A Facility Layout Design Support System

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Abstract

The design of facility layouts involves a decision process which, in general, due to its complexity, has to be decomposed into several sub-problems, namely: the selection of the most adequate manufacturing processes, the planning of equipment and labour requirements, the allocation of manufacturing operations to machines, the grouping of machines into sections (cells or departments), the selection of handling equipment, the specification of the work-in-process parking areas and the definition of the location of machines and sections on the manufacturing plant.

In this paper, this overall decision process is analysed and the conceptual framework of a system aimed at supporting some of the stages of such a process is described.

Keywords: Facilities layout design; Cellular Manufacturing Systems; Decision support systems

1   Introduction

The survival of industrial companies in a global and competitive market requires an increasingly efficient use of its resources, in particular those concerning the manufacturing process.

The efficient design of industrial plants has a definite impact on the reduction of production costs. Estimates presented by Tompkins et al [9] point towards a 10 to 30% reduction in the material handling costs, which account for about 15 to 70 % of the total operating costs of an industrial plant.

According to Sule [8], an efficient layout may also contribute to the reduction in the production cycles, work-in-progress, idle times, number of bottlenecks or material handling times and to the increase in the production output, with obvious implications on productivity.

The importance of industrial plant design arises also from its structuring nature, which is due to its long-term effects and to the difficulty in modifying it once it has been implemented.

Tompkins et al [9] consider that the industrial plant design process entails four design components, concerning namely the building, the warehousing system, the handling system and the facility layout.

Given the existing interaction among these components, it would be desirable to adopt a systemic approach in order to solve simultaneously the whole process. The main reasons demanding such an integrated approach are as follows:

- The feasible solutions for the facility layout problem are constrained by the geometry of the building.

- The location of the manufacturing equipment, warehouses and parking areas for work-in-process are major factors to be considered in the definition of the material handling system.

- The design of the facility layout is bound to affect the efficiency of the manufacturing system.

The envisaged integration in the approach to the different components of the industrial plant design faces major difficulties for two types of reasons. Firstly, the architectural and engineering problems and challenges are different in kind from the ones arising in the other components of the overall process. Secondly, the combinatorial nature of the problems associated with the location of the equipment, the design of the warehousing and material handling systems does not allow its joint solution in a satisfactory way. In fact, a systemic approach in order to solve simultaneously the whole process, if attainable, could not take into account many of the important details embedded in each of these problems.

Thus the approach to the different components of the overall process has to be separated, frequently being attributed to different designers or different design teams. Under these circumstances, there is an obvious need for significant interaction among the parties involved and for considerable flexibility of the systems adopted to support their decisions.

The decision support system (DSS) presented in this paper addresses only the facility layout design. However, in order to allow for the interaction with the other components of the overall process, this DSS was designed so as to take into account the following links:

- If the building geometry has been previously defined, the facility layout is specified taking it into account. Otherwise, the layout is set having only as a precondition that a common building can easily accommodate the overall shape.

- In the facility layout design, the types and characteristics of the material handling equipment are assumed to be given (taking into account the nature and quantity of each of the materials to be manipulated). However such characteristics may be modified in the course of the facility design.

- The shapes and sizes of the warehouses for the raw materials and finished products as well as those of the parking areas for the work-in-process are assumed to be known at

the outset. Again such characteristics can be modified at any stage of the facility design process.

It should than be noted that the underlying philosophy in the development of this DSS was to produce a tool to generate useful and realistic layout designs (even though relying on the ability of the decision maker to adapt the most adequate material handling and warehousing systems), rather than attempting an unrealistic systemic approach to the whole process, that would certainly result in a system less prone to solve real-life problems.

This DSS was developed for different types of discrete production systems, namely process based ones, group technology based ones and systems which are hybrid of these.

In the analysis of such systems, it is important to note at the outset their hierarchical nature entailing four different levels: the overall plant, the sections, the workspaces and the equipment.

In this context, the term section means either a department made up of similar types of machines (if the manufacturing system is process based) or a cell integrating different types of machines required to manufacture one or more types of parts (if the manufacturing system is group technology based). The term workspace denotes the area assigned to one machine, its supporting equipment and the parking area for the incoming and outgoing parts.

2   The Nature of the Facility Layout Design Process

The design of facility layouts involves a decision process, which, in general, due to its complexity, has again to be decomposed into several sub-problems. When specifying these sub-problems, their boundaries must be defined so as to minimise the interactions among them. Since such interactions cannot be eliminated, the different stages in which the overall process is tackled do not follow a rigid sequence and often involve feedback loops.

In Figure 1 the different stages of the facility layout design process are shown and those covered specifically by the DSS are depicted.

The facility layout design process derives from the need to create or modify industrial plants, to meet new market demands. In most cases, such a process is triggered by the detection of changes in the product demand mix (which may imply changes in the product outputs, the introduction of new products or the modification of existing ones) or the need for upgrading the current technological processes or for introducing new ones.

