE.FOR' has been compiled. This program has a facility to retrieve detailed Work Station Modules and incorporate them into a required layout in a similar way as
in the program 'IYTVAX00.FOR'.

4.5.4 AUTOMATIC POSITIONING PROGRAM
WITH COLLISION COURSE FINDING PROVISION

For automatic positioning of Work Station Modules inside the industrial bay, program 'POSCLASH5.FOR' has been compiled.

The functions, satisfying the layout strategy of section 4.3.2, shown on a VDU or printer, are as follows:

- list of work stations available with facility for any required changes {Fig. 14.};
- present situation of development {Fig. 15.};
- new development of the layout in manual and automatic mode, and in any combination of modes {Fig. 16. and 17.};
- facility for collision course finding of Work Station Modules with building elements, 'borders' and other 'obstacles';
- automatic stop at any work station colliding, with identification of work station Tag.No.;
- facility to show {Fig.18.} the situation at a clash;
- manual override allowing to find intelligently the best new position for the colliding work station in the bay;
- continuation of the development of layout in manual or automatic mode {Fig. 19. and 20.}, with a facility to
stop or to continue the development of new alternatives of the layout.

The system is controlled (positioning, repositioning etc.) by unique identification numbers or Tag Numbers.

NOTE:
The rotation axis for Work Station Modules manipulation is the Y-axis running through the far corner of the module on the left of the operator, as shown in Fig.5.

The Tag Number is a part of the Work Station Module and has to be treated as such.

The display area on a 12 inch VDU, which could be used for layout development, measures 18x33 meters in scale, with 77 maximum Work Station Modules.
Fig. 14.

File of existing Work Station Module volumes

<table>
<thead>
<tr>
<th></th>
<th>300.00</th>
<th>200.00</th>
<th>270.00 WS001</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>280.00</td>
<td>200.00</td>
<td>220.00 WS002</td>
</tr>
<tr>
<td>2</td>
<td>250.00</td>
<td>150.00</td>
<td>150.00 WS003</td>
</tr>
<tr>
<td>3</td>
<td>350.00</td>
<td>190.00</td>
<td>210.00 WS004</td>
</tr>
</tbody>
</table>

Do you wish to extend/update the existing file...YE or NO?

Fig. 15.

LAYOUT...The existing situation of development

Do you want to continue/change the layout...YE or NO?
You are now in POSITIONING MODE.
Are you starting a NEW layout, from the first W.St. in technological order? ...YES or NO
Do you wish to POSITION the considered WorkStation manually ... YE or NO

Please POSITION the W.S. by cross-hairs...
Fig. 17.

TOTAL VALUE OF -Z-DIMENSION IS

YOU ARE NOW IN AUTOMATIC MODE to activate press return new line once!

TOTAL VALUE OF -Z-DIMENSION IS

YOU ARE NOW IN AUTOMATIC MODE to activate press return new line once!

1 = INSIDE
2 = TOUCH (O.K. !)
3 = OUTSIDE.

Do you wish to test the line for clash?

YOU IN AUTOMATIC MODE to activate press return new line once!

RESULT

CLASH !!!
-WSD002
DO YOU WISH TO RE-POSIT THE CLASHING W.S. ONLY
..YES/NO..If NO you can reposition any No.of W.S.
You are now in the Manual...to...Auto Mode

Do you wish to re-POSITION the Work Station...YE or NO

Please POSITION the W.S. by cross-hairs...
Is the POSITION of W.S. according to your wish...YE or NO
Do you wish to continue developing the layout...

in automatic mode ... YE or NO

TOTAL VALUE OF -Z DIMENSION IS
11.17.31
YOU ARE NOW IN AUTOMATIC MODE to activate press return 'new line once'

LAYOUT ACCEPTABLE

Fig. 20. b)

LAYOUT...The existing situation of development
Do you wish to redraw the layout?...YES, NO..
If NO is typed, the session is over
4.5.5 DISPLAY PROGRAM

Program 'DISPLAY.FOR' has been compiled for displaying the layout and manipulation of the whole scene. It also allows the user to study developed alternatives, and provides a better 3-D presentation on VDU and/or printing. The user feeds in a requested distance, rotation, and elevation, and the layout is shown on VDU (see Fig. 21).

Fig. 21.
RESULT OF 'DISPLAYO' PROGRAM
4.5.6 AUXILIARY PROGRAMS

To simulate real situations in Factory Layout Planning some Auxiliary Programs have been compiled:

4.5.6.1 MANUAL FEEDING OF WORK STATIONS

Frequently, in practice, the plant layout engineer has a list of work stations available for the manufacturing programme. From the list, suitable machine tools and equipment must be selected and a 'technological' order of their relative positions in the layout has to be established. Interrelations of these operations is illustrated by Fig.22. Programs for 'technological' positioning developed at Strathclyde University (Dr.Carrie [13,14]), were originally intended to be used here. However, because of some technical difficulties experienced in the transfer of the Strathclyde programs, the program 'MFEED.FOR' was compiled instead. The program is substituting the results of Dr.Carrie's programs and feeds in a ready designed 'technological' line of work stations needed for the job. The program allows the user to change the 'technological' order, with changing requirements.

To accompany 'MFEED.FOR', program 'WSVTOTO.FOR' was written, which allows the reorganisation of Work Station Modules (in 'largest volume' presentation, see Fig. 5.), according to 'technological' order. This step was found necessary
because the 'largest volumes' of Work Station Modules are only used in some parts of programs, while in other parts the detailed Work Station Modules are used. The 'largest volumes' give a clearer presentation and understanding of layout development (see Fig. 20.b)), while layouts using detailed Work Station Modules may be used for detailed study or final placement of machines (anchoring bolts, etc.) on shop floor.

![Diagram](image)
4.5.6.2 CAPACITY CALCULATIONS

The layout engineer must of course be in possession of some basic figures about the new layout (see Chapter 2. Project stages 1. and 2.). The capacity calculation program 'M100.FOR' is intended for basic capacity calculations for the case where no detailed information about production is available.

The program provides calculation of:

- Volume of Material Handling;
- Number of work stations needed;
- Manufacturing area needed;
- Total length of industrial bay.

This program is an example of others which may be developed in the future to estimate and plan, e.g. manning levels, production capacity in relation to shift coefficient, general effectiveness of layout, etc.
5. THE TESTING OF PROGRAMS

All programs were running and were tested for required functions.

5.1 'WSBUILDR.FOR' Program

To produce a 3-D template of an average Work Station Module takes 10-15 minutes. The template gives a reasonable image of the work station and, even if positioned on a one meter grid, it was found that it could be used for the placement of machines within the usual shop floor tolerances of 10 cm.

The 'WSRECALL.FOR' program retrieves the filed 3-D template.

5.2 BUILDING 'CIVES3.FOR' Design Program

To place any civil engineering element via this program takes about 30 to 60 seconds, and any change could be introduced equally fast. The 3-D model of the interior of the bay produced gives a good image of the space available for the layout. The capacity of maximum 200 building elements is more than sufficient.

5.3 MANUAL POSITIONING PROGRAMS

These programs were most thoroughly tested and no special
problems were encountered by users. The positioning of objects was found to be very fast and easy procedure. The only disadvantage is the inaccuracy that arise in connection with the use of joystick. Due to that, incompatible pictures on VDU and printouts are produced, if an adjacent position of work stations is intended. The printout from the CALCOMP 960 plotter shows a double line where work stations touch, while the optical reading of crosshair/work station on VDU gives a single image. This is evidently caused by a combination of both hardware deficiency and the human factor error.

5.4 AUTOMATIC POSITIONING PROGRAM

The composite program 'POSCLASH5.FOR' was found to be easy to use and produced very fast automatic positioning of Work Station Modules according to the design specification.

When ever a clash with building elements occurs, the collision course finding is immediate and the manual override can start without any delay.

Similar problems to those mentioned in the last section have been found with the joystick position accuracy.

IDENTIFICATION BY TAG NOS:
The Tag Number of the 'largest volume' of work station is placed horizontally at the base plate level; while the tag
number of the detailed Work Station Module is written vertically in an upright position. This design is a result of the findings during the testing of 'DISPLAY.FOR' Programs, and makes the reading of Tag No. easier in any display position.

5.5 DISPLAY PROGRAM

'DISPLAY.FOR' program ran without any problems, and the device for observation of the scene from any angle and distance proved useful.
6. DISCUSSION OF RESULTS

The use of PICASO for 3-D design and simulation has proved to be very useful. PICASO is a unique 2-D and 3-D computer graphics system developed at Middlesex Polytechnic to simplify the human interface when manipulating shapes and objects. As with any software environment there are limitations imposed upon the user when using the available commands. CAFLAP's interface would have been greatly improved if the user had had control over line types when objects were subject to hidden-line removal. Objects would have looked tidier if their surfaces could have been shaded or even transparent; there was a need to move elements around the screen in real-time. These problems are not identified as specific criticisms of PICASO but rather to identify the type of graphics facilities CAFLAP could benefit from in future with access to a sophisticated real-time full-colour graphics workstation.

It is felt that the drawing of work stations or buildings by use of a joystick should be attempted in future development of CAFLAP, despite the knowledge of possible inaccuracies inherent in the joystick-VDU-printer combination.

Experience has shown that accuracy, using a scale of 1:50 and a layout grid of 250x250 mm, is satisfactory for the needs of any type of layout for any type of mechanical
engineering production; so inaccuracies resulting from use of joystick are within usual plant layout design tolerance (10 cm).

The interactive program 'IYTVA00.FOR' for manual positioning has all positive functions specified, and it is believed that it could be used for any plant layout almost universally. Small adaptations, for example the listing of Work Stations or, vice versa, printing Work Station lists not only in chronological but also in the 'technological' order, could easily be made on request. The same is true for the 'IYTWSFILE.FOR' program.

Although the 'POSCLASH5.FOR' Program is the most developed program of all, it has scope for further development as a more versatile tool. For example, collision course finding could be extended (on the principles already developed) for clashes of work station foundations with underground piping or power ducts network, etc. Similarly, principles for positioning according to Fig. 7. a) and b), could be applied to layouts such as Fig. 7. c) etc. This could spare present users possible errors with a negative reading of joystick. However, selfguarding mechanism, protecting user against the error during manipulation (negative angles), would be useful to add.

During the automatic positioning, with the hardware used here and system of identification of spaces (no hatching,
no tinting), the Maintenance Space cannot be placed in the Man-Space of the previous work station to increase the shop floor utilisation. This has to be considered as a calculated loss at this stage of development.

BENEFITS OF CAFLAP TO THE PLANT LAYOUT ENGINEER.

CAFLAP programs testing showed there are two main areas of benefits for the user:
Firstly, it makes plant layout work easier, and the task is accomplished faster.
Secondly, CAFLAP functions as a methodological tool, guiding the user to perform the plant layout tasks systematically and with a holistic approach. This improves the quality of the work and expands user's potential, leading towards a deeper understanding of the nature of plant layout problems. CAFLAP stimulates the user's creativity, giving an opportunity actually to override the computer when necessary. The user is thus the master of the computer, not just its follower. This is illustrated in Fig.23, which shows how CAFLAP benefits the plant layout engineer.
Work Station Module design: Simple and fast design by means of a kit.

Guiding the user in Work Station Module design

Enhancing creativity in the design of Maintenance Space and Fan Space

Stimulating systematic and holistic approach to complex tasks of Factory Layout Planning

Civil Eng. Space design: Simple and fast design of the building (bay)

Special feature: K.P. Product Space Zone design safeguards effective use of Product Space

Layout design: Systematic and fast design eliminating possible errors and omissions

Automatic positioning mode is time-saving

Override stimulates creativity

Automatic positioning designs layout in the best possible way in terms of synergetics.

Automatic positioning guarantees the most economic use of the space, while upholding ergonomic and maintenance principles

Fig. 23. THE MAIN BENEFITS OF CAFLAP TO THE PLANT LAYOUT ENGINEER
7. **INDUSTRIAL APPLICATION OF CAFLAP**

The interactive program for manual positioning was used during 1986-87 Factory Layout Planning projects for Eltron (London) Ltd. Eltron (London) Ltd., established in 1927, has three factories employing over 200 people and is one of the world's leading manufacturers of industrial electrical heating systems and equipment.

Eltron required new layouts for a two-fold increase of production capacity on 'green field' site, and cooperated with Middlesex Polytechnic on development of necessary layouts. For examples see Appendix III., Drawings No. 2 and 3.

Although it was not possible to do any detailed and exact quantitative control-study evaluation, work on the layout using CAFLAP proved much faster than had been possible hitherto by traditional methods.

Final results, with drawings printed on the CALCOMP 960 plotter, were also of a superior quality to those previously obtained. The results produced were more than satisfactory in fulfilling the practical needs of the production management team. Certainly if detail Work Stations Modules had also been incorporated at that time, the result would have been even more remarkable and well received by
Industry.

The automatic positioning program was also not then fully developed so that it was not possible to test its impact in a real industrial environment. However, test runs have shown that the method of automatic positioning of individual work station 3-D templates in construction or improvement situations, with the use of collision course finding and clash indication, is viable and very fast. Originally, as stated in chapter 4.2, the development of CAFLAP was aimed at layout and relayout of a medium size engineering company with batch production and with a maximum product weight of 60kN. These limits were set because the development of CAFLAP was targeted on companies with limited resources, premises, and manufacturing facilities. It was originally wrongly contemplated that the span of an industrial bay, or the type of M.H. equipment (e.g. cranes, fork lift trucks, conveyors) and shape of aisles, could limit the use of CAFLAP automated layout system. These factors could be restrictive and could cause problems for the use of computerised methods designing block plan plant layout (Chapter 3.2). But the CAFLAP method of positioning individual work stations in a 'technological' line is not restricted in this way. Hence the advanced development of the automated positioning method has actually disproved the existence of such a restriction, and CAFLAP may be used for any general application.
EVALUATION OF PROJECT ALTERNATIVES

Projects and alternatives, in a classical plant layout approach, are usually evaluated by means of comparison of the following main parameters:

- production programme per time unit
  (expressed in terms of quantity of products, weight, etc.)

- areas

- number of production machines

- number of operators

and indicators derived from the above e.g.:

- Ratio of Manufacturing Area to Total Area;
- Area per one work station (in m sq./1);
- Production output per 1 m sq. of Manufacturing Area (kN/m sq.) etc.

The Space Management concept offers a completely new approach to the economic evaluation of projects and their alternatives, giving more accurate results. This is achieved by considering new facts, established in the course of this research work, with following examples of resulting indicators e.g.:
Ratio of:

Manufacturing Space to total space of the hall;

Manufacturing Space to Product Space;

Manufacturing Space to Maintenance Space;

Manufacturing Space + Product Space to Manufacturing Services Space;

Manufacturing + Product + Manufacturing Services Spaces to 'Breathing Space'... etc.

The highest ratio of Manufacturing Space to the 'other' spaces is sought. A set of indicators may be tailored according to individual needs. They could also provide a very instructive feedback for designers and machine manufacturers.
8. PRESENT LIMITATIONS OF THE SYSTEM

AND

RECOMMENDATIONS FOR FURTHER DEVELOPMENT

At this stage of development the system has the following limitations:

There is no independent facility for collision course finding for travelling overhead cranes or installed robots. If they are to be avoided, the 'obstacles' have to be entered at present via 'CIVES3.FOR' program. In the same way that power and pipeline networks are considered.

A facility for an automatic design for an width of industrial bay and optimum industrial hall is not yet available.

There is as yet no facility to move the picture of the bay to keep pace with automatic development of the layout, and to produce the 'continuous bay' in graphical presentation. At present the area of layout shown is limited to individual sections, determined by the size of VDU.

Other programs (e.g. Strathclyde) desirable for 'technological' positioning of work stations are not incorporated in the overall system.
With respect to the above limitations, the following are areas for further development:

- to extend the already developed programs into all the remaining areas of plant layout;

- to use colours (colour VDU) for further improvement of identification of spaces (man, maintenance) and for space saving during collision course finding;

- to add a facility for complete automatic design of industrial bays and halls;

- to incorporate the 'technological' positioning programs and facility for automatic retrieving of information from Work Station Cards;

- to build a library of Work Station Modules of all British made machine tools;

- to incorporate/develop the system into a Computer Integrated Engineering System.
9. CONCLUSIONS

A Computer Aided Factory Layout Planning system has been developed to the stage where it is industrially useful: further refinements are suggested.

The SPACE MANAGEMENT principles used are abstracted from the complex reality of the Factory Layout Planning field. These principles, translated into CAFLAP system, enable layout tasks to be greatly simplified.

All the main ideas and principles of CAFLAP developed here have been confirmed by computer programs compiled and their results.

The Computer Aided Factory Layout Planning system should not be considered as a new drafting system, nor as an algorithm for finding the most suitable relative placement of work stations.

CAFLAP should be judged as a tool for:

- speeding up layout work through the application of CAFLAP ideas e.g. Work Station Modules, Space Management concepts and positioning systems;

- increasing the quality of layout work by means of design of Work Station Modules and
collision course finding positioning programs;
- diminishing manual repetitiveness of layout work;
- introducing facility for a more detailed layout
  in the early stages of a project, which will
  increase the quality and the quantity of information
  available for strategic decision making.

