

AN INTERACTIVE FACILITY LAYOUT ALGORITHM
FOR THE PERSONAL COMPUTER

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PREFACE

This thesis involved the development of a computer algorithm meant to assist the layout planner in the design of facility layouts. An IBM Personal Computer with a light pen and color monitor was used, and user knowledge of both basic layout concepts and general microcomputer usage was assumed. Although several other algorithms have been developed which actually create or improve layouts without any assistance from the designer, this program is used only as a tool; the creativity and subjective skill of the layout planner is fully utilized.

Because no other algorithms adequately combine the data manipulation powers of the computer with the creative abilities of the human, I believe that this work has a useful place in the arena of layout planning aids. As computer understanding matures, I feel that there will be more applications in which the computer and the human work as a team rather than as separate entities. This program works toward that end.

I wish to offer my sincere appreciation to my adviser, Dr. Carl B. Estes, for his careful guidance throughout this project and instruction in numerous courses. His input helped keep me on track, and to complete the project with relatively few problems. I would also like to express my

gratitude to Dr. Wayne Turner, both for his thoughtful input to this thesis and for the time and influence given to me as my academic adviser and assistantship supervisor. The things learned from him both directly and indirectly will undoubtedly benefit me greatly in the future. Additionally, I would like to thank Dr. Phil Wolfe for his invaluable assistance and input in the programming aspects of this work. Although computer programming was not an area of emphasis in my graduate work, my early instruction and recent comments from Dr. Wolfe served me well. I also wish to thank the Industrial Engineering department for both the educational experience gained and the financial assistance given me during my years there.

Lastly, I wish to thank my family, my friends, and especially Melissa, for their patience and unending support during the completion of my graduate work at Oklahoma State University. Your influence in my education will never be fully known.

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CHAPTER I

INTRODUCTION

Problem Environment

Facility Layout is concerned with the location within a facility of the various distinct operating units of the organization. Traditionally, application to manufacturing plants has provided the vast majority of facility layout problems, but the theory is equally applicable to any organization in which the interrelationships of the various departments are considered important. Examples include hospitals, warehouses, schools, offices, banks and airports (4). In each of these (including manufacturing), the access to or flow of materials, paper, people, information, supplies and services affects the efficiency and effectiveness of the entity.

Facility Layout Considerations

The process of layout planning involves determining the objectives of the facility and obtaining reliable data as two of the most important factors to success (12). These two factors, however, must be translated into some format which drives the layout process. According to a survey by Richard Muther (12) economic attractiveness, matching with

business needs, flexibility, flow of materials, and future adaptability ranked as the five most important objectives for a facility. A discussion of these will shed some light on how the layout process actually takes place. Taking these objectives one at a time, and then combining where appropriate, leads to a strong statement of relative importance.

Economics. Economic attractiveness can be broken down into two major parts: either the original cost of the facility or the re-layout of the facility (as appropriate to the problem), and the operating expenses of the facility. For a new facility, it is highly reasonable to assume that the location of departments within the building will have a relatively small effect on the first cost (given that total area remains about the same and radical shapes are avoided). Therefore, the economics is driven almost totally by the operating expenses. The operating expenses are two-fold: energy costs and material flow costs. (Notice that expenses independent of the facility design are not considered here.) The main energy costs associated with the placement of departments have to do primarily with maintaining comfort in areas with high personnel density (locate away from north and west walls) and minimizing air infiltration (avoid loading areas open to prevailing winds) (24). However, these energy based considerations can easily be treated as supplemental constraints to the material flow data. Likewise, the desire to achieve close physical placement of

waste heat sources and uses and to provide for easy cost center metering affect the relationships between departments in the same way as material flow considerations. Though obviously unrelated to material flow, they may become direct inputs to the REL chart (discussed further in Chapters II and III) in exactly the same manner as material flow. Consequently, the material flow costs appear to be the driving factor in the economic attractiveness of a new facility, at least so far as layout considerations are concerned.

The same logic can be applied to re-layouts in existing buildings with one exception. The initial cost is somewhat proportional to the degree of department movement. Therefore, material flow savings must be weighed against the initial cost on an incremental, move-by-move basis.

Matching. In describing this objective, Muther used such terms as "matching facilities to business needs," "balanced capacity," and "utilization of facilities." These pertain more to proper sizing and capacity issues rather than to layout design and will be considered as separate from this discussion.