When (re)specifying a product, the designers define its physical and functional characteristics and set targets on costs, quality and operational performance.

Engineering design is developed together with process planning and it includes the synthesis, analysis and assessment of the product against specifications.

Process planning - which is the final stage prior to those dealt with by the DSS - covers, for each part to be produced, the specification of all the manufacturing operations required to obtain the characteristics defined by the engineering design, and, for different sets of parts, the specification of the assembly operations required to obtain the final product.
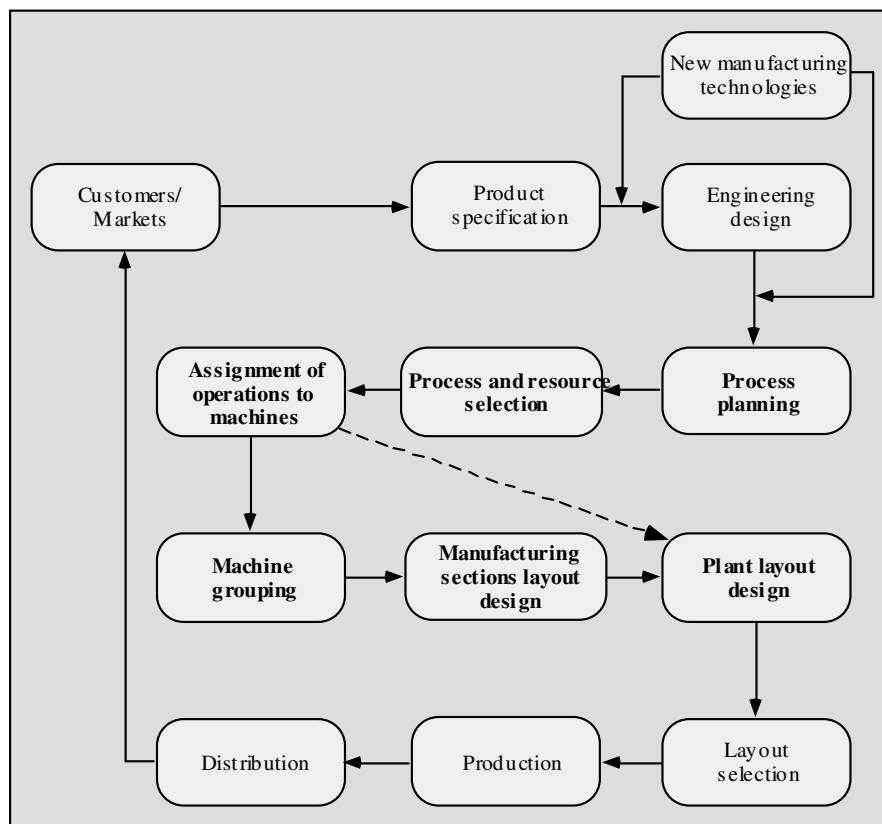
Figure 1: The structure of the facility layout design process.

In many cases, a part can be produced according to alternative manufacturing processes (i.e. according to different sequences of operations) and an operation can be performed in different types of machines by different types of labour. For each part, the process and resource selection involves the specification of a sequence of operations and consequently the definition of the types of machines and labour required to carry out such operations.

Once the operations and the number of machines of each type required to meet the production needs over a planning horizon are set, all the operations involved need to be assigned to the different machines.

The objective in machine grouping is to set up sections i.e. departments made up of similar types of machines or cells integrating different types of machines required to manufacture one or more types of parts.

Among the steps of the facility layout design process, the last ones - i.e. the section layout and plant layout definitions - consist of locating the machines within each section and locating the sections within the overall plant. It should be noted that in some cases, especially when the total number of machines is small, the grouping phase can be skipped and hence the machines are directly located in the overall plant.

It should be noted that the types and characteristics of the material handling equipment, which are specified tentatively at the outset, may need to be revised, firstly after the intra and inter-section flows become known and then after the section and plant layouts have been specified.

3   Global Characteristics of the DSS

In order to insure the DSS relevance, friendliness and ease of expansion, this system was given an overall conceptual structure and architecture whose characteristics will be briefly analysed in this section.

The system comprises a set of 5 main modules which address the main decision areas of the facility layout design process - process and resource selection, assignment of operations to machines, machine grouping, section layout design and plant layout design - together with a set of 2 modules dedicated to draft support functions. The main modules of the DSS make it a quite complete systems on the important issues of the decision process in question whereas the supporting modules contribute to its enhance the visual representation of the solutions.

This modular structure together with carefully designed interactions between the modules contributes to the flexibility of the DSS, allowing the user to approach the whole decision process in an integrated way or, alternatively, to address only parts of such a process. In any of these cases, the DSS is user friendly due to the adopted interface, which simplifies the user-machine communication process.