CAFLAP is therefore a device to:
- free engineers for more creative work;
- eliminate the number of project stages;
- ease finding optimum alternatives of layout;
- introduce new models into production
  in the shortest possible time;
- lower the cost of capital investment.

The developed SPACE MANAGEMENT concept also offers a new
approach to the economic evaluation of projects and their
alternatives, by means of comparison of ratios of spaces
(Chapter 7. -Economic Evaluation of Project Alternatives).
Assessment of the essential Manufacturing Spaces, together
with all the auxiliary, service, and 'breathing' spaces,
helps to find the areas of potential retrench. This then
leads to an expedient relayout and even to a rational
redesign of Work Station Modules. If an improvement of the
existing factory is undertaken, the assessment, with the
help of the spaces ratios, pinpoints the areas with the most abundant use of the auxiliary spaces which should be tackled first.

Computer graphics methodology, principles, and kinetic functions, have all been used in an innovative way to assist the creative design work of plant layout engineer.

An early decision was made to use simple hardware in this work, e.g. a small monochrome VDU and a basic printer. The aim was to make CAFLAP system accessible to a widest possible spectrum of users. Certainly this decision imposed some limitations on the extent of development of the Space Management ideas. Further development is therefore a matter of some compromise, but the main objectives of the current work have been achieved.

CAFLAP system is an important step forward in the direction of total computer integrated engineering system design.

BOB KOBLIHA

22nd July 1988.
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Appendix I

TERMINOLOGY

Standard terminology, given by British Standards, still fails to cover some areas in Production and Industrial Engineering. In these areas terminology varies from factory to factory and also internationally among English speaking countries. This is true especially in the field of Factory Layout Planning which is often accented by American English. Some terminology and expressions which, are frequently used in parallel, follow:

<table>
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<tr>
<th>Item</th>
<th>Term</th>
<th>Parallel Expression(s)</th>
<th>Remarks</th>
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<tr>
<td>1</td>
<td>Plant Layout</td>
<td>Factory Layout Planning</td>
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<td>Facility Layout</td>
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<td>Facility Allocation</td>
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<td>Economic Activity Location</td>
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<td>2</td>
<td>Project Stage</td>
<td>Project Phase</td>
<td>e.g. Muther[4]</td>
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<td>3</td>
<td>Feasibility Study</td>
<td>Programme Study</td>
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<td>Investment Study</td>
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<td>4</td>
<td>Investment Project</td>
<td>Programme</td>
<td>e.g. Ford Motor</td>
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<td>Tender</td>
<td>Company</td>
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<td>5</td>
<td>Project</td>
<td>Final Stage Project</td>
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<td>Working Detail Drawings</td>
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<td>&quot;as made&quot; drawings</td>
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<td>'technological' theoretical pos.</td>
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<td>to suit best technol. demands and economy of production</td>
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<td>Preventive Regular Maintenance</td>
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<td>Maintenance</td>
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<td>10</td>
<td>Manufacturing Auxiliary Services</td>
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<td>Services Subsidiary Services</td>
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<td>11</td>
<td>Services Energy supply</td>
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<td>12</td>
<td>Templates Templates and Tapes</td>
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<td>on 'Skins' Templates and Paste</td>
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<td>Parish[33]</td>
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COMPUTER PROGRAMS

1. 'WSBUILD.R.FOR'
2. 'WSRECALL.FOR'
3. 'CIVES.FOR'
4. 'IYTVAX00.FOR'
5. 'IYTWSSFILE.FOR'
6. 'POSCLASH5.FOR'
7. 'DISPLAY.FOR'
8. 'MFEED.FOR'
9. 'WSVTOTO.FOR'
10. 'M100.FOR'
"SHAPES FOR" PROGRAM

For Design and Planning of Work Stations and Equipment...

Improved on 10.10.86.

Further improvements introduced on 10.2.87.

Further improvement on 31.7.87 ("OPERATOR" added)

REAL A(3001),B(5000),C(5000),R(2000)

INTEGER SIDES

LOGICAL FIRST

CHARACTER*12 chemicals

CHARACTER*12 vNAME

CHARACTER*12 TAGNO

FIRST = .TRUE.

WRITE (6,50)

FORMAT (" • Work station design program.

Please start

An origin using only positive figures...

Including work station module volume...turning point is

At bottom corner. This is important for JC. CH and

Automatic positioning as well!

CALL BELL

CALL KEYPAD

WRITE (6,60)

FORMAT (" SHAPE and CONES"/" Select wanted")

CALL UPDISP (FILENAME, 10)

CONTINUE

WRITE (6,5001)

5001 FORMAT (" A UGY-shaped PARTS, start with foundat, plate")

WRITE (6,5020)

5020 FORMAT (" A D ANCHORING BOLTS or FOUNADATION BOLTS")

WRITE (6,5030)

5030 FORMAT (" C) CYLINDRICAL PARTS")

WRITE (6,5040)

5040 FORMAT (" C) CYLINDRICAL PARTS")

WRITE (6,5050)

5050 FORMAT (" P) PARABOLICAL PARTS")

WRITE (6,5060)

5060 FORMAT (" S) SPHERICAL PARTS")

WRITE (6,5070)

5070 FORMAT (" T) TAG NUMBER and Unique Identification no")

WRITE (6,5080)

5080 FORMAT (" A) NO MORE SHAPES REQUESTED-END OF SESSION")

WRITE (6,5090)

5090 FORMAT (" Please write the selected CODE")

CALL BELL

READ (6,40) CODE

40 FORMAT (A2/)

IF (CODE.EQ."00") GOTO 200

IF (CODE.EQ."40") GOTO 300

IF (CODE.EQ."70") GOTO 400
```
C 3.
61 IF (CODE.EU."CG") GOTO 500
62 IF (CODE.EU."PY") GOTO 600
63 IF (CODE.EU."AP") GOTO 700
64 IF (CODE.EU."UP") GOTO 900
65 IF (CODE.EU."IR") GOTO 800
66 IF (CODE.EU."UX") GOTO 100
67 C IF THE ENTRY DOES NOT CORRESPOND WITH THE CODE
68 C THE ERROR MESSAGE IS WRITTEN
69 C CALL BELL
70 C WRITE (6,70)
71 FORMAT (" Please enter your response again - using CAPITALS")
72 GOTO 30
73 70 CONTINUE
74 C BOX SHAPES ARE INTRODUCED
75 C CALL BELL
76 C WRITE (6,210)
77 FORMAT (" Please enter data for X,Y,Z,ROT,XS,YS,ZS in cm")
78 C CUBE DIMENSIONS MUST BE PUT IN CENTIMETERS
79 C NUMBERS MUST BE ENTERED IN 5 FIG., DEC., PHN AND 2 FIG., FURK
80 C ROTATION IN DEGREES (EXAMPLE 30,0)
81 C READ (5,220,END=230) X,Y,Z,ROT,XS,YS,ZS
82 C WRITE (10,220) X,Y,Z,ROT,XS,YS,ZS
83 C 220 FORMAT (HUG,2x)
84 C READ BUX (X,Y,Z)
85 C CALL TURMO (A,ROT,0,0,0,7,8)
86 C CALL SHIFTI (P,AS,IS,ZS)
87 C 230 CONTINUE
88 C GOTO 1000
89 C 300 CONTINUE
90 C CALL BELL
91 C WRITE (6,310)
92 FORMAT (" Please enter data for ROTATION and Shift XS,YS,ZS")
93 C CYLINDRICAL PARTS ARE INTRODUCED
94 C CALL BELL
95 C WRITE (6,320)
96 FORMAT (4(F6.2))
97 C 320 CALL TURMO (A)
98 C CALL SHIFTI (A,HGT,0,0,0,2,8)
99 C CALL SHIFTC (AS,IS,ZS)
100 C 330 CONTINUE
101 C GOTO 1000
102 C 400 CONTINUE
103 C CYLINDRICAL PARTS ARE INTRODUCED
104 C CALL BELL
105 C WRITE (6,405)
```
FREE ("Please write dimensions, DIAM, HEIGHT, SIDES, ROT, XS, YS, ZS")

CALL (5,410,END=420) DIAM, HEIGHT, SIDES, ROT, XS, YS, ZS

WRITE (10,410) DIAM, HEIGHT, SIDES, ROT, XS, YS, ZS

CALL CYLINDER (DIAM, HEIGHT, SIDES)

CALL TURN3D (ROT, 0, 0, 0, 0, 0, 0, 0, 0, 0)

CALL SHIFT (XS, YS, ZS)

CONTINUE

GOTO 1000

500 CONTINUE

CALL NULL

C

CONICAL PARTS ARE INTRODUCED HERE

C

WRITE (6,510)

510 FREE ("Please enter dimensions of cone DIAM, HEIGHT and NO of SIDES, ROTATION ROT and SHIFT XS, YS, ZS")

READ (5,520,END=530) DIAM, HEIGHT, ROT, XS, YS, ZS

WRITE (10,520) DIAM, HEIGHT, ROT, XS, YS, ZS

RETURN (2,F6.2,114,4F6.2)

CALL CYM (DIAM, HEIGHT, ROT)

CALL TURN3D (ROT, 0, 0, 0, 0, 0, 0)

CALL SHIFT (XS, YS, ZS)

CONTINUE

GOTO 1000

C

CONTINUE

C

CONICAL PARTS ARE INTRODUCED HERE

C

WRITE (6,510)

510 FREE ("Please enter dimensions of cone CYLINDER HEIGHT and NO of SIDES, ROTATION and SHIFT XS, YS, ZS")

READ (5,520,END=530) DIAM, HEIGHT, ROT, XS, YS, ZS

WRITE (10,520) DIAM, HEIGHT, ROT, XS, YS, ZS

FORMAT (7F3.2)

CALL PVP

AH

DIAM, HEIGHT)

CALL TURN3D (ROT, 0, 0, 0, 0, 0, 0)

CALL SHIFT (XS, YS, ZS)

CONTINUE

GOTO 1000

C

CONTINUE

C

PYRAMIDAL PARTS ARE INTRODUCED HERE

C

WRITE (6,510)

510 FREE ("Please enter dimensions for pyramidal parts WIDTH, DEPTH, HEIGHT and ROTATION and SHIFT XS, YS, ZS")

READ (5,520,END=530) WIDTH, DEPTH, HEIGHT, ROT, XS, YS, ZS

WRITE (10,520) WIDTH, DEPTH, HEIGHT, ROT, XS, YS, ZS

RETURN (2,F6.2,114,4F6.2)

CALL CYM (DIAM, HEIGHT, DEPTH)

CALL TURN3D (ROT, 0, 0, 0, 0, 0, 0)

CALL SHIFT (XS, YS, ZS)

CONTINUE

GOTO 1000

C

CONTINUE

C

PYRAMIDAL PARTS ARE INTRODUCED HERE

C

WRITE (6,510)

510 FREE ("Please enter dimensions for pyramidal parts WIDTH, DEPTH, HEIGHT and ROTATION and SHIFT XS, YS, ZS")

READ (5,520,END=530) WIDTH, DEPTH, HEIGHT, ROT, XS, YS, ZS

WRITE (10,520) WIDTH, DEPTH, HEIGHT, ROT, XS, YS, ZS

FORMAT (7F3.2)

CALL PVP

AH

DIAM, HEIGHT, DEPTH)

CALL TURN3D (ROT, 0, 0, 0, 0, 0, 0)

CALL SHIFT (XS, YS, ZS)

CONTINUE

GOTO 1000

C

CONTINUE

C

PYRAMIDAL PARTS ARE INTRODUCED HERE

C

WRITE (6,510)

510 FREE ("Please enter dimensions for pyramidal parts WIDTH, DEPTH, HEIGHT and ROTATION and SHIFT XS, YS, ZS")

READ (5,520,END=530) WIDTH, DEPTH, HEIGHT, ROT, XS, YS, ZS

WRITE (10,520) WIDTH, DEPTH, HEIGHT, ROT, XS, YS, ZS

FORMAT (7F3.2)

CALL PVP

AH

DIAM, HEIGHT, DEPTH)

CALL TURN3D (ROT, 0, 0, 0, 0, 0, 0)

CALL SHIFT (XS, YS, ZS)

CONTINUE

GOTO 1000

C

CONTINUE

C

HERE ARE INTRODUCED ALL SPHERICAL PARTS

C

WRITE (6,710)

710 FREE ("Please enter dimensions for spherical parts DIAM, NO of horizontal tiles and NO of vertical tiles")

READ (5,720,END=730) DIAM, NH, NV, ROT, XS, YS, ZS

HERE ARE INTRODUCED ALL SPHERICAL PARTS

C

WRITE (6,710)

710 FREE ("Please enter dimensions for spherical parts DIAM, NO of horizontal tiles and NO of vertical tiles")

READ (5,720,END=730) DIAM, NH, NV, ROT, XS, YS, ZS
181 WRITE (10,720)U1AM,nn,NN,ROU,AS,YS,ZS
182 720 FORMAT (1F8,2,2I8,4F8,2)
183 CALL SPHERE (A,CIAM,HI,IV)
184 CALL TURN3H(A,ROU,0,0,0,2,B)
185 CALL SHIFT3(B,AS,YS,ZS)
186 730 CONTINUE
187 GOTO 1000
188
189 900 CONTINUE
190 CALL DELL
191 C 4-D TEMPLATES/HOVEL OF "OPERATOR" IS INTRODUCED
192 C
193 C
194 C 4-D TEMPLATES/HOVEL OF "OPERATOR" IS INTRODUCED
195 910 FORMAT (" Please enter data for ROTATION and SHIFT...
196 AS,YS,ZS")
197 READ (5,920,ERR=30)ROT,AS,YS,ZS
198 920 WRITE (10,920)ROT,AS,YS,ZS
199 C
200 CALL TURN3D(A,ROU,0,0,0,2,B)
201 CALL SHIFT3(B,AS,YS,ZS)
202 930 CONTINUE
203 GOTO 1000
204
205 800 CONTINUE
206 810 CALL DELL
207 C
208 C 4-D TEMPLATES/HOVEL OF "OPERATOR" IS INTRODUCED
209 C
210 C
211 C 4-D TEMPLATES/HOVEL OF "OPERATOR" IS INTRODUCED
212 810 FORMAT (" Please enter data for ROTATION and SHIFT..."
213 AS,YS,ZS")
214 READ (5,920,ERR=30)TAG5,ROT,AS,YS,ZS
215 920 WRITE (10,920)ROT,AS,YS,ZS
216 C
217 CALL CHR5(TAG5,5,2,60,0,8)
218 CALL TRANS3R(A,TAG5)
219 CALL TURN3D (A,ROU,0,0,0,2,B)
220 830 CONTINUE
221 GOTO 1000
222
223 1000 CONTINUE
224 IF (FIRST) GOTO 1010
225 CALL JOIN (4,5)
226 GOTO 110
227 GOTO 110
228
229 1010 CONTINUE
230 CALL COPY (5,8)
231 FIRST = .FALSE.
232 GOTO 30
233
234 100 CONTINUE
235 CALL CLDISC (FILMAH,10)
236
237 CALL UPDISC("ASFDIM",10)
238 FAC =10("FAC")
239 FUR =10("FUR")
240 FURY =10("FURY")
IF THE SHAPE IS ACCORDING TO OUR REQUIREMENT SAY YES

WRITE(*,2100)

READ(5,2110)ANS

FORMAT(' IS THE WORK STATION OF A REQUIRED LIKENESS YES/NO?')