The system was developed on a UNIX based workstation with the software architecture shown in Figure 2.

The OSF-Motif GUI (Graphical User Interface) was selected due to its similarity to the current GUI standards on personal computers (MsWindows, Mac-OS), which avoids the need

User interface
Application programs

X11/OSF-Motif	CPlex	db-Vista	

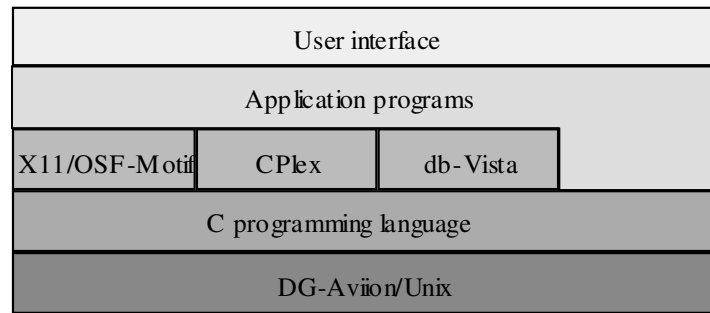| C programming language |
|---|
| DG-Aviion/Unix |

Figure 2: DSS software architecture.

for an extensive training of the common users.

The C language was adopted to insure the portability of the DSS over different operating systems. Both CPlex (a linear and integer programming solver) and db-Vista (a data base management system) are C based which made them easy to integrate in the overall system.

The need to continuously upgrading any DSS is, in general, of paramount importance. The recognition of this fact in the development of the DSS described in this paper contributed to shape some of its features, in particular,

- the adoption of a C based layered software environment (which is comparatively stable),

- the modularity of the system,

- the usage of the object oriented methodology in the design of the data base, and

- the adoption of structured programming practices in the development of application programmes.

4　Functional Structure of the DSS

The functional structure of the DSS is shown in Figure 3. The diagram presents

- the inputs and outputs of the overall system,

- the different modules included in the system (process and resource selection, assignment of operations to machines, machine grouping, basic drafting, workspace drafting, section layout design, facility layout design),

- the inputs and outputs of each module, and

- the interactions between different modules (full lines are used when the output of one module is directly used as the input to another one and dashed lines represent useful information available to the decision maker, so that he can either change the input parameters or select an alternative solution in a previous module).
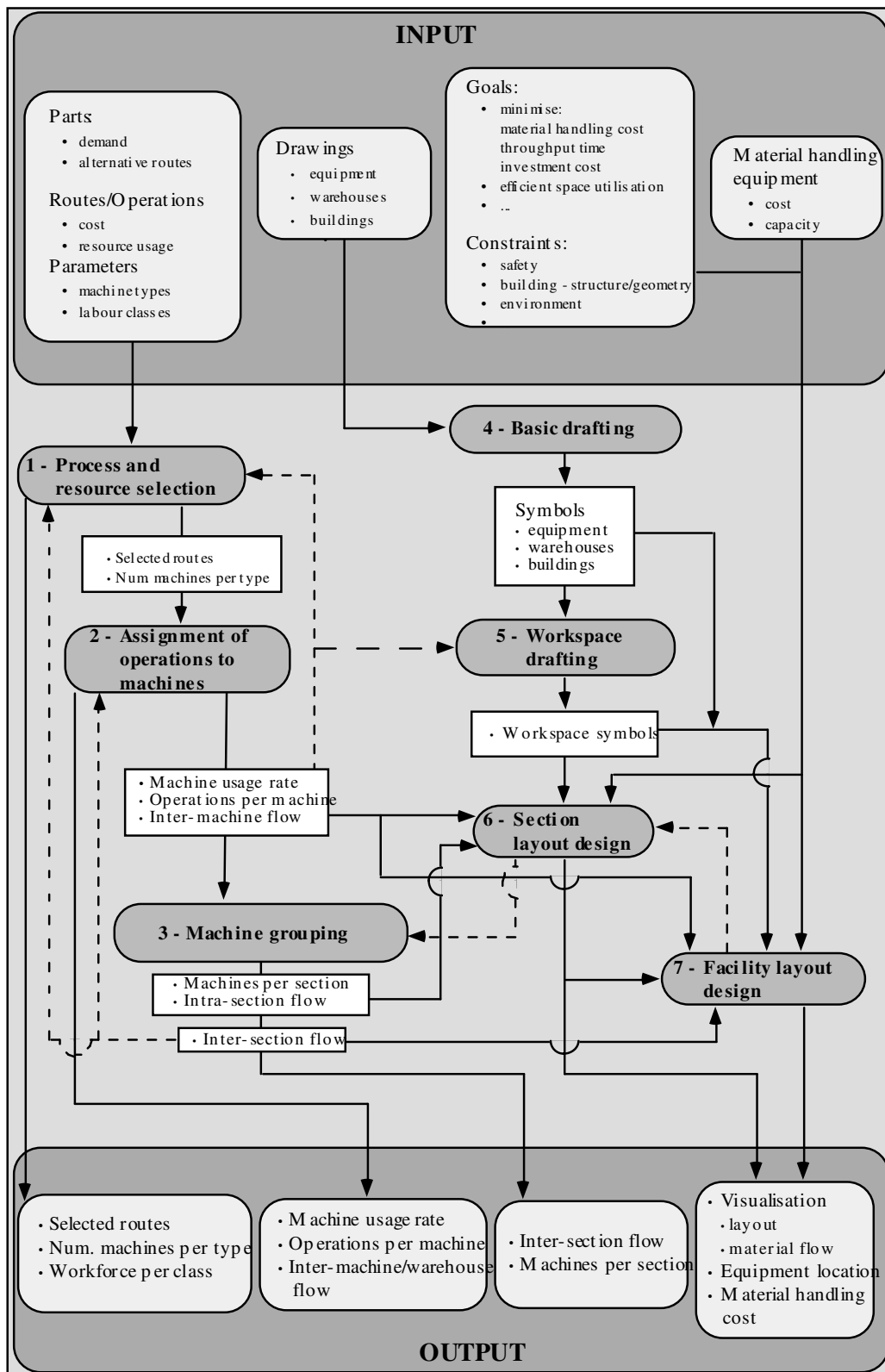
Figure 3: Functional structure of the DSS.

The ability of the DSS to support the user in generating different scenarios for each of the modules is of crucial importance due to the existing interactions between such modules. These scenarios are generated by either of the following rationales:

i) The likelihood of having different solutions, for each different set of input data in each module, within a range of costs acceptable to the user is high. As the system can store in each module a set of solutions for each different set of input data (that are within a user–defined range of the best one found), the user can choose which shall be used as input to the next module. As these sets of data are inputted to downstream modules different scenarios are generated.

ii) Some of the data introduced in each module is forecasted, particularly when of the planning of a new facility, and can vary within a certain range. The user can introduce different sets of data to generate different scenarios or can use information from downstream modules to review values introduced in previous ones. For example, if a solution to the assignment of operations to machines module shows that a machine of a certain type has a low usage rate, the user can review the efficiency parameter for that machine type introduced in the process and resource selection module, envisaging a reduction on the number of machines of that type required

The model for the process and resource (equipment and labour) selection problem assumes the availability of alternative process plans (routes) for each part and is based on data concerning the several operations included in each of these routes. For a given planning horizon, the model solutions specify:

- the required number of machines of each type,

- the required number of workers in each of the several predefined labour classes,

- the route (or routes) for each part, and

- the type of machine in which each operation is performed and the usage rate of each machine.

The joint definition of equipment and labour was considered in order to model situations in which there is a need to take into account alternative production processes (more capital intensive or more labour intensive) and the possibility of some workers operating simultaneously several machines. The model can also account for production shifts and overtime work.

The results derived from this model are used as inputs to the assignment of operations to machines. The goal of the underlying problem is to define in detail the specific machine in which each manufacturing operation will be carried out. Here, the manufacturing operations are assigned to the machines under a twofold objective: (i) to minimise the number and the types of operations performed in each machine and (ii) to insure that the operations taking place in the same machine are preceded and are succeeded by similar operations i.e. operations which take place in similar machines. In this way, the assignment of operations to machines is done so that, for each machine, the incoming flow comes from the same machine or from a set of nearly identical machines and the outgoing flow is directed also to the same machine or to

a set of nearly identical machines. The objective of this procedure is to enable the generation, at a later stage, of a favourable material flow pattern within the plant.

The usage rates of the machines, obtained as a result of this assignment, may suggest that a better allocation of operations to machines can be achieved either by reviewing the input parameters or by adopting alternative manufacturing processes for some of the parts. For instance, if one operation that is carried out in several machines makes only a residual use of one of them, this use could be eliminated by transferring the operation in question to one of the machines with higher occupation rate. Such a transfer may require an increase in the limit imposed on overtime for the relevant class of labour.

Once the flows of parts between pairs of machines become known, the user can then introduce the relevant data concerning the material handling equipment (such data will include unit operating costs, speed, load and unload time). However, this data may be reviewed at a later stage, when the inter-section and intra-section flows are known or when the locations of the machines and sections are established.

The machine grouping module deals with the allocation of machines to departments or to cells. The DSS offers a set of heuristic procedures to assist the decision-maker in the cell formation process, whilst the grouping of machines into departments is done manually. The coexistence of cells and departments, to form a hybrid production system, is accounted for in the DSS. A typical example of the use of this capability of the system is related to the use of shared equipment in a group technology environment. As a result of its high cost and capacity, it may be advantageous to place or to group it in a special department, originating a hybrid configuration.