IF (ANS.EQ."YES") GOTO 230

IF (ANS.EQ."NO") GOTO 240

CONTINUE

WORK STATION DETAILED DRAWN BY HELP OF THE ABOVE PROGRAM

IS FILED UNDER A UNIQUE TAG NUMBER

EACH WORK STATION HAS ITS OWN FILE

ENTER FILENAME (SHAKE=a tag no. of work station drawn)

READ(5,2310)SHAKE

FORMAT(A12)

CALL QUILOC(C,SHAKE)

STOP

C

"FOULT" - FOUNDATION BOLT

THIS IS A SUBROUTINE DRAWING AN ARCHURING BOLT

SUBROUTINE FOULT (F)

REAL H(39), E(88), F(127)

CALL LINE3D(0,0,0,2,0,0,0,0,-2,0,10)

CALL LINE3D(E,2,0,0,0,0,-2,0,0,0,10)

CALL JOIN(E,1)

CALL LINE3D(0,0,2,0,0,0,0,0,-8,0,0,10)

CALL JOIN(E,F)

RETURN
301 C
302 C "OPERATION" - 3-D TEMPLATE
303 C
304 C SUBSTITUTE OPERATOR (T)
305 C
306 C THICK, ARMS, LEGS
307 C
308 C HEAD
309 C 
310 C HEAL (1000), D (1200), T (2000)
311 C
312 C
313 CALL BOX (A, 55, 0, 50, 0, 35, 0)
314 CALL SHIF3 (A, 0, 0, 90, 0, 0, 0)
315 CALL BOX (A, 100, 0, 90, 0, 20, 0)
316 CALL QU3 (A, 0)
317 CALL BOX (B, 10, 0, 50, 0, 0, 0)
318 CALL SHIF3 (C, 35, 0, 0, 0, 0, 0)
319 CALL JO13 (E, C)
320 CALL BOX (E, 20, 0, 25, 0, 20, 0)
321 CALL SHIF3 (E, 21, 0, 180, 0, 0, 0)
322 CALL JON (C, E)
323 CALL C10 (D, 20, 0, 15, 0, 6)
324 CALL DEFL3D (F, 270, 0, 0, 0, 0, 0, 0, 1, 7)
325 CALL SHIF3 (F, 270, 0, 155, 0, 20, 0)
326 CALL JO11 (F, 7)
327 CALL GRAVITY (F)
328 C
329 C RETURN
330 C
331 C
332 C...
333 C...
334 C... BUILD UNDER THE NAME "SPIKE,FUR"
335 C
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Job queued to SSSPRINT on 9-MAY-1987 12:13 by user BDB, VMS (RESMOO12, 6001), under account RE.
C 9.
1 C PROGRAM "RECALL8.FOR"
2 C THIS PROGRAM IS RECALLING/PRESENTING THE WORK STATIONS DRAWN
3 C BY REPL OF PROGRAM "WFILE.FOR"
4 C
5 REAL X(5000)
6 CHARACTER*12 XNAME
7 CHARACTER*12 TAGNO
8 CALL OPENCC("SFUL",10)
9 FAC =UNICH(FAC *)
10 FORX =UNICH(FORX *)
11 FURY =UNICH(FURY *)
12 FRAA1 =UNICH(FRAA1 *)
13 FRAA2 =UNICH(FRAA2 *)
14 FRAY1 =UNICH(FRAY1 *)
15 FRAZ =UNICH(FRAY2 *)
16 PICA =UNICH(PICA *)
17 DISTR =UNICH(DISTRC *)
18 ROTAT =UNICH(ROTATE *)
19 ELEVTN =UNICH(ELEVEN *)
20 CALL CLUISC("SFUL",10)
21 CALL STAA
22 CALL FACVUR(FAC)
23 CALL FORVAT(FORX,FURY)
24 CALL FRAY(FRAA1,FRAA2,FRAY1,FRAY2)
25 CALL PLANT(PICA *)
26 CALL FORPSU(0.0,0.0,DISTR,ROTAT,ELEVTN)
27 WRITE (6,50)
28 FORMAT ("PLEASE FILE IN THE WORK STATION tag No.")
29 WRITE (12)
30 FORMAT (A12)
31 CALL J3JOY(TAGNO)
32 CALL DRA1IT(Y)
33 CALL NGRO
34 CALL PICA
35 CALL F1ATION
36 STOP
37 END
38 C
39 C FILE UNDER THE NAME "RECALL8.FOR"
40 C
"CIVEL.FOR" PROGRAM IS WRITTEN FOR DESIGN OF CIVIL ENGINEERING SPACE (SECTION OF A BAY) - CONSISTING OF CIVIL ENGINEERING ELEMENTS (HERE PRESENTED AS BOXED ONLY!)

DATA ARE FEED IN MANUALLY ONLY

WRITE AND VDU IS USED

REAL A(99),U(100), CESPAC (10000)
REAL AIR(100),ZAI(100),ZAI(100),ZU1S(100),ZU1S(100)
REAL DGH(100),ZT(100),X(100)

INTEGER SELECT,DESSEL, ALPHA,GRA

DATA SELECT/10013/
DATA DESEL/40433/
DATA ALPHA/30/
DATA GRAPH/15/

THE CIVIL ENGINEERING ELEMENTS AND OTHER SPACES - ALL DIMENSIONS SHOULD BE ENTERED IN DECIMETERS (DM)

CALL START
CALL GPUSCN(DL** , lu )
DISTNC = DiSTNC( 'DIS1NC')
RUTAT = DiSTNC( 'ROUT')
XTDIK = DiSTNC( 'XDTK')
ZDKX = DiSTNC( 'ZDKX')

CLASS = DiSTNC( 'SPACE ')
CALL CLDISC("CIVELK",10)
CALL FORMAT (80,0,0,0)
CALL FRAME(-35,0,25,0,-25,0,25,0)
CALL PBE(0,0,0,0,0,0,0,0,0)
CALL PLANE (ZDKX)
CALL ARSH(HEL,MT,MLZ,SPACE)

PRESENT SITUATION IS DRAW

CALL PRESENT
CALL DEVELOP
CALL CLOSE
CALL FINISH
STOP
12.

   END

   C...

63

SUBROUTINE DEVELOP
REAL A(100), B(100), C(100)
REAL X10(100), Y10(100), Z10(100), XD10(100), YD10(100), ZD10(100)
REAL LX1(100), LT(100), L1(100)

INTEGER CEE
INTEGER SELECT, DESEL, ALPHA, GRAPH
DATA SELECT/100/ DATA CEE/35/ DATA ALPHA/10/ DATA GRAPH/100/

75

IF REQUESTED A NEW DEVELOPMENT FOLLOWS

80

CONTINUE

85

FORMAT ('Do you wish to change/develop the layout...YES/NO')

90

READ (5,70) Ans

95

IF (ANS.EQ.'NO',I0.ANS.EQ.'N') GOTO 500

100

IF (ANS.EQ.'YES',I0.ANS.EQ.'Y') GOTO 125

105

WHITE (6,120)
FORMAT ('Please enter your response again')

110

CONTINUE

115

CALL CEFPAC

120

CONTINUE

125

CALL CUDISC ('CELDIM',10)

130

READ (16,100,IER=135) , X1(D1), Y1(D1), Z1(D1), XD1(D1), YD1(D1), ZD1(D1),

135

GOTO 130

140

WRITE (6,130) , X1(D1), Y1(D1), Z1(D1), XD1(D1), YD1(D1), ZD1(D1)

145

CONTINUE

150

CALL CUDISC ('CELDIM',10)

155

WRITE (6,140)

160

WRITE (6,150) PLEASE ENTER NO. OF CIV.E. ELEMENTS (W/CEE) REQUIRED

165

WRITE (6,160) DESEL

170

WRITE (6,170) GRAPH

175

READ (5,180)

180

WRITE (6,180) CEE

185

READ (5,190)

190

WRITE (6,190) ALPHA

195

READ (5,200)

200

WRITE (6,200) SELECT

205

WRITE (6,210)

210

WRITE (6,210) CEE

215

WRITE (6,220) GRAPH

220

READ (5,230)

230

WRITE (6,230) CEE

235

READ (5,240)

240

WRITE (6,240) SELECT

245

WRITE (6,250)

250

WRITE (6,250) CEE

255

READ (5,260)

260

WRITE (6,260) GRAPH

265

READ (5,270)

270

WRITE (6,270) CEE

275

READ (5,280)

280

WRITE (6,280) GRAPH
3.

```
121 C WRITE(1,10)ALPHA
122 C WRITE(10)SELECT
124 260 FORMAT (' Please enter items No., dim. & posn. of objects in dm
to end development/extension type 99 ')
126 WRITE (0,270)
127 270 FORMAT ('1,2A,*A10*,4A,*A10*,4A,*A10*,4X,*A10*,4X,*A10*,4X,*A10*,4X,
128 *A10*,5X,*A10*,5X,*A10*,5X,*A10*)
129 C WRITE(10)DESEL
130 C WRITE(10)GRAPH
131 280 CONTINUE
132 WRITE(150), (1,10)
133 A SELECT (CELLDN),10
134 IF (1.E0,99) GOTO 280
135 C WRITE(10)ALPHA
136 C WRITE(10)SELECT
137 CALL OPDLS ('CELDIN',10)
138 UN 200 I=1.99
139 IF (X(1.1(I)),EU,0,0,AND.XY1U(1),EU,0,0) WRITE 200
140 WRITE(190), (1,10)
141 EDG(1),Y(1,1,1)
142 190 FERAT(13,9F8.2)
143 C WRITE(10,10)DESEL
144 C WRITE(10,10)GRAPH
145 WRITE(190), (1,10)
146 EDG(1), (I,1,1)
147 200 CONTINUE
148 CALL CLEISC ('CELDIN',10)
149 C A PAUSE IS INTRODUCED FOR CHECKING
150 C TO CONTINUE TYPE 'G'
151 C CALL CLEISC ('CELDIN',10)
152 C CALL RFSAG
153 OU 300 I = 1.99
155 IF (X(1.1(I)),EQ.0,0,0,AND.Y(1.1(I)),EQ.0,0) GOTO 300
156 CALL PUX (A,XY1D(I),XV1U(I),ZLBD(I))
157 CALL SHIFT3(A,XY1D(I),XV1U(I),ZLBD(I))
158 CALL TURFDU (A,EDG(1),YT(1),XT(1),ZT(1))
159 IF (I.EQ.1) CALL COPY (B,CESPA)
160 IF (I.EQ.1) CALL DNAU (B,CESPA)
161 300 CONTINUE
162 CALL UMDII (CESPA)
163 CALL OUTD (CESPA,'CEVID')
164 GOTO 50
165 500 CONTINUE
166 RETURN
167 END
168 C...
169 C...
170 C...
171 C...
172 C...
173 C...
174 C...
175 C...
176 C...
177 C...
178 C...
179 C...
180 C...
```
CALL GHI13C(A,xLA,0,0,0,0,0,FLUAT,HLZ-1)*SPACE,SPACE,0,0)
CALL DRAVIT(A)
CALL GHI13C(A,xLA,0,0,0,0,0,FLUAT,HLZ-1)*SPACE,0,0,0,0,0,SPACE)
CALL DRAVIT(A)
RETURN
END

SUBROUTINE PRESENT
REAL ALPHA,0(198),CESPAC(10000)
REAL XMD(100),YMD(100),ZMD(100),XDIS(100),YDIS(100),ZDIS(100)
REAL DG(100),XT(100),Y(100)
INTEGER AC,
DATA SELECT,DESEL,ALPHA,GRAPHl
DATA SELECT/*40033/
DATA ALPHA/*30/
DATA GRAPH/*35/

C... FOR PUTAT(" LAYOUT...The present situation of development")
CALL DEVEL
CALL UPIUC("C5ID",10)
CALL DISTCUT("DISTIC")
CALL ROTAT="RULANT"
CALL ELEYTIF("ELEYTN")
CALL ZOUF="#I"("ZOUF")
CALL SUXUH="#IX"("LXY")
CALL NLY="#I"("NLY")
CALL NXL="#I"("NLE")
CALL SPACE="#I"("SPACE")
CALL UPIUC("C5ID",10)
CALL SHW(GLA,ALY,ELZ,SPACE)
CALL UPIUC("C5LIUN",10)
CONTINUE

MEAD(10,90,ENL=110),XMD(10),YMD(10),ZMD(10),XDIS(10),YDIS(10),ZDIS(10),
ZDSI(1),DGR(1),ZT(1),XT(1)
FURMAT(13,9FD,2)
CWRITE(60,0,10),(XMD(1),YMD(1),ZMD(1),XDIS(1),YDIS(1),ZDIS(1),DG(1),
ZT(1),XT(1))
GOTO 60
CONTINUE

CALL UPIUC("C5LIUN",10)
CALL SHW(GLA,ALY,ELZ,SPACE)
CALL UPIUC("C5LIUN",10)

DO 150 I=1,90
CALL UDA (A,XMD(1),YMD(1),ZMD(1))
CALL SHIFIT(A,XDIS(1),ZDIS(1))
CALL UBMD (A,DGR(1),ZT(1),XT(1),2,6)
IF (1.LE.1) CALL COPY (B,CESPAC)
IF (1.LE.1) CALL JUIN (B,CESPAC)
CONTINUE

CONTINUE

CALL UPIUC(CESPAC)
RETURN
END
241 C.....
241 C THIS IS "CIVES3.FOR PROGRAM"
241 C USING PRINTER (COMMANDS) AND "DIM" FUNCTIONS
17. COMMON/LCHS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
6FRAME
CHARACTER*12 FRAME(77)
DATA A,1,Z/231*999.0/
DATA XPOS,ZPOS/154*999.0/
DATA ANGLE/77*0.0/
CALL START
CALL $VUL
CALL OPDISC(VESDIL',1U)
EAC=DIU('FAC *)
FOKX=LLHC 'F0RX *)
FRAY=FHAY (FRAY *)
FRAY2=,$X (FRAY2 *)
DISTC=DINT ('DISTNC *)
ROTATN=DINT ('ROTATN *)
ELEVr=DINT ('ELEV N *)
NLY=DINT ('NLY *)
NLZ=DINT ('NLZ *)
SPACE=DINT ('SPACE *)
CALL CLUISC('KSVOLD',1O)
CALL FACTOR(FAC)
CALL FORMAT(FORX,FORY)
CALL FRAME(FRA1,FRA2,FRAY,FRAY2)
CALL PLSX(PICPLA)
CALL PEYE(0.0,0.0,0.0,DISTNC,ROTATN,ELEVIR)
CALL NECH(HLA,NLY,NLZ,SPACE)
CALL KCLOSE
CALL UPDISC('KSVOLD',10)
N=1
GOTO 5
5 HEAD(10,10,ESU=20)J(X(J),Y(J),Z(J),FRAME(J)(1:12)
10 FORMAT(15,3F6.2,A12)
47 N=1
50 GOTO 5
40 CALL CLUISC('KSVOLD',10)
43 N=1
50 GOTO 5
51 CALL PKST(N,S)
52 CALL JUSX(N-6,PICPLA,DISTNC)
53 CALL FINISH
54 STOP
55 END
C... SUBROUTINE $VUL
58 INTEGER ANS,N,S
59 COMMON/LCHS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
60 FRAME
1. OUTPUT OF CURRENT DATA FILE

2. WRITE(6,10)ALPHA

3. IF(AUX.EQ.'Y'.OR.ANS.EQ.'N')GOTO 150

4. IF(AUX,EQ.'Y'.OR.ANS.EQ.'N')GOTO 150

5. WRITE(6,70)

6. *WRITE(6,10)DESEL

7. *WRITE(6,20)

8. *WRITE(6,10)SELECT

9. *READ(5,40)ANS

10. *READ(5,40)ANS

11. *WRITE(6,70)

12. *WRITE(6,10)ALPHA

13. IF(AUX.EQ.'Y'.OR.ANS.EQ.'N')GOTO 150

14. IF(AUX.EQ.'Y'.OR.ANS.EQ.'N')GOTO 150

15. *WRITE(6,10)SELECT

16. *READ(5,40)ANS

17. *READ(5,40)ANS

18. CONTINUE

19. CONTINUE

20. WRITE(6,10)DESEL
SUBROUTINE RESH(NLX, NLY, NLZ, SPACE)

REAL NLX(1000)
CALL GRILDA(NLX, 0, 0, 0, 0, FLOAT(NLY-1)*SPACE, 0, SPACE, 0, 0)
CALL GRAHIT(A)
CALL GRILDA(NLX, 0, 0, 0, 0, FLOAT(NLZ-1)*SPACE, 0, SPACE, 0, 0)
CALL GRAHIT(A)
RETURN
END

C... THIS IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION

C... PRINTER THE PRESENT SITUATION OF LAYOUT DEVELOPMENT

C... Formats for existing situation of development

CALL HELL
CALL OPDISC('RESHIN',10)
NLX = DIM2(NLX)
NLY = DIM2(NLY)
NLZ = DIM2(NLZ)
SPACE = DIM2(SPAC)
CALL CLDISC('RESUII',10)
CALL RESH(NLX, NLY, NLZ, SPACE)
CALL UDPO(DS('Y xpos',11))
READ(10,50) XPOS(1), YPOS(1), ZPOS(1), ANGLE(1), FRAME(1)
FUNIT(15,10,2,2)
CALL BOX(0.,1.,0.,0.,0.,2.,k)
CALL TURN3D(ANGLE(1),0.0,0.0,0.0,2.,0)
CALL JOIN(K,0.)
CALL DRAW3D(0,1.0,XKURK,0.0,0.2,UKR,1)
20.