The paradigm of a cellular manufacturing system is to manufacture each part in only one cell, so that flows between cells do not occur. In most cases such a goal is not attainable, but it is possible to reduce the inter-cellular flow by reallocating the operations to the machines, by duplicating some machines or by subcontracting some parts or operations. Hence, the solutions for the cell formation problem given by the system's heuristics may suggest the reviewing of the parameters adopted in the previous modules.

Prior to the use of the layout modules, the user needs to introduce the graphical symbols required to visualise the layouts. This is done on the drafting modules: the basic drafting module and the workspace drafting module.

The basic drafting module, is a basic CAD package which allows the user to draw the geometric objects to be included in both the workspace and the facility layout representation (machines, warehouses, buildings, etc.).

The machines are not placed directly on the plant area, but instead they are included in workspaces. Each workspace is drawn in the workspace drafting module and it involves the specification of (i) the space required to place and to operate the corresponding machine, to install materials and tools and to provide for parking areas, (ii) the location of the pickup point and (iii) the location of the drop-off point.

Initially, the workspaces are drafted by type of machine, on the assumption that their geometrical configuration is identical. When this is not the case, the workspace of each machine may be modified individually.

Once each manufacturing section is defined, the facility layout problem is solved and the relative location of the machines in the manufacturing sections and of these in the overall plant is obtained. The same heuristic procedure is used to support the definition of the layout for each section and for the overall plant. This procedure attempts to minimise the overall material handling cost, taking into account the intra-section and inter-section flows, the data concerning the material handling equipment and the geometric configuration of workspaces and warehouses and their relative location within the whole plant. It should be noted that, for both layout modules, the user is allowed to adjust the solutions proposed by the heuristic procedure, supporting him with appropriate information, which includes a visual representation of the flows between workspaces and between sections.

5   Model Base

5.1   The Process and Resource Selection Problem

The mixed integer linear programme proposed for the process and resource selection problem is a single planning period static model (see Refs. [10, 11] for a detailed explanation of this model). In this model, the objective is to minimise the overall costs incurred in the planning period and the following parameters are assumed to be given:

- the number of parts of each type to be manufactured during the planning horizon,

- the different conditions in which each class of labour can be used (number of existing workers, availability of new workers, number and duration of shifts, overtime limits, unit costs),

- the different types of machines involved in the manufacturing system and, for each of them, its capacity and costs, the number of existing units as well as the investment involved in the acquisition of each new unit, and,

- for each part, the alternative routes available, and, for each operation, the unit processing time and cost.

The model is solved using the branch-and-bound algorithm of the CPlex package [3]. The branching strategy selected uses a depth-first search procedure for selecting the next node to process when backtracking, selects first the up branch at each node and assigns branching priority to all integer variables representing machine types. This strategy led to results, which, in the less favourable cases, were within 8% of the estimated lower bound for the objective function. These results were obtained for a set of randomly generated test problems aimed at representing a wide range of real world situations. For problems involving 3 production shifts and overtime, 25 machine types, 15 labour classes, 50 parts, and, on average, 3 routes per part and 10 operations per route, the computational effort involved in solving these problems never exceeded 5 minutes of CPU time on a Data General Aviion workstation.

5.2   The Assignment of Operations to Machines

In the assignment of operations to machines, the following parameters are assumed to be given:

- the number of parts of each type to be manufactured during the planning horizon,

- for each type of machine involved in the manufacturing system, the number of machines available and their capacity,

- the route(s) used to manufacture each part,

- the processing time for each operation.

The following three steps are involved in the procedure proposed to solve this problem:

- Operations that can only be performed in a specific machine (because this is the only one of its type) are assigned initially.

- Machines that are exclusively assigned to a single operation are then fully loaded. If, after this step, for any type of machine, there is only one unit which remains to be loaded, then all the unassigned operations (or fractions of the operations) that have to be performed on that type of machine are assigned to that machine.

- The final step consists of assigning the remaining operations or fractions of operations to machines which are still completely unloaded.

The first two steps can be solved in a trivial way. The problem arising in the third one was modelled as a mixed integer linear programme (see Refs. [10,12] for a detailed explanation of this model). This model is sequentially applied to the various machine types, previously sorted by increasing slack capacity or, in the case of a tie, by increasing number of machines yet to be loaded. For each machine type, the model seeks to distribute the unassigned operations or fractions of operations to the available units so that, for each machine, the incoming flow comes from the same machine or from a set of nearly identical machines and the outgoing flow is directed also to the same machine or to a set of nearly identical machines. In other words, the objective is to insure that, for each machine, both the sources for the incoming flows and the sinks for the outgoing flows are as similar as possible.

In the objective function of the proposed mixed integer programme, this is achieved by defining, for all possible pairs of operations, which can be performed on the same machine, a penalty which is a function of the dissimilarity of the sets of machines in which the previous and the following operations of the corresponding routes are performed.

For some machines, this objective function can lead to an excessive number of operations (and set-ups). The recognition of this fact led to the inclusion of a correction parameter in the objective function that allows the user to penalise to a smaller or a greater extent the fragmentation of the usage of each machine and, in this way, to limit such a fragmentation.

Computational experiences using the Cplex package [3] showed that the proposed mixed integer programming model could not be solved optimally, within an acceptable time limit, for problems with more than three machines of the same type. So, an algorithm, based on the simulated annealing procedure, was developed to solve this problem (see Refs. [10, 12] for a detailed explanation of the procedure). This algorithm was tested with a vast set of generated problems, aimed at representing a wide range of real world situations, and it was possible to conclude that, even is less favourable conditions, its performance is acceptable. For instance,

for a set of problems comprising 5 machines of the same type, the average CPU time on a Data General Aviion workstation was 1360 seconds and the maximum difference between the solution found and the lower bound for the objective function was 3%.

5.3   The Machine Grouping Problem

In process based manufacturing systems the machine grouping problem is trivial since it consists merely in grouping in each department machines of the same type (i.e. with near identical functional capabilities).

In cellular (or group technology based) manufacturing systems the parts with similar processing requirements are classified into part families. The machines involved in the production of each part family are grouped in manufacturing cells.

Two heuristic procedures were included in the DSS described in this paper to support the machine grouping decisions concerning cellular manufacturing systems. The main difference between them lies on the input data required: either the machine-part incidence matrix or the flow matrix. These two heuristics were adopted bearing in mind the following advantages:

- they do not require the pre-definition of the number and the size of the cells,

- the final solution which they generate is complete i.e. it includes families of both machines and parts (exempting the user of visually inspecting the BDM - Block Diagonal Matrix – to form the families).

The heuristic which uses the machine-part incidence matrix is the one proposed by Ganesh and Srinivasan [2], which solves the manufacturing cell formation problem so as to maximise the grouping efficacy of the BDM. This heuristic uses a non–hierarchical clustering procedure, in which the initial partitioning of the machines in cells derives from an approximate solution to the pmedian problem.

Ganesh and Srinivasan [2] reported that, among the algorithms based upon the incidence matrix (namely ZODIAC (Chandrasekharan and Rajagopalan [1]) and GRAFICS (Srinivasan and Narendran [6]), their heuristic leads to solutions with the highest grouping efficacy. According to the authors' experience with the DSS, even for large problems (e.g. involving 30 machines), the CPU time falls within acceptable limits (for the previous dimension, about 30 seconds).

The heuristic based on the flow matrix was that proposed by Okogbaa et al [6] which solves the cell formation problem so as to minimise the inter-cellular flow.

The paper presented by Okogbaa et al [6] shows that their inter-cell flow reduction heuristic leads to inter-cellular flows which are lower than those derived from the algorithms based on the incidence matrix. According to authors' experience with the DSS, the computational effort required by this heuristic is about the same as that associated to the alternative procedure based on the incidence matrix.

In the DSS under analysis, the user may group the machines manually, by using an interface that, on request, provides updated information on the intra and inter-section flows. Such an
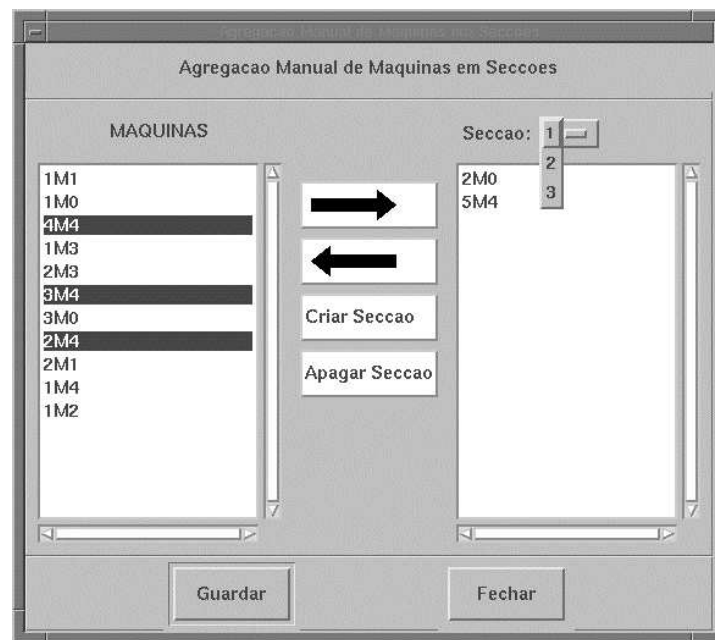
Figure 4: Interface for the manual grouping of machines (the machines still unassigned to sections are shown on the left list, the current section to be displayed on the right list is chosen with the pop-up button, machines are introduced in or withdrawn from the current section with the arrow buttons and the two other buttons are used to create or delete sections).

interface (see Figure 4) allows the user to modify the solutions generated by any of the heuristics addressing the cell formation problem. This combined procedure may be of interest whenever hybrid solutions are required.