181 80 CONTINUE
182 70 CALL CLODISC("APUSU",11)
183 60 RETURN
184 50 END
185 40 C
186 30 C 'JOIST' SUBROUTINE IS FOR MANIPULATION OF ANY
187 20 C 'OBJECT' USING ORDER "N" (NOT VIA TAG NOS. !)
188 10 C
189 0 C...
190 30 C...
191 20 SUBROUTINE JOIST(R,N,P,FICPLA,DISTCC)
193 0 INTEGER N,P
194 30 COMMON/LCAS/AX(77),Y(77),ZPOS(77),ZPOS(77),ANGLE(77),
195 0 EXEC
196 30 INTEGER SELECT,DESEL,ALPHA,GRAPHI
197 0 CHARACTER*12 NAME(77)
198 30 DATA SHCM1"/100/33/
199 0 DATA NAME1"/60/13/
200 0 DATA ALPHT"/30/
201 0 DATA GRAPHT"/15/
202 0 C
203 0 C CHANGE OF LAYOUT IS CONSIDERED
204 90 WRITE(6,85)ALPHA
205 85 FORMAT(A2,6)
206 80 WRITE(6,86)SELECT
207 80 WRITE(6,96)
208 90 FORMAT(" Do you wish to envele the layout-YE or NO")
209 90 WRITE(6,97)
210 0 WRITE(6,5)GRAPHI
211 100 READ(110),ANG
212 100 FORMAT(I2)
213 100 IF(ALPHA.EQ."C",GRAND.EQ."R")goto 250
214 100 IF(ALPHA.EQ."Y",GRAND.EQ."R")goto 150
215 120 FORMAT(" Please enter your response again")
216 150 CONTINUE
217 160 CALL BELL
218 170 CALL PI11(3,0,-5.0,3)
219 170 WRITE(6,170)
220 0 FORMAT(" Which workstation?")
221 0 READ(5,*);
222 10 IF(NLX.EQ.0)goto 190
223 0 CALL NUX(P,X(K),Y(K),Z(K))
224 0 CALL SCRENC(CHR,K,X1,Y1)
225 0 CALL SCRENC(CHR,K2,X2,Y2)
226 0 CALL NEFAG
227 0 CALL BELL
228 0 CALL UPDISC("NEDIM",10)
229 0 NLT #10("NLX")
230 0 NLY #11("NLY")
231 0 NLZ #12("NLZ")
232 0 SPACE #11("SPACE")
233 0 CALL CLODISC("NEDIM",10)
234 0 CALL NEDIM(L1,L2,ULZ,SPACE)
235 0 ANGLE(R) = AIANG(Z=11,E2=21)180.0/3.14159265
236 0 APUS(R) = Y1*DISTC/PICPLA
237 0 ZPOS(R) = X1*DISTC/PICPLA
238 0 UD 180 R = 1,10
239 0 CALL NUX(P,10),Y(K),Z(K))
240 0 XWORK = APUS(R)
21.1

ZWORK = ZPOS(K)
242 IF(X=URK,9,999,0,AND,ZWORK,9,999,0))GOTO 180
243 CALL TURN3D(F,ANGLE(K),0,0,0,0,2,K)
244 CALL HEK3D(FNAME(K))((112),0,2,60,0,0)
245 CALL TRANSP(0,1)
246 CALL TURN3D(T,270,0,0,0,0,1,0)
247 CALL JUR3D(K,0)
248 CALL URANS(0,1,0,URK,0,0,ZWORK,1)
249 180 CONTINUE
250 GOTO 160
251 190 CONTINUE
252 CALL ODPISC("#SPUS",11)
253 DO 200 I = 1,H
254 IF(XPOS(I),9,999,0,AND,ZPOS(K),9,999,0))GOTO 200
255 WRITE(I10,210),XPOS(I),ZPOS(K),ANGLE(K),FNAME(K)
256 210 FORMAT(15,3F10,2,A12)
257 200 CONTINUE
258 CALL CCLTISC("#SPUS",11)
259 250 RETURN
260 END
261 C....
262 C....
263 C FILE UNDER "ITVAX940.FOR"
264 C
C PROGRAM INTERACTIVE LAYOUT (IYTSFILE)
C INCORPORATING WORK STATION DETAILS (WSFILE)
C READING FROM FILES "WSFILE"
C DETAILED WORK STATIONS ARE RECALLED VIA
C ORDER "WS" ONLY! (NOT VIA TAG NOS. !)
C
REAL X,Y,Z,P,XPOS,ZPOS,ANGLE
INTEGER NWS,NS
COMMON/LCAS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),*
FRAME
CHARACTER*12 FRAME(77)
DATA X,Y,Z/231*999.0/
DATA XPOS,ZPOS/154*999.0/
DATA ANGLE/77*0.0/
CALL START
CALL %SVOL
CALL %DISC('KESDIK',10)
FAC =DIN('FAC ')
FURY =DIN('FURY ')
FRAX1 =DIN('FRAX1 ')
FRAX2 =DIN('FRAX2 ')
FRAY1 =DIN('FRAY1 ')
FRAY2 =DIN('FRAY2 ')
PICPLA =DIN('PICPLA ')
DISTNC =DIN('DISTNC ')
ROTATN =DIN('ROTATN ')
ELEVTN =DIN('ELEVTN ')
ZOOM =DIN('ZOOM ')
NLX =DIN('NLX ')
NLY =DIN('NLY ')
NLZ =DIN('NLZ ')
SPACE =DIN('SPACE ')
CALL CLDISC('KESDIK',10)
CALL FACTOR(FAC)
CALL FORMAT(FAC,FURY)
CALL FRAMES(FRAX1,FRAX2,FRAY1,FRAY2)
CALL FRAME(PICPLA)
CALL PEYER(0,0,0,0,0.0,DISTNC,ROTATN,ELEVTN)
CALL MRESR(NLX,NLY,NLZ,SPACE)
CALL NCLOSE
CALL GPDISC('%SVOLU',10)
NWS=NWS+1
READ(10,10,END=20)J,X(J),Y(J),Z(J),PNAME(J)(1:12)
FORMAT(15,3F8.2,A12)
NWS=NWS+1
GOTO 5
CALL CLDISC('%SVOLU',10)
NWS=NWS+1
CALL PSRIT(NWS)
CALL JUSTR(HGS,PICPLA,DISTNC)
CALL FINISH
STOP
END
C SUBROUTINE WSFILE
INTEGER HGS,WS
COMMON/LCAS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),*
57 !FRAME
58 INTEGER SELECT, DESK,J, ALPH, GRAPH
59 CHARACTER(12) FRAME(77)
60 DATA SELECT/*4003*/
61 DATA DESK/*8043*/
62 DATA ALPH/*30*/
63 DATA GRAPH/*5*/
64 C
65 C OUTPUT OF CURRENT DATA FILE
66 C
67 WRITE(9,10) ALPH
68 10 FORMAT(*",A2,9*)
69 WRITE(10,10) SELECT
70 WRITE(6,20)
71 20 FORMAT(//' File of existing work Station Module volumes"//)
72 WRITE(4,35) ITEM,"ULM X","ULM Y","ULM Z","Tag No"
73 35 FORMAT(A5,1A8,67)
74 CALL UPDISC("6VOLD",10)
75 10 CONTINUE
76 READ(10,40,EN=50) J,X(J),Y(J),Z(J),FRAME(J)(1:12)
77 40 FORMAT(15,3F2,2,A12)
78 WRITE(6,50) J,X(J),Y(J),Z(J),FRAME(J)(1:12)
79 50 FORMAT(15,3F2,2,A12)
80 C PLEASE NOTE ABOVE WAS THE EXTRA SPACE "X" DELETED
81 GOTO 10
82 60 CONTINUE
83 CALL CLDISC("6VOLD",10)
84 60 WRITE(5,85) ANS
85 85 FORMAT(A2)
86 IF(ANS.EQ.0. 'Y'; ANS.EQ. "N")GOTO 150
87 IF(ANS.EQ. 'Y'; ANS.EQ. 'N')GOTO 100
88 90 ERROR MESSAGE
89 WRITE(4,90)
90 90 WRITE(6,90) SELECT
91 WRITE(6,90) GRAPH
92 90 READ(5,85) ANS
93 85 FORMAT(" Please enter your response again ! Use CAPITALS!")
94 95 GOTO 80
95 95 C ENTRY IS WRITTEN
96 100 C
97 100 WRITE(6,110)
98 110 FORMAT(" Please enter the file=YE or NO")
99 110 WRITE(6,110) SELECT
100 WRITE(6,110) GRAPH
101 110 WRITE(6,110) FRM1
102 110 C NEW ENTRY IS WRITTEN
103 C
104 C
105 C
106 120 FORMAT(" Please enter Item no., Dim of w.s. X,Y,Z, and TAG No")
107 120 C
108 C
109 C
110 130 Format(" Please enter Item no., Dim of w.s. X,Y,Z, and TAG No")
111 130 C
112 C OUTPUT LATEST DATA TO DISC AND TERMINAL
113 C
114 WRITE(6,10) ALPH
115 WRITE(6,10) SELECT
116 WRITE(6,20)
CALL UPDISC("*SVOLD",10)
CONTINUE
DO 140 J=1,10
120 IF (X(J),EQ.,999.0,AND,Y(J),EQ.,999.0) GOTO 140
121 WRITE(10,40)X(J),Y(J),Z(J),FRAME(J)
122 CONTINUE
123 140 CONTINUE
124 CALL CLD1SC("*SVOLD",10)
125 WRITE(10,10)DESEL
126 WRITE(10,10)GRAPHI
127 CONTINUE
128 RETURN
129 END

SUBROUTINE RESH(NLX,NLY,NLZ,SPACE)
REAL A(1000)
CALL GK1L3DCA(NLX,0.,0.,0.,0.,0.)
CALL DH1RIT(G)
CALL GK1L3D(A,NLY,0.,0.,0.,0.,0.,0.)
CALL DR1RIT(C)
CALL GK1L3D(A,NLZ,0.,0.,0.,0.,0.,0.)
CALL DHI1RIT(A)
RETURN
END

THIS IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION

SUBROUTINE PRESIT(NLX)
INTEGER NXS
COMMON/LCASX(X(77),Y(77),Z(77),XPUS(77),ZPOS(77),ANGLE(77),&}
&FRAME
INTEGER SELECT,DESEL,ALPHA,GRAPHI
CHARACTER*12 FRAME(77)
CHARACTER*12 NAME
DATA SELECT/-40033/
DATA DESEL/-40433/
DATA ALPHA/-30433/
DATA GRAPHI/-35/
PRINT(* THE PRESENT SITUATION OF LAYOUT DEVELOPMENT
WHITE (6,5)ALPHA
FURNAT("*",A2,9)
WHITE (0,5)SELECT
WRITE(10,10)
FURNAT("LAYOUT-the existing situation of development"/)
WHITE (6,5)DESEL
WHITE (6,5)GRAPHI
CALL HEL
CALL UPDISC("*RESID",10)
NLX =DIM("NLX")
NLY =DIM("NLY")
G26.

CALL CUDISC("MENOR",10)
CALL ME5H(NLX,RLY,NLZ,SPACE)
CALL OPD3SC('wSPUSD',ll)

READ(11,00,EHL = 70) J, XPUS(J), ZPUS(J), ANGLE(J), FNAME(J)

CALL HOX(P,X(J),Y(J),Z(J))
XWORK = XPUS(J)
ZWORK = ZPUS(J)
IF(XWORK.EQ.999.0.AND.ZWORK.EQ.999.0)GOTO 80

CALL TUR3D(T, 270.0,0.0,0.0,1.0)
CALL JUi"0

DETAIL SHAPE OF THE WORK STATION IS RETRIEVED FROM A DISK

call IL3I(V, ;SNAME)
call JUIN(U, V)
call DRAW3H(V, 1.0,X*ORK,0.0,Z*ORK,1)
CONTINUE

CALL CUDISC("wSPUSD",11)

INTEGER ADS, N*S

DATA SELECT/*40033/
DATA DESEL/MQ4 33/
DATA ALPHA/"3 Ü /
DATA GRAPH1/"n 35/
237  CALL FLIT(1,0,-5,0,3)
238  WRITE(6,170)
239  170  FORMAT(' which workstation?')
240  READ(5,*)M
241  IF(M.EQ.0) THEN
242    CALL HUX(P,X(M),T(X),Z(X))
243    CALL SCREEN(IC(X),X1,Y1)
244    CALL SCREEN(IC(X),X2,Y2)
245    CALL HEXPAL
246    CALL HLL
247    CALL OPUISC(\'HESDIN\',10)
248    NLX = IN\('NLX'
249    NLX = IN\('NLX'
250    NLZ = IN\('NLZ'
251    SPACE = IN\('SPACE'
252    CALL CLIPSC\(\'HESDIN\',10)
253    CALL HESIN(NLX,NLY,NLZ,SPACE)
254    ANGLE(M) = ATAN2(Y(M)-Y(M),X(M)-X(M))*100/3.14159265
255    XPUS(K) = Y(M)*MSTNY/PICPLA
256    ZPUS(K) = X(M)*MSTNY/PICPLA
257    DU 100 = 1.76
258    CALL HOAP(P,XK,YK,ZK)
259    ANU= XPUP(K)
260    ANU= ZPOS(K)
261    IF(XMUL(\',E0.999.0,AU,ZKORR,EU,999.0)GOTO 100
262    CALL TUNJEU(P,ANGLE(K),0.0,0.0,2,5)
263    WNAME=FRAME(K)
264    CALL NEKSH(FNAME(K)(1:12),E3.260.0,0.0)
265    CALL THANG(0,0)
266    CALL FUNKRU(T,270.0,0.0,0,0,1.0)
267    CALL NUN(0,0)
268    C DETAIL SHAPE OF THE WORKSTATION IS RETRIEVED
269    C FORCE = 0.05
270    C
271    C
272    CALL JND0(Y,\'*SHAPE')
273    CALL JD0(E,0)
274    CALL JN3D0(Y,1.0,XKORR,0.0,2*ANA,1)
275    180  CONTINUE
276    GOTO 160
277    190  CONTINUE
278    CALL OPUISC\(\'XPOSU\',10)
279    DU 200 = 1.76
280    IF(XMUL(\',E0.999.0,AU,ZPUS(K),EU,999.0)GOTO 200
281    WIK((11,210),K,XPOS(K),ZPUS(K),ANGLE(K),FNAME(K)(1:12)
282    210  FORMAT(15,3F10.2,A12)
283    200  CONTINUE
284    CALL CLIPSC\(\'XPOSU\',10)
285    250  RETURN
286    END
287    C...
288    C....
289    C FILE UNDER 'ITYASFILE'
"PÜSLASHb.FOR" PROGRAM IS AN INTERACTIVE PROGRAM
FOR AUTOMATIC POSITIONING OF A LINE OR A GROUP OF
WORK STATION WITHIN BUILDING (CIVIL ENG, SPACE)
INCLUDING COLLISION COURSE FINDING WITH
OBJECTS (WALLS, COLUMNS ETC) WITHIN BUILDING
AND FACILITY TO ENTER BUILT BUILT LAYOUT AT ANY WORK STATION
FOR KEY-LAYOUT VIA JOYSTICK AND AUTOMATIC

THE "M Peel" PROGRAM RESULTS (ON DR.C. SYSTEM) ARE INTRODUCED
AND "M.S. IN AN PRODUCTION LINE ORDER VIA "WSVTGIC"
DISC "EXITUR.DAT" ARE ENTERED

GENERAL: I AM SOLVING A TASK OF AUTOMATIC POSITIONING
OF GROUP OF AGN STATION (MAX. NUMBER OF W.S. IS 77)

PROGRAM INTERACTIVE LAYOUT (INTLAY)

INTEGER I,XAS, YAS, ZAS, XPUS, ZPUS, ANGLE, X(77), Y(77), Z(77),
CHARACTER*12 FRAME
CHARACTER*12 NAME
INTEGER SELECT, DESSEL, ALPHA, GRAPH

DATA X(77), Y(77), Z(77), XPUS(77), ZPUS(77), ANGLE(77),
FRAMES(77)

CALL START
CALL rSVUL
CALL QPDISCC
"MESD1K', 10)
FOR X = 1 TO 77
FOR Y = 1 TO 77
FOR X1 = 1 TO 77
FOR X2 = 1 TO 77
FOR A = 1 TO 77
FOR Z = 1 TO 77
FOR FRAMES = 1 TO 77
FOR GRAPH = 1 TO 77
CALL CLDISC('MESDIM', 10)

CALL FACTOF(FAC)
CALL FRAME(FRAX1, FRAX2, FRAY1, FRAY2)
3c\

61
62

CALL
CALL

PLAWE(P I C P L A )
P E * E ( 0 . 0 , 0.0 , 0 .0 , D I ST. M C , H U T A T N , E L E V T N )

63
64

CALL

f ' . E S H U.'LX , NLV , N L Z , S P A C E )

CALL

0PDI5C('"SV0LD',10)

b5

übS=l
R E A D ( 1 0 , 1 0 , E N U = 2 0 ) J , X ( J ) , V ( J ) , Z ( J ) , FH A ME ( J ) ( 1 : 1 2 )

66

5

67
68

10

FÜR**AT(I5,3F8.2,A12)
NwS=N'.iS* 1
GOTO 5

20

C A L L

73
74

40

KW5s:v.-.S-l
C A L L PRES1T
CnuiiNoE

7b
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77

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85

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100

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c

95

FOI<"l.*T(A2)
1 E ( * I ; S . E U . ' N U ' . Ü R . ANS.ED. * U * ) G ü T u

2900

K O R M AT ( ' P l e u s e e n t e r
<;RITE(6,50)DESEL
j*RiTE(o,5U)CRAPIII

2900
100

CALL
STOP
END

100

your

response

agalti

-

use

CAPI T A L S ' )

C A L L
POSIT(PICPLA,DISTNC)
C0NT1MIE
C A L L
NCLÜSE

99

F1Ü1SH

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P O S C O L 2 . EUR

PRUGKAf"

c...
SUbROUTINE
XfiTEGER

108

WSVUL

ANS,N*S

OJMML];i/LC*S/X(77),Y(77),Z(77),XPÜS(77),ZPO£(77),ANGLE(77),
*.ENAME( 7 7 )
ITJ'l EGER S E L E C T , D E S E L ,
ALPHA,GRAPH1

109
110
1 1 1
112

C H A R A C T E H M 2 FNArfE
DATA
SELECT/"40O33/

113
114

DATA
DATA

DESEL/"40433/
ALP![A/"30/

DATA

GRAPHI/-35/

115
117
118

c
c
c

OUTPUT

119
120

10

FORPAT(*+',A2,S)

116

layout...

GüTH 40
C U M ' I N DE

98

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106
107

continue/cnange the

.;KITE(6,50)SELECT
*HITK(o,9U)

91

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103
104

to

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90

101

*an t

I E ( A.VÜ . EO . " i E ' . OR , A''iS . E D . ' i ' ) G G T O
»RlTE(o,5Ü)ALPÜA

86
87
88

O

FORMAT (* Do y o u
i.m
o r n n ? ')
«HITKID,50)DESEL
wHlTE(o,50)GRAPHI
REAü(5,B5)Ai;S

85

96
97

rGRR.AT(*t',A2,S)
WRITE(6,5G)SELECT
t.ftITE(6,70)

82

89

(r)i*S)

ttRlTE(ti,50)ALPHA

81
83
84

CLD13CC'ÄSVULD',10)

OF

CURRENT

* RIT E ( b , 1 0 ) A L P H A

DATA

FILE


**FILE OF EXISTING WORK STATION MODULE VOLUMES**

```
WRITE(6,10)SELECT
WRITE(6,20) FORMAT (1x) 'FILE OF EXISTING WORK STATION MODULE VOLUMES')
CALL PDISC('SVULD',10)
```

```
WRITE(6,10)ALPHA
WRITE(6,10)SELECT
WRITE(6,10)DESEL
WRITE(6,10)GRAPHI
```

```
READ(10,40,X(J),Y(J),Z(J),FNAME(J)(1:12)
```

```
WRITE(6,10)ALPHA
WRITE(6,10)SELECT
WRITE(6,10)DESEL
WRITE(6,10)GRAPHI
```

```
CONTINUE
```

```
CONTINUE
```
C... SUBROUTINE MESH(NLX, NLY, NLZ, SPACE)
187 REAL (1000)
188 CALL GRID(UA, NLX, 0, 0, 0, FLOAT(NLY-1)*SPACE, 0, SPACE, 0, 0)
189 CALL DRAWIT(A)
190 CALL GRID(UA, NLY, 0, 0, 0, FLOAT(NLZ-1)*SPACE, 0, SPACE, 0, 0)
191 CALL DRAWIT(A)
192 CALL GRID(UA, NLZ, 0, 0, 0, FLOAT(NLY-1)*SPACE, 0, SPACE, 0, 0)
193 CALL DRAWIT(A)
194 CALL GRID(UA, NLY, 0, 0, 0, FLOAT(NLZ-1)*SPACE, 0, SPACE, 0, 0)
195 CALL DRAWIT(A)
196 CALL GRID(UA, NLZ, 0, 0, 0, FLOAT(NLY-1)*SPACE, 0, SPACE, 0, 0)
197 CALL DRAWIT(A)
198 CALL GRID(UA, NLY, 0, 0, 0, FLOAT(NLZ-1)*SPACE, 0, SPACE, 0, 0)
199 CALL DRAWIT(A)
200 CALL DRAWIT(A)
201 RETURN
202 END
203
204 C... SUBROUTINE MESHIT(NLS)
205 C THIS IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION
206 C
defines the present situation of development
207 C
defines the present situation of development
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defines the present situation of development
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defines the present situation of development
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defines the present situation of development
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defines the present situation of development
240 C
defines the present situation of development
CALL UPDISC("$SVTOK",12)
CALL UPDISC("$SPUSA",11)
CALL UPDISC("$SPUSA",11)
FORMAT(15,3F6.2,A12)
CALL TRANSJ(J,1)
CALL TURN3(J,1270,0,0,0,0,1,0)
CALL JOIN(J,1,0)
CALL TURN3(J,ANGLE(J),0,0,0,0,2,0)
CALL DHAW(R)
CALL D30D(J,1,0,WORK,0,0,2,WORK,1)
GOTO 40
CONTINUE
CALL CLDISC("$SPUSA",11)
CALL CLDISC("$SVTOK",12)
RETURN
END

SUBROUTINE POSIT(PICPLA,DIST*C)

THIS IS A SUBROUTINE FOR ENTIRE POSITIONING OF W.S.
INCLUDING SUBROUTINE JOY2 (FOR MANUAL POSITION OF ONE W.S.)
SUBROUTINE JOY2 (FOR EACH AT ANY SITUATION ARE FOR
GROUP TECHNOLOGY LAYOUT
AND SUBROUTINE PLACE (FOR AUTOMATIC PLACING OF SELECTED
GROUP/LINE OF WORK STATIONS INTO AN OPTIMAL PLACE)

REAL X , Z, XPOS,ZPOS,ANGLE,ASUM,ZSUM
REAL XS,ZS,AS
REAL JR
REAL w(7000),CESPACC10000)
LOGICAL ROUND
INTEGER i

C(A","LCF.S/A (77 ), Y C77 ), XPOS C77 ) ,ZPOS(77 ) ,ANGLE(77 ) ,
PARAM(77)
INTEGER SELECT,DESEL, ALPHA,GRAPH1
CHARACTER*12 NAME
CHARACTER*12 SUAME
DATA X,17,2/231*999.0/
DATA XPOS,ZPOS/154*999.0/
DATA ANGLE/77*0.0/
DATA SELECT/"40033/
DATA DESEL/"40033/
DATA ALPHA/"30/
DATA GRAPH1/"35/

CONTINUE
WRITE(6,10)ALPHA
FORMAT("*",A2,4)
301 WRITE(6,10)SELECT
302 WRITE(6,20)
303 FORMAT (" You are now in POSITIONING MODE ")
304 WRITE (6,22)
305 FORMAT (" Are you starting a new layout, from the first W. St. 
306 in technological order? /*YES or NO*/ 
307 WRITE(6,10)SELECT
308 WRITE(6,10)DESEL
309 WRITE(6,10)GRAPHI
310 42 CONTINUE
311 READ(5,43)ANS
312 FORMAT (42)
313 IF (ANS.EQ. 'NO',UR,ANS.EQ. 'Y') GOTO 7000
314 IF (ANS.EQ. 'Y',UR,ANS.EQ. 'N') GOTO 25
315 WRITE (6,44)
316 FORMAT (" Please enter your response again - use capitals")
317 GOTO 42
318 7000 CONTINUE
319 CALL JUSSI (KAS,PICA,DISCAL)
320 GOTO 7100
321 25 CONTINUE
322 C WRITING IN THE 'FIRST' WORK STATION ONLY
323 7 READ (12,30)J,X(J),Y(J),Z(J),FRAME(J)(1:12)
324 30 FORMAT (15,3F8,2,A12)
325 WRITE(6,10)ALPHA
326 WRITE(6,10)SELECT
327 WRITE (6,10)GRAPHI
328 50 FORMAT (" Do you wish to position the considered work 
329 Station manually ... YE or NO?/* 
330 WRITE(6,10)DESEL
331 WRITE(6,10)GRAPHI
332 100 READ(5,110)ANS
333 110 FORMAT(42)
334 IF (ANS.EQ. 'NO',OR,ANS.EQ. 'N') GOTO 405
335 IF (ANS.EQ. 'Y',OR,ANS.EQ. 'Y') GOTO 150
336 WRITE (6,10)ALPHA
337 WRITE(6,10)SELECT
338 WRITE (6,120)
339 120 FORMAT (" Please enter your response again")
340 WRITE (6,10)DESEL
341 WRITE(6,10)GRAPHI
342 GOTO 100
343 100 C IF YOU SELECT 'NO' YOU ARE GOING DIRECTLY INTO 
344 C THE AUTOMATIC POSITIONING PROGRAM -SUBROUTINE "PLACE"
361 150 CONTINUE
362 160 CALL PDEL
363 #11E (6,200)
364 200 FORMAT (* Use joystick for corrective action*)
365 C
366 C BUILDING IS CALLED IN
367 C
368 CALL IE3D (CESPAC,'CIVIL')
369 CALL GRAINIT (CESPAC)
370 C CALL JOY2 (J,PICPLA,DISTC,G,A5,ZS,AS)
371 C
372 C
373 405 CONTINUE
374 WRITE(J, 10)ALPHA
375 WRITE(J, 10)SELECT
376 WRITE(J, 350)DICR
377 410 FORMAT ('Do you wish to continue developing the layout...'
378 IN AUTOMATIC MODEﺴ Way or NU?')
379 WRITE(J, 340)DICR
380 WRITE(6,10)GRAPH
381 420 READ(5,430)ARS
382 430 FORMAT(A2)
383 IF(ANS.EQ."NU",0,ANS.EQ."Y")GOTO 700
384 IF(ANS.EQ."YE",0,ANS.EQ."Y")GOTO 450
385 WRITE(J,10)ALPHA
386 WRITE(J,10)SELECT
387 WRITE(J,350)DICR
388 440 FORMAT("Please enter your response again")
389 WRITE(6,10)DELETE
390 WRITE(6,10)GRAPH
391 WRITE(6,10)GRAPH
392 450 CONTINUE
393 C
394 C CONTINUES IN AUTOMATIC MODE
395 C
396 C
397 C PROGRAM IS GOING TO SUMUP DIRECTLY
398 C
399 400 ATUG(J) = AS
400 401 ATUG(J) = ZS
402 ANGLE(J) = AS
403 GOTO 500
404 7100 CONTINUE
405 CALL UPDISC ("SVTUR",12)
406 406 C CALL NEAPAC
407 C
408 C THE NEXT (CURRENT) W.S., AFTER THE SELECTED W.S.
409 C (IF WORK STATIONS ARE POSITIONED)
410 C TO START AUTOMATIC POSITIONING SYSTEM,
412 C IS RETRIEVED
413 C
414 7110 CONTINUE
415 READ (12,10)J,A(J),I(J),Z(J),FRAME(J)(1:12)
416 IF (J,EQ.L) GOTO 7110
417 IF (J,EQ.L) GOTO 7120
418 7120 CONTINUE
419 XS = ATUG(J)
420 ZS = ZTUG(J)
421 480  AS = ANGLE(J)
422 481  CONTINUE
423 482  CALL 1030 (CESPAC,"CIVIL"")
424 483  CALL DRAWIT (CESPAC)
425 484  C 485  BECAUSE THE NEXT ROUND IS ADDING TO "K" ZS=SUMZ
426 486  C
427 487  500  CALL SUMUPZ (J,ASUM,ZSUH,XS,ZS,AS)
428 488  WRITE(6,10)ALPHA
429 489  WRITE(6,520)
430 490  520  FORMAT (" TOTAL VALUE OF -Z- DIMENSION IS")
431 491  540  FORMAT (F10.2)
432 492  WRITE(6,540) ZSUH
433 493  WRITE(6,10)GRAPH1
434 494  C 495  A NEW (EXIT) K,S, IS CONSIDERED
436 496  555  CALL COLLCAS (T,CESPAC,RESULT)
437 497  566  WRITE (12,36,READ=700)X(K),Z(K),F(K),(1:12)
438 498  CALL PLACE(K,ASUM,ZSUH,AS,1)
439 499  567  WRITE (6,10)SELECT
440 500  577  IF (RESULT.EQ.2) THEN
441 501  587  IF (RESULT.EQ.3) THEN
442 502  GOTO 5500
443 503  ELSE
444 504  GOTO 4000
445 505  END IF
446 506  CALL FIELD (T,CEUSPC,RESULT)
447 507  WRITE (10,DESEL)
448 508  WRITE (10)GRAPH1
481\ Clipboard
482 \ WHITE(6,4200)
483 \ 4200 FORMAT ("Do you wish to see the scene of the clash")
484 \ 4250 READ (5,4300)A NS
485 \ 4300 FORMAT (A2)
486 IF (ANS.EQ.,"NO",OR.ANS.EQ.,"N") GOTO 6100
487 IF (ANS.EQ.,"YES",OR.ANS.EQ.,"Y") GOTO 6000
488 \ 4400 FORMAT ("Please enter your response again - use capitals")
489 \ GOTO 4250
490
491
492 \ 5000 CONTINUE
493 \ WHITE (6,5200)
494 \ 5200 FORMAT ("Touch !")
495 \ 5500 CONTINUE
496 \ CALL DRAWIT (T)
497 \ CALL DRAWIT (CESPAC)
498 \ WRITE (6,10)ALPHA
499 \ WRITE (6,10)SELECT
500 \ WRITE (6,3100)
501 \ 3100 FORMAT ("Layout Acceptable")
502 \ WRITE (6,10)SELSEL
503 \ WRITE (6,10)GRAPHI
504 \ CALL NEPAG
505 \ CALL OHPITT (CESPAC)
506 \ CONTINUE
507 \ THE CLASHING WORK STATION WILL BE REPOSITIONED
508 \ J = K
509 \ ANUS(K) = ASUS
510 \ ZMUS(K) = ZSUM
511 \ ANGLE(K) = AS
512 \ 5400 CONTINUE
513 \ 5400 FORMAT (A)
514 \ CALL REPAC
515 \ CALL DRAWIT (CESPAC)
516 \ CALL DRAWIT (T)
517 \ WHITE (6,10)GRAPHI
518 \ WRITE (6,10)GRAPHI
519 \ WRITE (6,10)SELECT
520 \ WRITE (6,10)ALPHA
521 \ WRITE (6,10)SELECT
522 \ WRITE (6,6120)
523 \ 6120 FORMAT ("Do you wish to re-position the clashing W.S. only/"
524 \ "...YES,NO...it is up to you can reposition any no.of W.S."
525 \ WRITE (6,10)SELSEL
526 \ WRITE (6,10)GRAPHI
527 \ WRITE (6,10)GRAPHI
528 \ WRITE (6,10)ALPHA
529 \ WRITE (6,10)SELECT
530 \ WRITE (6,6120)
531 \ 6120 FORMAT ("Do you wish to re-position the clashing W.S. only/"
532 \ "...YES,NO...it is up to you can reposition any no.of W.S."
533 \ WRITE (6,10)SELSEL
534 \ WRITE (6,10)GRAPHI
535 \ 6120 CONTINUE
536 \ THE CLASHING WORK STATION WILL BE REPOSITIONED
537 \ J = K
538
539
540
38.
541 6500 GOTO 150
543 700 CONTINUE
544 C
545 C  POSITION OF THE LAST WORK STATION IS RECALLED
546 C
547 CALL UPDISC ("SPOSA",11)
548 UO 3300 L = 1.42
549 IF (XPOS(L),L,999.0,AUX,ZFUS(L),EG,999.0) GOTO 3300
550 WRITE (11,3200) L,XPOS(L),ZFUS(L),ANGLE(L),FRAME(L)(1:12)
552 3200 FORMAT (15,3F8.2,A12)
553 C
554 3300 CONTINUE
555 CALL CLDISC ("SPOSA",11)
556 CALL CLDISC ("HYSTUR",12)
557 C
558 C FOR A NEXT FINAL PRESENTATION THE LAYOUT IS REDRAWN
559 C WITH DETAILS OF WORK STATIONS RETRIEVED
560 C
561 CALL WEIPAC
562 CALL PRESET (N8)
563 C
564 C
565 C FINAL DECISION IS MADE REGARDING CONTINUATION
566 C OR STOPPING THE PROGRAM
567 C
569 C WRITE (6,10)ALPHA
570 C WRITE (6,10)SELECT
571 C
572 3320 FORMAT (" Do you wish to recheck the layout?...YES,NO...")
573 C " If NO is typed, the session is over")
574 WRITE (6,10)DESEL
575 WRITE (6,10)GRAPHI
576 3360 READ (5,3330)ANG
577 3330 FORMAT (A2)
578 IF (ANG.EQ."NO",OK,ANG.EQ."YES") GOTO 3400
579 IF (ANG.EQ."YES",OK,ANG.EQ."NO") GOTO 15
580 WRITE (6,3340)
581 WRITE (6,10)ALPHA
582 WRITE (6,10)SELECT
583 3340 FORMAT (" Please enter your response again - use capitals")
584 WRITE (6,10)DESEL
585 WRITE (6,10)GRAPHI
586 GOTO 3300
587 C
588 3400 CONTINUE
589 C
590 RETURN
591 C
592 C...
593 C SUBROUTINE JOY2 (J,PICPLA,DISINC,K,XS,ZS,AS)
594 C
595 C SUBROUTINE "JOY2" IS A MODIFIED SUBROUTINE JOYS
596 C WHICH WILL ALLOW TO POSITION ONLY ONE WORK STATION
597 C IN TIME.
598 C
599 C THIS IS BECAUSE OF THE 'ZPOS' DIMENSION WHICH HAS
600 C TO BE SUMMED.
C 601 C
C 602 C
REAL X,Y,Z,POS,ZPOS,ANGLE
605 REAL CESPAC(10000)
606 INTEGER RVS,ANS
607 COMMON/LEXS/A(77),I(77),Z(77),APS(77),ZPOS(77),ANGLE(77),
608 IFNAME(77)
609 INTEGER SELECT,DESEL, ALPHA,GRAPH
610 CHARACTER*17 FRAME
611 CHARACTER*12 FRAME
612 DATA X,1,2/231*999.0/
613 DATA APS,0PS/154*999.0/
614 DATA ANGLE/77*0.0/
615 DATA SELECT/*90033/
616 DATA DESEL/*0433/
617 DATA ALPHA/*30/
618 DATA GRAPH/*35/
619 C
620 WRITE(6,10)ALPHA
621 10 FORMAT(12,32,5)
622 WRITE(6,10)SELECT
623 WRITE(6,50)
624 50 FORMAT(' You are now in the Manual ..to.. Auto Mode')
625 C
626 70 CONTINUE
627 C CHANGE OF LAYOUT IS CONSIDERED
628 WRITE(6,90)
629 90 FORMAT(' Do you wish to re-POSITION the work Station...IE or NO')
630 WRITE(6,100)DESEL
631 WRITE(6,10)GRAPH
632 100 READ(5,110)ANS
633 110 FORMAT(12)
634 IF(ANS.EQ.'NO',OR,ANS.EQ.'NA')GOTO 250
635 IF(ANS.EQ.'IE',OR,ANS.EQ.'IA')GOTO 150
636 WRITE(6,10)ALPHA
637 WRITE(6,10)SELECT
638 WRITE(6,120)
639 120 FORMAT(' Please enter your response again')
640 WRITE(6,100)DESEL
641 WRITE(6,10)GRAPH
642 GOTO 70
643 C
644 150 CONTINUE
645 153 CONTINUE
646 155 CONTINUE
647 WRITE(6,10)ALPHA
648 WRITE(6,10)SELECT
649 155 FORMAT(' Please POSITION the w.S. by cross-hairs...')
650 WRITE(6,100)DESEL
651 WRITE(6,10)GRAPH
652 C
653 1ST movement POSIT the right bottom corner..press spacer.. 
654 2ND movement POSIT/turns the w.S. around this corner...
655 C
656 press spacer.
657 C
658 160 CALL BELL
659 C
660 C
FIRST WORK STATION VOLUME IS READ AUTOMATICALLY VIA SUBROUTINE "POSIT" (AREA TABLE 25-30)...