5.4 The Facility Layout Problem

The most common approaches to the facility layout problem focus on developing a block layout, which aims at combining optimally the shapes and the relative locations of the manufacturing sections included in the facility. In most of these approaches the areas of the sections are fixed while their shape is allowed to change freely or, at most, within certain limits. This is rather unrealistic when developing a detailed layout of a facility since the shape of many sections (or workspaces) should be regarded as fixed.

In the DSS presented in this paper the layout is designed in two stages. Firstly, the layouts of the sections are established, setting the relative locations of the corresponding workspaces without being able to modify their shapes. Thereafter the sections - with their configurations defined in the previous stage remaining unchanged - are arranged in the overall plant.

An unconstrained non-linear optimisation model was included in the DSS to solve the problem of arranging the workspaces in manufacturing sections and of these in the plant area (see Refs. [10, 13] for a detailed explanation of the model and of the procedure used to solve it). This model extends that proposed by Imam and Mir [4] and Mir and Imam [5] in two areas:

- Pickup and drop-off points were considered in each workspace or manufacturing section. When costing the flow leaving one of these units and entering another one, the distance is calculated between the drop-off point of the former and the pickup point of the latter.

- Each workspace or section can freely rotate around its geometric centre by 90°, 180° or 270° relatively to its initial orientation.

Both these aspects were found to be crucial to model the plant layout and its corresponding material handling costs with adequate realism.

The main characteristics of the facility layout model included in the DSS are as follows:

- Its objective is the minimisation of the overall material handling costs. In order to avoid an inadequacy found in the procedures proposed by Iman and Mir [4] and Mir and Imam [5], namely the generation of clusters of nearly independent manufacturing units scattered over a wide overall layout area, the distances between such clusters were penalised in the objective function.

- The distance between any two points - (x_i, y_i) e (x_j, y_j) - is given by the rectilinear measure, $d_{ij} = |x_i x_j| + |y_i \text{-} y_j|$.

- The geometric representation of a workspace includes (i) the rectangular area bounding the workspace, (ii) the geometric model of the corresponding machine and of other relevant resources and (iii) the locations of the pickup point and of the drop-off one.

- A manufacturing section includes a set of workspaces and its whole geometric representation includes (i) the rectangular area bounding the section, (ii) the geometric models of the corresponding workspaces and (iii) the locations of the pickup point and of the drop-off one.

- For each unit included in the layout, the locations of the pickup point and of the drop-off one are usually defined by the user at the outset. If this is not the case, the centre of the rectangular area associated to the workspace or the section in question is used instead.

- The rectangular areas associated to the workspaces or sections are not allowed to overlap.

- The plant area is not limited.

The proposed heuristic uses the concepts of enveloping block and controlled convergence (See Refs. [4, 5] for a detailed description of these concepts).