ANGLE(J) UN IS TO HAVE FIRST V.S. OF A GROUP OF MACHINES READY FOR AUTOMATIC READING.

CALL AXIL(P,X(J),Y(J),Z(J))
CALL SCRE(ICHAR,X1,T1)
CALL SCRE(ICHAR,X2,12)
CALL RERAPC
CALL BEIL
CALL UPUGS("RESUM",10)
NLX = D1N("NLX ")
NLY = D1N("NLY ")
SPACE = D1N("SPACE ")
CALL CULISC("RESDM",10)
CALL RESMIL(NLY,4LY,SPACE)
CALL (1.31) (CESPAC,"CIVIL")
CALL UMAK (CESPAC)
AS = ATAN2(Y2-Y1.X2-X1)*180.0/3.14159265
XS = Y1*DISTNC/PICPLA
ZS = X1*DISTNC/PICPLA
CALL NUX(P,X(J),Y(J),Z(J))
CALL AXIL(P,X(J),Y(J),Z(J))
CALL HERSHT:(A-E(J),Cl:i2),b,2,2,60.0,1)
CALL TPANSP(U,T)
CALL T0R3D(T,270.0,0.0,0.0,1,G)
CALL JUR3 (G)
"SNAf-lE = FNAME(J)
CALL IN3D (V ,*SNAHE)
CALL JUJ (G ,)
CALL fURf*3D(V,AS,0.0,0,0,2,R)
CALL SHIFT3(R,XS,0.0,ZS)
CALL DRAHT (R)
CALL UKAV3D(V,1.0,XS,O.C,Z5,1)

WRITE(6,200) XPUS(M = XS
ZPOS(N) = ZS
ANGLE(D) = AS
COHTE
WRITE (6,200) FORMAT ("* Is the PUSITION of V.S. according to your wish...
WRITE(6,10)DESEL
WRITE(6,10)GRAPHI
GOTO 210 FORHATC Please enter your response again")
WRITE(6,10)DESEL
WHITE(6,10)SELECT
WRITE (6,10)DESEL
WRITE(6,10)GRAPHI
GOTO 210
AI.

721 C POSITION OF THE WORK STATION POSITIONED VIA JOYSTICK
722 C IS RECORDED/FILED IN "SPUSA",11
723 C
724 C CALL UPDISC("SPUSA",11)
725 C
726 C IF(apos(1,10,999,0),apos(1,10,999,0)) DOUT 291
727 C WRITE(10,270)apos(1,10,2,12)
728 C CONTINUE
729 C
730 C CALL CLODISC("SPUSA",11)
731 C
732 C RETURN
733 C
734 C
735 C
736 C
737 C
738 C
739 C
740 C
741 C
742 C
743 C
744 C
745 C
746 C
747 C
748 C
749 C
750 C
751 C
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721 C
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767 C
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769 C
770 C
771 C
772 C
773 C
774 C
775 C
776 C
777 C
778 C
779 C
780 C

...
BECAUSE GE TURNING DURING T]RE POSTITN THE ANGLE IS CHANGING AND THIS IS CHANGING THE ACTUAL DISTANCE OF THE NEXT STATION

\[ D = \frac{d}{\cos \theta} \]

INSTEAD OF THE ORGINAL \( Z_{POS}J \) \( Z_{POS}J \) IS TAKEN

\[ F = \frac{d}{\cos \theta} \]

SUM OF \( Z \) DIMENSION

\[ \sum Z = Z_0 + F \]

\[ A = \sum A \]

RETURN

SUM THE PLACE \( x,xsum,zsum,as,t \)

(PLACING A NEW N.S. IN THE DIRECTION "Z")

THIS SUBROUTINE IS ACTUALLY PLACING A WORK STATION INTO AN OPTIMUM POSITION RELATED TO OTHER SPACES (e.g., VOLUMES, CIVIL ENG SPACE AND K.H. SPACE), NO INTERVENTION OF THE USER IS NECESSARY.

REAL \( A, Z, ZPOS, ZPOS \)

REAL XSUM, ZSUM, AS

INTEGER \( x, z, xPOS, zPOS, ZPOS, ZPOS, ZPOS, ZPOS, ZPOS \)

COMMON/LCLS/ (77), (77), (77), (77), (77), (77), (77)

FRAME(77)

INTEGER SELECT, DESEL, ALPHA, GRAPHI

CHARACTER*12 FNAME

CALL HEL

WRITE(6,10)ALPHA

FORMAT(*",A2,S1)

WRITE(6,10)SELECT

WRITE(*,20)

FORMAT(*, F20.10) SELECT

WRITE(*,20) DESEL

WRITE(*,20) GRAPHI
AFTER THE SUM UP THE NEXT PLACES THE WORK STATION

VOLUME IN AN OPTIMUM POSITION WITH A NEW "Z" DIMENSION

BUT THERE ARE NO CHANGES IN "X" DIMENSION YET

CALL DELL
CALL UDISC("RESDIM"),10)

ALX = DIM("ALX")

ALZ = DIM("ALZ")

SPACE = DIM("SPACE")

CALL CLDISC("RESDIM"),10)

CALL MESUR(xm,yl,ol,2k,3k)

CALL UDIM((1)

RETURN

END

SUBROUTINE SIGNAL

CONTINUE

*RITE (6,40)

FORMAT (" DIAGNOSTIC 1")

CONTINUE

RETURN

END

SUBROUTINE FOR COLLISION OF THE LAST WORK STATION AND THE BUILDING (CIVIL ENG. SPACE)

SUBROUTINE COLLOC (WS1,CESPAC,RESULT)

REAL X(1300)

REAL CESPAC(10000)

INTEGER RESULT,AREA

COMMON /UCS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),

CHARACTER*12 FRAME

CHARACTER*12 *NAME

INTEGER SELECT,GESEL,ALPHA,GRAPH
DATA ALPHA/*30/
DATA GRAPHIC/*15/
C FIRST CALL IN CIVIL ENG. SPACE
CALL INSPAC (CESPAC,'CIVILD')
C
C FOLLOW'S SUBROUTINE FOR CHECKING RESULT
C OF COLLISION
C
WRITE (4,10) ALPHA
FORMAT (*4,32,1)
WRITE (4,10) SELECT
WRITE (4,10)
FORMAT (*1 = INSIDE/* 2 = TOUCH (O.K.)/* 3 = OUTSIDE")
WRITE (6,10) DESEL
WRITE (6,10) GRAPHIC
CALL INSPAC (-SI,CESPAC,RESULT)
WRITE (6,100) RESULT
FORMAT (16)
IF (RESULT.EQ.0) RETURN
100 CONTINUE
RETURN
C
C "INSPAC" IS CONTROLLING THE PROCESS IN
C THE COLLISION FINDING
C
SUBROUTINE INSPAC (WSI,CESPAC,RESULT)
REAL (ES),CESPAC(1), OBJECT(100)
C WS1 = WORK STATION WHICH IS (AS A LAST ONE) POSITIONED
C IN THE BAY (CIVIL ENG. SPACE)
C CESPAC = BUILDING (CIVIL ENG. SPACE)
C OBJECT = IS ANY CIVIL ENG. ELEMENT OF WHICH THE BUILDING
C CONSISTS
C
INTEGER RESULT, AREA
C NUM =CAS/X(77),1(77),2(77),APIS(77),ZPOS(77),ANGLE(77),
C RH LOCK IS GIVEN BY A NUMBER OF PICASSO CONTOURS
C AND IS ACTUALLY GIVING (BY ANALYSIS) A NUMBER
C OF OBJECTS OF WHICH THE BUILDING CONSISTS
C AND IS LIMITING THE NUMBER OF LOOPS
C
C IF BLOCK = CESPAC(2)/6,0
C CALL ABO (CESPAC, WS, OBJECT)
C CALL COLISH (WSI, OBJECT, RESULT, AREA)
C WRITE (6,90) RESULT
C FORMAT (16)
C IF (RESULT.EQ.1) RETURN
C CONTINUE
C RETURN
C
END
C
C
C
"AHAD" IS KEH'IKEEAT FURH CIVIL ENGINEERING
DRAIN HGNUEDE CIVIL ENGINEERING SPACES (ELEMENTS)
THE "NFTH, RTH) IN TIME
SUBROUTINE ABCE (CESPAC, NTH, OBJECT)
REAL CESPAC(100), OBJECT(100)
INTEGER FORM, TO
COMMON/LCWS/X(77), Y(77), Z(77), XPUS(77), ZPOS(77), ANGLE(77),
*FRAME(77)
IF (NTH.LT.1) THEN
GOTO 200
ELSE IF (NTH.GT.100) THEN
GOTO 250
ELSE
GOTO 270
ENDIF
CONTINUE
WRITE (6,310)
FORMAT("DIAGNOSTIC = +HUNG READING 1")
WRITE (6,320)
FORMAT("DIAGNOSTIC = TOO BIG -ERROR 2")
REAL CURS(1), OBJECT(100)
INTEGER RESULT, AREA
COMMON/LCWS/X(77), Y(77), Z(77), XPUS(77), ZPOS(77), ANGLE(77),
*FRAME(77)
INTEGER SELECT, USEL, ALPHA, GRAPH!
DATA SELECT/40033/
DATA USEL/10 133/
DATA ALPHA/30/
DATA GRAPH/35/
WRITE (6,10) ALPHA
FORMAT("",A2,S)
WRITE (6,10) SELECT
CALL 3D (WE1, XMIN1, XMAX1, YM1N1, YM1N1, ZMIN1, ZMAX1)
CALL NULLJp (OBJECT, XMIN2, XMAX2, YM1N2, YM1N2, ZMIN2, ZMAX2)
RESULT = 3
WRITE (6,30) RESULT
FORMAT (18)
AREA = 1

C HORIZONTAL PLANE IN AREA "X" IS TESTED (AREA=1)
C
IF (XMIN2.EQ.XMAX1,LK) RETURN
GOTO 100
C CONDITION OUTSIDE ... 3 IS CONSIDERED
IF (XMIN2.LE.XMIN1,GR,XMIN2,GT,XMIN1) RETURN
GOTO 150
C
RESULT = 1
WRITE (6,31) RESULT
FORMAT (18)
RETURN
RESULT = 2
WRITE (6,32) RESULT
FORMAT (18)
RETURN
C
END OF PROGRAM "COLLCS1.FOR"

REAL V(2000), CSPAC(10000)
INTEGER INT, I
DATA SELECT/*40033/
DATA USEL/*40033/
DATA ALPHA/*30/
DATA GRAPHI/*35/
CALL DELL
CALL PL1T(3.0,-5.0,3)
WRITE (6,70) ALPHA
FORMAT('+',A2,S)
1001 WRITE(6,70)SELECT
1002 *KITE(6,80)
1003 80 FORMAT(" Which work station... to start from? Type tag no.../
1004 &" to end ... type "END"")
1005 WRITE(6,70)DESEL
1006 WRITE(6,70)GRAPHI
1007 CONTINUE
1008 90 CONTINUE
1009 READ (5,110) `NAME
1010 110 FORMAT (A12)
1011 WRITE (6,110) `NAME
1012 110 FORMAT (A,110) `NAME
1013 IF (`NAME(113),EQ,"END") GOTO 190
1014 DO 120 J = 1,76
1015 IF (`NAME(12),EQ,FNAME(J)(1:12)) GOTO 140
1016 CONTINUE
1017 120 CONTINUE
1018 WRITE (6,130)
1019 130 FORMAT (" Please enter your TAG NO exactly again")
1020 GOTO 90
1021 C
1022 C
1023 140 CALL DOX(P,X(J),Y(J),Z(J))
1024 CALL SCREEN(LCHAR,X1,Y1)
1025 CALL SCREEN(LCHAR,X2,Y2)
1026 CALL HEAVAC
1027 CALL DELL
1028 CALL 'DULSC("MESD1",10)
1029 NLX = INT("NLX ")
1030 NLY = INT("NLX ")
1031 NLZ = INT("NLZ ")
1032 SPACE = INT("SPACE ")
1033 CALL CULISC("MESD1",10)
1034 CALL HEAVAC(NLX,NLY,NLZ,SPACE)
1035 CALL HEAVAC
1036 CALL DELL
1037 CALL 'DULSC("MESD1",10)
1038 ANGLE(J) = ATAN2(Y2-Y1,X2-X1)*180.0/3.14159265
1039 XPOS(J) = Y1*DIST1/10
1040 ZPOS(J) = X1*DIST1/10
1041 DO 180 A = 1,76
1042 CALL DOX(P,X(A),Y(A),Z(A))
1043 XWORK = XPOS(M)
1044 ZWORK = ZPOS(M)
1045 IF(XWORK.EQ.999.0.AND.ZWORK.EQ.999.0)GOTO 180
1046 CALL HEAVAC(FNAME(M)(1:12),6,2,60,0,0)
1047 CALL TRANSF(G,T)
1048 CALL TURN3D(T,270.0,0.0,0.0,1,0)
1049 CALL JOIN(U,V)
1050 CALL JOIN(U,V)
1051 CALL TURN3D(V,ANGLE(R),0.0,0.0,2,H)
1052 CALL SHIFTJ (R, XWORK,0.0,ZWORK)
1053 CALL DRAWIT (R)
1054 CALL TURN3D(U,1.0,XWORK,0.0,ZWORK,1)
1055 180 CONTINUE
1056 GOTO 60
1057 190 CONTINUE
CALL OPDISC("#SPOSA",11)
BEGIN = 1.76
WRITE(10,210)*XPOS(M),ZPOS(M),ZPOS(M),ANGLE(M),FRAME(M)(1112)
FORMAT(15,3F10,2,A12)
CONTINUE
CALL CLDISC("#SPOSA",11)
RETURN
END

SUBROUTINE PRESIDENT (LAS)
THLL IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION
WITH DETAILED WORK STATIONS DRAWN
REAL CESPACE(10000),V(2000)
INTEGER NLS,NLY,NLZ,SPACE
DATA SELECT/"10033/
DATA RES/"40433/
DATA ALPH/"30/7
DATA GRAPH/"15/
PRINTING THE PRESENT SITUATION OF LAYOUT DEVELPMENT
PRINT(c:")
WRITE(6,10)ALPHA
WRITE(6,10)SELECT
WRITE(6,20) FORMAT(20)
WRITE(6,10)DES
WRITE(6,10)GRAPH
CALL BELL
CALL UPDISC("LESID",10)
NLS = 1X("NLX ")
NLY = 1X("NLY ")
NLZ = DKN("NLZ ")
SPACE = DKN("SPACE ")
CALL CLDISC("RESGK",10)
CALL #ESA(LX,NLY,NLZ,SPACE)
CALL #ESA(LX,NLY,NLZ,SPACE)
CALL #ESA(LX,NLY,NLZ,SPACE)
BUILDING IS CALLED IN
CALL INJU (CESPACE,"CIVILL")
CALL DRAW (CESPACE)
CALL UPDISC("*SYUK",12)
READ(12,60,END=50,J(J),Y(J),Z(J),FRAME(J)(1112)
CALL OPDISC("#SPOSA",11)
READ(11,80,END=90),XPOS(J),ZPOS(J),ANGLE(J),FRAME(J)(1112)
FORMAT(15,3F8,2,A12)
CALL DUAX(P,A(J),Y(J),Z(J)
WRITE = XPOS(J)
DRAW = ZPOS(J)
CALL TUMHJAP(ANGLE(J),0,0,0,0,2,R)
CALL HERSH(FRAME(J)(1112)),X,2,60,0,0)
CALL TRANS(0,1)
CALL TURU3D(T,279,0,0,0,0,0,1,0)
CALL JOIN(R,U)
WNAME = FNAME(J)
CALL TUR3D(V,WNAME)
CALL JOIN(U,V)
CALL SHAFT3(V,XWORK,0,0,ZWORK)
CALL DRAT3(V)
CALL DRA3D(U,1,XWORK,0,0,ZWORK,1)
CONTINUE
CALL CLOSE("GPOSA",11)
CALL CLOSE("ASVIT",12)
RETURN
END
C....
C....
C....
C FILE ORDER "PUSHASH.PRT"
DISPLAY.FOR

1 C  THIS IS A PROGRAM FOR DISPLAY OF WHOLE DESIGNS.
2 C  SCHEME TO ENABLE THE USER TO OBSERVE THE LAYOUT
3 C  FROM ANY REQUESTED POSITION.
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"DISPLAY.FOR"

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1 C THIS IS A PROGRAM FOR DISPLAY OF WHOLE DESIGNS.
2 C SCHEME TO ENABLE THE USER TO OBSERVE THE LAYOUT
3 C FROM ANY REQUESTED POSITION.
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"DISPLAY.FOR"

C

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2 C SCHEME TO ENABLE THE USER TO OBSERVE THE LAYOUT
3 C FROM ANY REQUESTED POSITION.
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"DISPLAY.FOR"

C

1 C THIS IS A PROGRAM FOR DISPLAY OF WHOLE DESIGNS.
2 C SCHEME TO ENABLE THE USER TO OBSERVE THE LAYOUT
3 C FROM ANY REQUESTED POSITION.
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"DISPLAY.FOR"

C

1 C THIS IS A PROGRAM FOR DISPLAY OF WHOLE DESIGNS.
2 C SCHEME TO ENABLE THE USER TO OBSERVE THE LAYOUT
3 C FROM ANY REQUESTED POSITION.
SUBROUTINE PRESENT (*560*)

 THIS IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION.

 REAL P(500), R(5000), U(2000), V(5000)
 INTEGER I*8
 COMMON/LCS/A(77), Y(J77), 2(J77), XPOS(J77), ZPOS(J77), ANGLE(J77),
 FRAME(J77)

 INTEGER SELECT, RESID, ALPHA, GRAPH
 CHARACTER*12 NAME

 DATA SELECT/'A0433/
 DATA RESID/*30/
 DATA GRAPH/*39/

 PRINTING THE PRESENT SITUATION OF LAYOUT DEVELOPMENT

 FORAT('+', A2, S1)
 WRITE(6,10) SELECT
 WRITE(6,20) NAME
 WRITE(6,14) GRAPH
 CALL BELL
 CALL UPDISC('ENT', 10)
 CALL DIS('A0433')
 CALL RES('30')
 CALL GRAPH('39')
 CALL LAYOUT('A0433', 100)
 CALL RES('30')
 CALL GRAPH('39')

 BUILDING IS CALLED.

 CALL LAYOUT ('CIVIL*')
 CALL REV('CIVIL*')

 CALL UPODISC('SVIUM', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
 CALL REV(J)
 CALL DIS('3F8, 3A12')
 CALL UPODISC('CIVIL*', 12)
 READ(11, 60, END=90) J, XPOS(J), YPOS(J), ANGLE(J)
CALL CLULSC("ASPUSA",11)
CALL CLULSC("ASVTOR",12)

RETURN
END

C
C...

SUBROUTINE RESH(ULL,MLY,MLZ,SPACE)
PEAL A(1000)
CALL GRIL30A,MLY,0,0,0,FLOAT(MLY=1)*SPACE,0,SPACE,0,0)
CALL URARITA(A)
CALL GRIL30A,MLY,0,0,0,FLOAT(MLY=1)*SPACE,0,0,SPACE,0)
CALL URAAIT(A)
CALL GRIL30A,MLY,0,0,0,0,FLOAT(MLZ=1)*SPACE,0,SPACE,0,0)
CALL URAAIT(A)
CALL GRIL30A,MLY,0,0,0,0,FLOAT(MLZ=1)*SPACE,SPACE,0,0,0)
CALL URAAIT(A)
CALL GRIL30A,MLY,0,0,0,0,FLOAT(MLZ=1)*SPACE,SPACE,0,0,0)
CALL URAAIT(A)
RETURN
END

C...
C...
C...
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C...
C...

FILE UNDER 'DISPLAY'
THIS IS A MANUAL FEED PROGRAM "MFEED.FOR"

FEEDING INFORMATION ABOUT POSITION OF WORK STATION
ACCORDING TO TECHNOLOGICAL ORDER/LINE

THE PROGRAM IS ALSO SIMULATING THE DR. CARRIES
PROGRAM FOR TECHNOLOGICAL POSITIONING OF WORK STATIONS

THE PROGRAM IS FEEDING INFORMATION INTO A FILE "TECHORD"
(IN TECH. LINE ...1,2,3,4, ECT....)

FROM THIS DISK THE INFORMATION ARE READ INTO THE
AUTOMATIC POSITIONING PROGRAM "POSCLASH"

INTEGER ANS

CALL START

OUTPUT OF LISTING DATA TO

THE LINE IS NOT CHANGING (MUST REMAIN IN A TECHNOLOGICAL ORDER / IN A LINE)

INFORMATION MAN TO BE FILE IN FORMAT LINE NO., CODE TAG NO.

CONTINUE

WRITE (6,10)

READ (11,130,END=135) N,VSM

WRITE (15,A1?)

CONTINUE

READ (11,130,END=135) N,SHARP(1:12)

WRITE (15,140) N,SHARP(1:12)

CONTINUE

READ (11,130,END=135) N,SHARP(1:12)

WRITE (15,140) N,SHARP(1:12)

CONTINUE

WRITE (6,10)

READ (5,150) ANS

IF (ANS.EQ."NO",YES.LE."NO") GOTO 50

IF (ANS.EQ.="YE",YES.LE."YE") GOTO 70

ERROR MESSAGE

WRITE(6,160)

WRITE (15,140) N,SHARP(1:12)

CONTINUE

READ (5,150) ANS

IF (ANS.EQ."NO",YES.LE."NO") GOTO 50

IF (ANS.EQ.="YE",YES.LE."YE") GOTO 70

ERROR MESSAGE

WRITE(6,160)

WRITE (15,140) N,SHARP(1:12)

CONTINUE

READ (5,150) ANS

IF (ANS.EQ."NO",YES.LE."NO") GOTO 50

IF (ANS.EQ.="YE",YES.LE."YE") GOTO 70

ERROR MESSAGE

WRITE(6,160)

WRITE (15,140) N,SHARP(1:12)

CONTINUE

READ (5,150) ANS

IF (ANS.EQ."NO",YES.LE."NO") GOTO 50

IF (ANS.EQ.="YE",YES.LE."YE") GOTO 70

ERROR MESSAGE

WRITE(6,160)

WRITE (15,140) N,SHARP(1:12)

CONTINUE

READ (5,150) ANS

IF (ANS.EQ."NO",YES.LE."NO") GOTO 50

IF (ANS.EQ.="YE",YES.LE."YE") GOTO 70

ERROR MESSAGE

WRITE(6,160)
56.

```fortran
61 C CONTINUE
62 170 WRITE (6,172)
63 172 FORMAT (' To run program requested type the prefix letter'/
64 G" for adding a new work station at the end type -A="/)
65 A" for inserting work station above a W.S. type -I="/)
66 B" for deleting any work station type -W="/)
67 READ (5,174) ACTION
68 174 FORMAT (A1)
69 IF (ACTION.EQ."A") GO TO 175
70 IF (ACTION.EQ."I") GO TO 300
71 IF (ACTION.EQ."W") GO TO 400
72 WRITE (5,160)
73 GO TO 170
74 175 CONTINUE
75 180 FORMAT (" Please enter line no. and W.S.no to end type 200"/
76 READ (5,130) N,WSNAME(N)(1:12)
77 IF (N.NE.200) GO TO 210
78 CALL OPDISC ("TECHORD",11)
79 READ (11,130,END=200) I,WSNAME(I)(1:12)
80 IF (I.EQ.200) GO TO 210
81 CALL OPDISC ("TECHORD",11)
82 WRITE (6,190)
83 190 FORMAT (" Please enter line no. and W.S.no to end type 200"/
84 READ (5,130) N,WSNAME(N)(1:12)
85 IF (N.NE.200) GO TO 210
86 CALL OPDISC ("TECHORD",11)
87 200 CONTINUE
88 CALL OPDISC ("TECHORD",11)
89 READ (11,130,END=200) I,WSNAME(I)(1:12)
90 IF (I.EQ.200) GO TO 210
91 CALL OPDISC ("TECHORD",11)
92 WRITE (6,190)
93 210 CONTINUE
94 210 CALL OPDISC ("TECHORD",11)
95 CALL OPDISC ("TECHORD",11)
96 READ (5,130) N,WSNAME(N)(1:12)
97 IF (N.NE.200) GO TO 210
98 CALL OPDISC ("TECHORD",11)
99 READ (11,130,END=200) I,WSNAME(I)(1:12)
100 IF (I.EQ.200) GO TO 210
101 CALL OPDISC ("TECHORD",11)
102 READ (5,130) N,WSNAME(N)(1:12)
103 IF (N.NE.200) GO TO 210
104 CALL OPDISC ("TECHORD",11)
105 WRITE (6,160)
106 READ (11,130) N,WSNAME(N)(1:12)
107 IF (I.EQ.200) GO TO 210
108 WRITE (6,160)
109 300 CONTINUE
110 CALL OPDISC ("TECHORD",11)
111 WRITE (10,130) J,WSNAME(J)(1:12)
112 READ (5,130) N,WSNAME(N)(1:12)
113 CONTINUE
114 CALL OPDISC ("TECHORD",11)
115 WRITE (10,130) J,WSNAME(J)(1:12)
116 READ (5,130) N,WSNAME(N)(1:12)
117 CALL OPDISC ("TECHORD",11)
118 WRITE (6,160)
119 READ (11,130,END=3501N) N,WSNAME(N)(1:12)
120 WRITE (6,160)
121 CALL OPDISC ("TECHORD",11)
122 READ (11,130,END=3501N) N,WSNAME(N)(1:12)
```

57.

121  GO TO 340
122  CALL CLUISC ("TECHORD.DAT", 11)
123  CALL CLUISC ("TECHORD.DAT", 11)
124  CONTINUE
125  C
126  C  PRINT THE DEVELOPED LIST OF W.S. ON THE VDU
127  C
128  GO TO S
129  400  CONTINUE
130  C
131  C  KEEPING/DELETING AN EXISTING W.S. AND REPOSITIONING
132  C  THE LINE OF WORK STATION
133  C
134  CALL CLUISC ("TECHORD.DAT", 11)
135  CALL CLUISC ("TECHORD.DAT", 11)
136  WRTE (6,405)
137  405  FORMAT ("A Type position and W.S. which has to be deleted")
138  READ (5,130) K,ASPE(K)
139  410  IF(K.EQ.0) GO TO 410
140  J=K
141  IF (K.GT.0) J=J-1
142  WRTE (10,130) J,ASPE(K)
143  GO TO 410
144  CONTINUE
145  430  CONTINUE
146  CALL CLUISC ("TECHORD.DAT", 11)
147  CALL CLUISC ("TECHORD.DAT", 11)
148  CALL CLUISC ("TECHORD.DAT", 11)
149  CALL CLUISC ("TECHORD.DAT", 11)
150  440  READ (10,130) M,ASPE(M)
151  WRITE (11,130) M,ASPE(M)
152  GO TO 440
153  450  CALL CLUISC ("TECHORD.DAT", 11)
154  CALL CLUISC ("TECHORD.DAT", 11)
155  CONTINUE
156  C
157  C  PRINT THE DEVELOPED LIST OF W.S. ON THE VDU
158  C
159  GO TO 5
160  560  CONTINUE
161  STOP
162  END
163  C
164  C
165  C
166  C  FILE "AFILE"
167  C
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Queued to SSSPRINT on 9-NOV-1987 12:11b by USER BM01, UIC [RESM0012,0BM1], under account: BM01
Printer _LP00: on 9-NOV-1987 12:11c from queue LP00.
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Queued to SSSPRINT on 9-NOV-1987 12:11b by USER BM01, UIC [RESM0012,0BM1], under account: BM01
Printer _LP00: on 9-NOV-1987 12:11c from queue LP00.
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PROGRAM/ SUBROUTINE SHYIUKO

( WORK STATION (VOLUMES) TO TECHNOLOGICAL ORDER)

THIS SUBROUTINE IS RETRIEVING WORK STATION REQUESTED
FOR A SUGGESTED PRODUCTION LINE FROM THE "WSYLOD" FILE
AND REORGANIZES THEM IN TECHNOLOGICAL ORDER-LIKE, I.E. FOR
PRODUCTION OR PRODUCT ORIENTATED LAYOUT OR GROUP
TECHNOLOGY ORIENTATED LAYOUT).

REAL X(1), 2, XPUS, ZPUS, ANGLE
INTEGER J, K, N, I
COMMON/X(77), Y(77), Z(77), XPUS(77), ZPUS(77), ANGLE(77),
* FRAME(77),
CHARACTER* 12 FNAME
CHARACTER* 12 SNAME(77)

CALL START

FIRST NAME OF W.S. IN TECHNOLOGICAL ORDER IS RETRIEVED

CALL UDIPSC ("SYUKO", 12)
CALL UDIPSC ("ECORUR", 11)
CONTINUE
READ (11, 50, END=400) N, SNAME(N)(1:12)
FORMAT (15, A12)

CONTINUE
CALL UDIPSC ("SYUKO", 10)
CONTINUE
READ (10, RD, END=100) J, X(J), Y(J), Z(J), FNAME(J)(1:12)
FORMAT (15, F6.2, A12)

COMAPARE LIST OF W.S. VOL. WITH TECHNOLOGICAL ORDER
IF (FNAME(J)(1:12) .NE. FNAME(K)(1:12)) GOTO 100
IF (X(J)-X(K)(1:12) .NE. X(J)-X(K)(1:12)) GOTO 90
CONTINUE
GOTO 60
CONTINUE
WRITE (12, 150) J, X(J), Y(J), Z(J), FNAME(J)(1:12)
FORMAT (15, F6.2, A12)
CALL UDIPSC ("SYUKO", 10)
GOTO 26
CONTINUE
GOTO 50
CONTINUE
READ (12, 170, END=550) K, X(K), Y(K), Z(K), FNAME(K)(1:12)
FORMAT (15, F6.2, A12)
WRITE (6, 490) K, X(K), Y(K), Z(K), FNAME(K)(1:12)
60.

61 480 FORMAT (15,3FB,2,1X,A12)
62    K = K+1
63 490 GOTO 450
64 550 CONTINUE
65    CALL CRIISC (*SVIOD*,12)
66    C RETURN
67    STUF
68    EOD
C 62.