The small number of techniques for the layout of rectangular facilities with unequal areas and fixed dimensions limits the comparison of the proposed heuristic with others. Nonetheless, the heuristic was adjusted to the different underlying conditions of some of the best-known techniques so that its efficiency could be compared. For example, Imam and Mir [4] solve the layout problem for fixed dimension facilities in an unlimited plant area, but do not consider pickup and drop-off points. Hence, in order to make the two techniques comparable, the pickup and drop-off points were placed in the geometric centre of the resources and a problem with 20 machines, suggested by Imam and Mir [4], was solved.
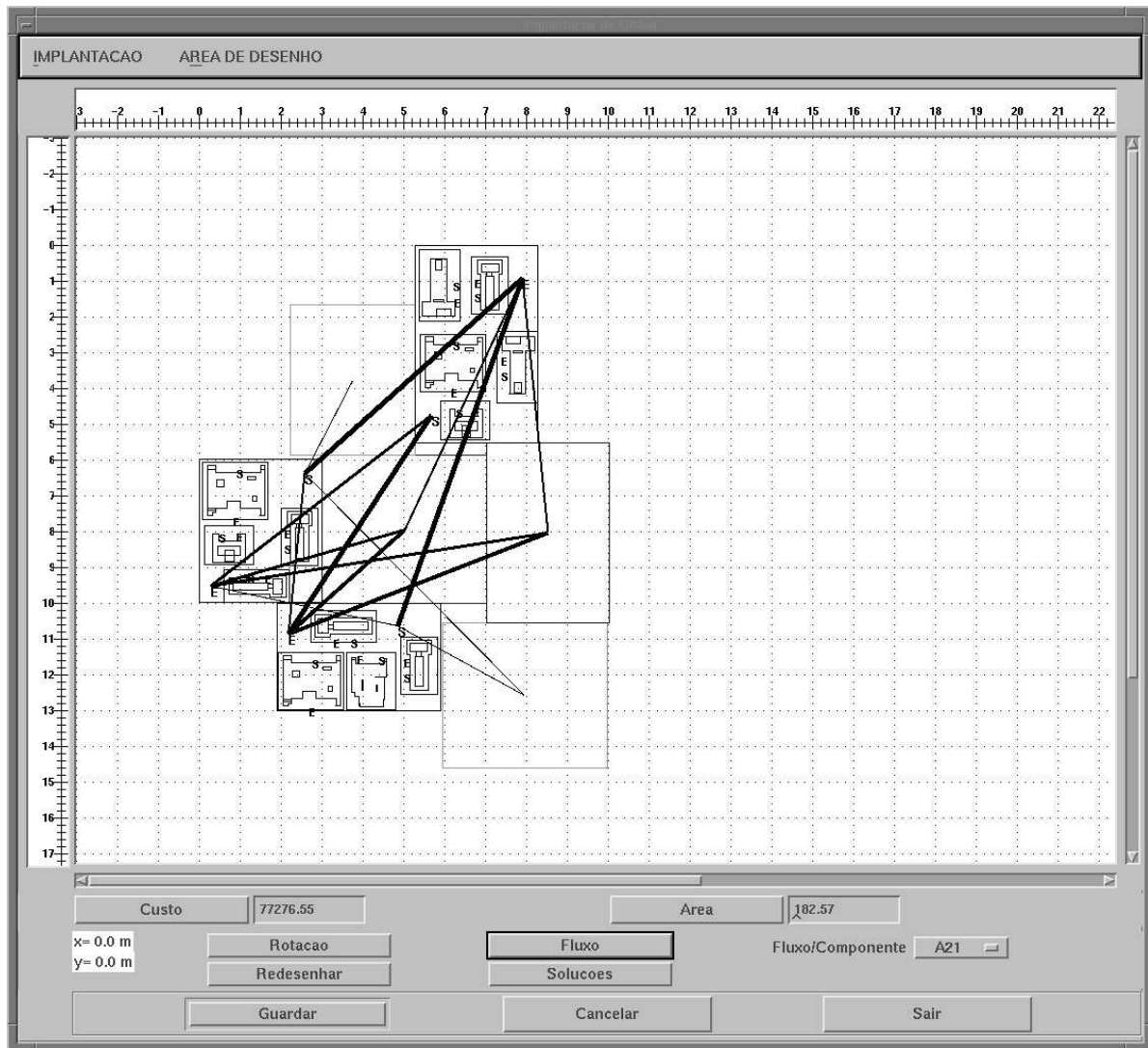
Figure 5: Main window of the facility layout module.

The tests that were carried out have shown that the proposed heuristic performed better that the FLOAT procedure by Imam and Mir [4] and the HOT procedure by Mir and Imam [5].

The solution found at the end of the proposed procedure in then shown graphically to the user, as illustrated in Figure 5, which presents an example of the layout of several sections in the plant.

6   Conclusions and future developments

The majority of the goals defined initially for the DSS presented in this paper were attained. To start with, a system was developed which supports in a friendly and comprehensive way the most important stages of the facility planning procedure. Secondly, the modularity of the

system was assured, allowing the user to approach the whole decision process in an integrated way or, alternatively, to address only parts of such a process. Thirdly, the choice of the underlying software components selected to develop the DSS - made at the beginning of a long development process - was found to be correct. Had this choice been inadequate and it might have jeopardised the development of the overall DSS at later stages. Finally, the expandability and portability of the system are thoroughly assured, thus guaranteeing the possibility of further development of the DSS.

Inevitably, the proposed system did not attain all the idealised requirements for a Facility Layout Design Support System. In what regards its limitations, there are two main issues which are worth noting.

The first one concerns the design of the material handling system, which is not supported by the current model basis of the DSS. The separate modelling of the material handling system is quite feasible. However, given the interactions between that system and the facility layout, a wholistic approach is clearly desirable. Though such an approach poses major difficulties unless some gross oversimplifications are introduced in the modelling process. Whilst that approach is found unfeasible, it is appropriate to keep the two subsystems separate but realistically modelled, leaving to the DSS user the task of integrating the solutions to the corresponding sub-problems.

The second issue is related, for each layout, to the evaluation of the dynamic behaviour of the underlying manufacturing system. In particular, the assessment of the space required for the work-in-process storage areas. The incorporation of techniques such as simulation or queue networks may prove useful in this context for the types of manufacturing systems addressed by the DSS.

Although the system as a whole as still to be tested in a real-life application, the facility layout design module was already used with great success in redesigning the plant layout of a cork factory.

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