C.....THIS IS PROGRAM "M100.FOR"
C FOR BASIC CAPACITY CALCULATION FOR FACTORY LAYOUT PLANNING
C
C INTEGER ACTION
C WRITE(6,19)
C 10 FORMAT("CAFLAP MASTER PROGRAM")
C
C Functions of the program are:
C
C......to enable to enter and run individual programs separately
C......to change sequences/order of execution
C......to ease interaction between programs
C
C WRITE(6,20)
C 20 FORMAT("MENU of the CAFLAP master program")
C WRITE(6,110)
C 110 FORMAT(" A VOLUME OF MATERIAL HANDLING(VULMH)")
C WRITE(6,120)
C 120 FORMAT(" B NUMBER OF WORK STATIONS (NOWS)")
C WRITE(6,130)
C 130 FORMAT(" C MANUFACTURING AREA-In sq.m-(MAREA)")
C WRITE(6,140)
C 140 FORMAT(" D TOTAL LENGTH OF INDUSTRIAL BAY-In P-(BAYLGH)")
C WRITE(6,150)
C 150 FORMAT(" E to finish type XX")
C
C......To finish type XX
C
C WRITE(6,160)
C 20 FORMAT("PROGRAM IS NOT SELECTED PLEASE TRY AGAIN")
C GOTO 10
C
C 210 CALL VOLUM
C 220 CALL NOWS
C 230 CALL MAREA
C 240 CALL BAYLGH
C 250 STOP
C END
C
C SUBROUTINE VULMH
C FACTORY LAYOUT PLANNING-VOLUME OF MATERIAL HANDLING
C THE FOLLOWING PROGRAM CALCULATES A VOLUME OF MATERIAL (VULMH)
C
C C IN UNIT LOADS(UNL) PASSING THOUGH A FACTORY/INDUSTRIAL BAY
C
C THIS PROGRAM IS AN ENTRY PROGRAM
C WRITE(6,10)
C 10 FORMAT("FACTORY LAYOUT PLANNING-VOLUME OF MATERIAL HANDLING")
C WRITE(6,11)
C 11 FORMAT("STEP 1 CALCULATES THE NUMBER OF PARTS PER UNIT LOAD(UNPMP)
C VOLUME OF UNIT LOAD IN CUBIC METERS AND VOLUME OF PARTS
C TO BE MACHINED IN THE BATCH IN CUBIC METERS IS TO BE DECIDED"
C 12 FORMAT("CALCULATED BY PRODUCTION DEPTPRIOR THIS PROGRAM STARTS.
C WRITE(6,20)
62 20 FORMAT("PLEASE ENTER VOLUME OF UNL (VULUNL) IN CU METERS")
63 * WRITE(6,30)
64 30 FORMAT("PLEASE ENTER VOLUME OF PART (VULPT) IN CU METERS")
65 C VOLUMES TO BE ENTERED VIA KEYBOARD
66 READ(*,1) VULUNL, VULPT
67 NPPUNL = VULUNL / VULPT
68 C NOW THE SYSTEM WILL PRINT IN COLUMNS THE ABOVE DATA
69 * WRITE(6,40)
70 40 FORMAT(4A, "VULUNL", 7X, "VULPT", 9X, "NO PARTS PER UNL")
71 * WRITE(6,50) VULPT, NPPUNL, VULPT, APPUL
72 50 FORMAT(5X, F5.3, 3X, F11.6, F10.2)
73 C
74 C STEP 2. CALCULATE THE NUMBER OF UNIT LOADS GOING THROUGH BAY
75 C PER YEAR (NUHLPLP), SO WE HAVE TO ENTER PRODUCTION PROGRAMME
76 C IN PARTS PER YEAR (PROUNPHUG)
77 C
78 * WRITE (6,60)
79 60 FORMAT("ENTER THE PRODUCTION PROGRAMME IN PARTS PER YEAR (PROUNPHUG)"
80 READ (1,*) PPROG
81 * WRITE (6,70)
82 70 FORMAT(6A, "PROUNPHUG", 4A, "NO PARTS PER UNL", 9X, "NO UNL PER YR")
83 * WRITE (6, 80) PPROG, NPPUNL, NULPH
84 80 FORMAT(2X, F12.1, 3X, F10.1, 15X, F12.2)
85 C THIS IS THE BEGINNING OF PROGRAM VOLUM
86 C
87 C STEP 3. CALCULATE NUMBER OF UNIT LOADS GOING THROUGH
88 C THE INDUSTRIAL BAY PER HOUR (UNLPH).
89 C THE PRODUCTION YEAR HAS NUMBER OF WORKING HOURS GIVEN
90 C BY LOCAL CONDITIONS, THIS CAN BE ALSO
91 C EXPRESSED BY YEARLY CAPACITY OF A WORK STATION [EFWSH]
92 C AVERAGE YEARLY CAPACITY OF A WORK STATION FOR 48HRS WEEK
93 C AND ONE SHIFT
94 C IS 2000 HOURS (OF COURSE THIS HAS TO BE ADJUSTED ACCORDING
95 C TO YOUR LOCAL
96 C CONDITION... LOCAL CONDITION INCLUDE HOURS CONVENTION
97 C (NUMBER OF WORKING HOURS PER WEEK [AND NUMBER OF SHIFTS]).
98 C
99 * WRITE (6, 90)
100 90 FORMAT("ENTER PRODUCTION YEAR, NUMBER OF HOURS- (EFWSH)"
101 READ (5, 90) EFWSH
102 90 FORMAT(5X, 1000, 3X, 15X, 1000)
103 * WRITE (6, 100) EFWSH
104 100 FORMAT(5X, F5.3, 3X, F11.6, F10.2)
105 RETURN
106 END
107 C THIS IS THE END OF PROGRAM "EXVOLUM"
108 C
109 C SUBROUTINE HOW3
110 C PROGRAM NUMBER OF WORK STATION NEEDED (NOXS)
111 C * WRITE (6, 120)
112 120 FORMAT(6A, "CALCULATE NUMBER OF WORK STATION NEEDED USING UNL")
113 C THIS CALCULATION HAS AN ADVANTAGE FOR ANY FUTURE
114 C CALCULATION BECAUSE
115 C OF SPACES CONSIDERATION (PRODUCT SPACES ARE ALWAYS
116 C CALCULATED FROM UNIT LOADS)
STEP 1 - NUMBER OF STANDARD HOURS PER UNIT LOAD HAS TO BE CALCULATED

<table>
<thead>
<tr>
<th>.LINE</th>
<th>C</th>
<th>STEP 1 - NUMBER OF STANDARD HOURS PER UNIT LOAD HAS TO BE CALCULATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>118</td>
<td>C</td>
<td>WRITE(6,210)</td>
</tr>
<tr>
<td>119</td>
<td>C</td>
<td>FORMAT(2,240)</td>
</tr>
<tr>
<td>120</td>
<td>C</td>
<td>READ(11,5,SHPPM,NPPUNL)</td>
</tr>
<tr>
<td>121</td>
<td>C</td>
<td>WRITE(6,210)</td>
</tr>
<tr>
<td>122</td>
<td>C</td>
<td>WRITE(6,210)</td>
</tr>
<tr>
<td>123</td>
<td>C</td>
<td>WRITE(6,210)</td>
</tr>
<tr>
<td>124</td>
<td>C</td>
<td>WRITE(6,210)</td>
</tr>
<tr>
<td>125</td>
<td>C</td>
<td>HEAD(5,*)SHPPM,NPPUNL</td>
</tr>
</tbody>
</table>

STEP 2 - NUMBER OF WORK STATION FOR THE PARTICULAR PRODUCTION PROGRAMME IS CALCULATED (OR BASIS OF UNIT LOADS)

<table>
<thead>
<tr>
<th>LINE</th>
<th>C</th>
<th>STEP 2 - NUMBER OF WORK STATION FOR THE PARTICULAR PRODUCTION PROGRAMME IS CALCULATED (OR BASIS OF UNIT LOADS)</th>
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</thead>
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<tr>
<td>130</td>
<td>C</td>
<td>WRITE(6,240)</td>
</tr>
<tr>
<td>131</td>
<td>C</td>
<td>READ(11,5,UNLPH)</td>
</tr>
<tr>
<td>132</td>
<td>C</td>
<td>WRITE(6,240)</td>
</tr>
<tr>
<td>133</td>
<td>C</td>
<td>WRITE(6,240)</td>
</tr>
<tr>
<td>134</td>
<td>C</td>
<td>WRITE(6,240)</td>
</tr>
<tr>
<td>135</td>
<td>C</td>
<td>WRITE(6,240)</td>
</tr>
<tr>
<td>136</td>
<td>C</td>
<td>HEAD(5,*)UNLPH</td>
</tr>
<tr>
<td>137</td>
<td>C</td>
<td>WRITE(6,240)</td>
</tr>
<tr>
<td>138</td>
<td>C</td>
<td>WRITE(6,240)</td>
</tr>
<tr>
<td>139</td>
<td>C</td>
<td>WRITE(6,240)</td>
</tr>
</tbody>
</table>

This is "BAYLG" program for computation of a total length of "CONTINUOUS" industrial bay.

Data MFAREA is received from the program "BAYLG" of "BAYLG" program for computation of a total length of "CONTINUOUS" industrial bay.

This is "BAYLG" program for computation of a total length of "CONTINUOUS" industrial bay.

"BAYLG" is determined width of bay according to following quantitative requirements.
176 C *size of project
177 C *size of an average work station
180 C *size of aisles-material handling areas
181 C *system of material handling
182 C *and is usually 6, 9, 12, 15, 18, 21, 24, etc, meters
183 C
184 *SIZE(0, 100)
185 400 FORMAT(" Calculate length of "Continuous" industrial bay\(BAYL\)")
186 C
187 C *The determination of sizes of the bay is useful for graphical
188 C *design of work station in position in the bay and for decision
189 C *regarding dimensions of the industrial Hall(plant needed).
190 C *Maximum length of a bay should not exceed length 198 m.
191 C
192 *SIZE(0, 100)
193 410 FORMAT(" Please enter the size of manufacturing area in sq, m")
194 C
195 *SIZE(0, 120)
196 420 FORMAT(" Please enter dimension of bay width(BAYW) in meters")
197 C
198 C BAAYW(FLOAT) BAAYW
199 *SIZE(0, 120) BAAYW
200 430 FORMAT(" Total length of "Continuous" Bay(BAYL) in m. 15", 3X, F7.2)
201 C
202 RETURN
203 C...
204 C...
205 C... END block THE AREA "100, 100"
Drawing No. 1.
Sheets 1 to 6
<table>
<thead>
<tr>
<th>M/C NAME</th>
<th>M/C NO</th>
<th>CARD NO</th>
<th>POSITION</th>
<th>PAGE NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>GARRETT</td>
<td>17229248</td>
<td>18</td>
<td>CD(03-04)</td>
<td>001</td>
</tr>
</tbody>
</table>

| 01 | CLASS NO. | 17229248 |
| 02 | DESCRIPTION. | NC DRILL |
| 03 | COMPONENT-SUB-SYS. DIM/M | PUNCHED CARD READER (0.76, 0.63, 1.45) |
| 04 | STATIC LOAD/KN | 14 |
| 05 | TECHNOLOGICAL SPEC. |
| 06 | REMARKS | NO ANCHORING FOUNDATIONS |

| 07 | MANUFACTURER. | RICHARD GARRETT |
| 08 | ORDER REF. |
| 09 | OTHER INFORMATION. |
| 10 | DYNAMIC LOAD/KN |
| 11 | TEMPLATE FOR MSL001 |

![Diagram of machinery and foundation setup]
<table>
<thead>
<tr>
<th>M/C NAME</th>
<th>M/C NO</th>
<th>CARD NO</th>
<th>POSITION</th>
<th>PAGE NO</th>
</tr>
</thead>
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<tr>
<td>R. GARRETT</td>
<td>17229248</td>
<td>18</td>
<td>CD (03-04)</td>
<td>003</td>
</tr>
</tbody>
</table>

### SPECIFICATIONS

#### A MACHINE

<table>
<thead>
<tr>
<th>No</th>
<th>Specification</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Maximum workpiece dimensions (XxYxZ)</td>
<td>38</td>
<td>mm</td>
</tr>
<tr>
<td>02</td>
<td>Maximum workpiece Weight</td>
<td>7</td>
<td>kg</td>
</tr>
<tr>
<td>03</td>
<td>Front to back table travel</td>
<td>370</td>
<td>mm</td>
</tr>
<tr>
<td>04</td>
<td>Left to right table travel</td>
<td>610</td>
<td>mm</td>
</tr>
<tr>
<td>05</td>
<td>Vertical slide travel</td>
<td>685</td>
<td>mm</td>
</tr>
<tr>
<td>06</td>
<td>Table feed rate</td>
<td>2.4</td>
<td>mm/min</td>
</tr>
<tr>
<td>07</td>
<td>Outside dimensions (XxYxZ)</td>
<td>2.1x1.6x1.6</td>
<td>mm</td>
</tr>
<tr>
<td>08</td>
<td>Weight</td>
<td></td>
<td>kg</td>
</tr>
</tbody>
</table>

#### B POWER SUPPLY

<table>
<thead>
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<th>Specification</th>
<th>Value</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>01</td>
<td>Output voltage (no Load)</td>
<td>380</td>
<td>V</td>
</tr>
<tr>
<td>02</td>
<td>Maximum machine current</td>
<td>1.76</td>
<td>A</td>
</tr>
<tr>
<td>03</td>
<td>Machine control system</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>Maximum Input Power</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>Outside dimensions (XxYxZ)</td>
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<td>mm</td>
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<tr>
<td>06</td>
<td>Weight</td>
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<td>kg</td>
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#### C DIELECTRIC FLUID SUPPLY

<table>
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<td>01</td>
<td>Dielectric fluid COOLANT</td>
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<td>Tank capacity</td>
<td>30</td>
<td>L</td>
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<tr>
<td>03</td>
<td>Filter element</td>
<td>YES</td>
<td></td>
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<tr>
<td>04</td>
<td>Outside dimensions (XxYxZ)</td>
<td>0.5x0.3x0.2</td>
<td>mm</td>
</tr>
<tr>
<td>05</td>
<td>Weight</td>
<td></td>
<td>kg</td>
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#### D CONTROL

<table>
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<tr>
<td>01</td>
<td>Control axes</td>
<td>X, Y, Z</td>
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<tr>
<td>02</td>
<td>Interpolation</td>
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<td>03</td>
<td>Minimum command unit</td>
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<tr>
<td>04</td>
<td>Table position display</td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>Block No. display</td>
<td>DIGITAL</td>
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<tr>
<td>06</td>
<td>Program capacity</td>
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<tr>
<td>07</td>
<td>Input method</td>
<td>TAPE</td>
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<td>08</td>
<td>Mirror image</td>
<td>YES</td>
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<td>09</td>
<td>X Y axes change</td>
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<td>10</td>
<td>Single block feed</td>
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<tr>
<td>11</td>
<td>Dry run</td>
<td>YES</td>
</tr>
<tr>
<td>12</td>
<td>Machine lock</td>
<td>YES</td>
</tr>
<tr>
<td>13</td>
<td>Backlash compensation</td>
<td>YES</td>
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<tr>
<td>14</td>
<td>Memory cell</td>
<td>NO</td>
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<tr>
<td>15</td>
<td>Self diagnostic FCN</td>
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<tr>
<td>16</td>
<td>Automatic positioning function</td>
<td>ON TAPE</td>
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<tr>
<td>17</td>
<td>Inch/°m display</td>
<td>NO</td>
</tr>
<tr>
<td>18</td>
<td>Outside dimensions (XxYxZ)</td>
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<td>19</td>
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#### E REMARKS

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<tr>
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<td>TIME INTERVALS</td>
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<td>A MECHANICAL</td>
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<tr>
<td>01 CHECK &amp; EXAMINE</td>
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</tr>
<tr>
<td>02 BEARINGS</td>
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<tr>
<td>03 DRIVE BELTS</td>
<td>X</td>
</tr>
<tr>
<td>04 SAFETY DEVICES</td>
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<td>05 MVC CALIBRATION</td>
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<td>06 TABLE ALIGNMENT</td>
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<td>08 NOSE &amp; PIPES</td>
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<tr>
<td>09</td>
<td></td>
</tr>
<tr>
<td>10 CLEAN &amp; LUBRICATE</td>
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</tr>
<tr>
<td>01 MOVING PARTS</td>
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<tr>
<td>02 MOVING SURFACES</td>
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</tr>
<tr>
<td>03</td>
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<td>11 REPLACE</td>
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<td>02 AUTOMATIC CONTROLS</td>
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<td>03 FUSES</td>
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<td>04 BRUSHES</td>
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<td>05 CHARGE COILS</td>
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<td>03 PIPES &amp; VESSELS</td>
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<td>04 PUMP BEARINGS</td>
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<td>05</td>
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<td>12 CLEAN</td>
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</tr>
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<td>02 OIL FILTERS</td>
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</tr>
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</table>

PLACE X IN APPROPRIATE TIME SCALE

NOTE:
OVERHAUL ONCE EVERY YEAR
<table>
<thead>
<tr>
<th>M/C NAME</th>
<th>M/C NO</th>
<th>CARD NO</th>
<th>POSITION</th>
<th>PAGE NO</th>
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</thead>
<tbody>
<tr>
<td>R.GARRETT</td>
<td>17229248</td>
<td>18</td>
<td>CD(03-04)</td>
<td>005</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
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<tbody>
<tr>
<td>001</td>
<td>OIL</td>
<td>SHELL VIERRA OIL 69</td>
<td>DEPENDS ON USAGE</td>
</tr>
<tr>
<td>002</td>
<td>GREASE</td>
<td>ALVANIA GREASE NO. 2</td>
<td>DEPENDS ON USAGE</td>
</tr>
<tr>
<td>003</td>
<td>COOLANT</td>
<td>MINERAL OIL</td>
<td>DEPENDS ON USAGE</td>
</tr>
</tbody>
</table>
| 004| HYD.OIL   | /                      | /               | /
| 005|           |                        |                 | /

**KEY:**
- OIL
- GREASE
- COOLANT
**INSTALLATION DETAILS**

<table>
<thead>
<tr>
<th></th>
<th>A MACHINE DETAILS</th>
<th>D HANDLING REQUIREMENTS</th>
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</thead>
<tbody>
<tr>
<td>01</td>
<td>MANUFACTURER</td>
<td>Crane Maximum Lift kg</td>
</tr>
<tr>
<td>02</td>
<td>MACHINE TYPE</td>
<td>Fork Lift Truck</td>
</tr>
<tr>
<td>03</td>
<td>MACHINE MODEL</td>
<td>Others</td>
</tr>
<tr>
<td>04</td>
<td></td>
<td></td>
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<td>01</td>
<td>Height m</td>
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<td>02</td>
<td>Width m</td>
<td>Fork Lift Truck</td>
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<tr>
<td>03</td>
<td>Depth m</td>
<td>Others</td>
</tr>
<tr>
<td>04</td>
<td>Weight kg</td>
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<td>Loads</td>
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<tr>
<td>02</td>
<td>Method of Fixing</td>
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**DRAWING OF FOUNDATION FLOOR**

**NO ANCHORING FOUNDATIONS**
Drawing No. 2.
Drawing No. 3.