Flexibility. This objective is becoming more and more important as products and services of organizations change with increasing rapidity (22). Though flexibility is often required due to anticipated changes in technology, product or product demand, it does not come without a cost. Figure

1 illustrates the "Spine Concept" (22). Because each department has exterior wall access, each can be expanded individually with changing needs. For this flexibility, a higher initial cost of construction or poorer initial utilization is incurred, and definite constraints on the ability to locate departments near those with high shared material flow must be dealt with.

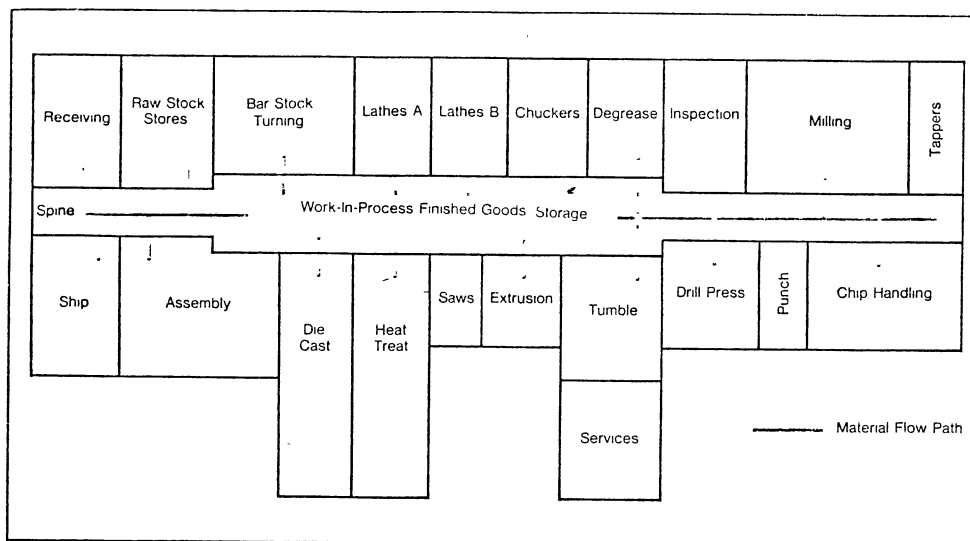


Figure 1. The "Spine Concept"
(Source: 22, p. 40)

If the process lends itself to automated material handling, the effects of this factor are reduced, but longer travel or "backtracking" must still be considered. In any case, even if flexibility is considered necessary at any

expense, there is no reason to expect that the material flow relationships of departments would be of less than the second most important objective in determining long range cost.

Although future adaptability was listed by Muther as a distinct objective, no difference is shown between it and flexibility. This discussion will consider them to be the same.

Material Flow. Although ranked fourth in Muther's list of prime objectives, the preceding discussion has shown that material flow relationships are normally the driving force concerning economic attractiveness, are highly important even when flexibility and future adaptability must be maintained, and are not contradicted by "matching" requirements. Furthermore, the data requirement previously listed as the other most important success factor (besides objectives, see page 1) is almost totally defined by material flow data. The importance of this factor is obvious.

The Layout Process in Practice

Although many writers are making statements that the day of layouts based upon material flow considerations is over (9) (22), no other criteria has displaced it from its position of prominence. Both economics and flexibility are really just constraints on the problem of designing a layout which minimizes operating costs -- or more specifically,

material flow.

The problem, therefore, which finally reaches the layout planner's desk is to assimilate mounds of data and develop a layout which minimizes operating cost while meeting the constraints of the organization. It is this problem which is addressed by this thesis and for which a solution -- in the form of a computer program to be used as a tool -- is presented.

Layout Aids

Both intuition and actual experience point to the fact that assimilating and using the aforementioned data can be an overwhelming task. A facility with only ten departments has 45 interrelationships, not to mention constraining factors and special considerations. The ability of the human mind is strained to keep this much data straight, as anyone who has worked on a problem of this type well knows.

Several aids have been developed to assist the facility planner in producing layouts. Systematic Layout Planning (SLP) is the only manual approach in widespread use. The most frequently used computer packages are ALDEP, CRAFT, CORELAP, COFAD and PLANET. Each of these techniques will be discussed in detail in the next chapter. For now, suffice it to say that they all have serious drawbacks in the areas of time required and/or quality of results and/or accessibility.

For these reasons, a tool is needed which is easy and

fast to use, yields good results and is easily accessed. Development of such a tool is the subject of this thesis.

Research Goals

The outcome of this research effort is an interactive computer algorithm to aid the facility planner in quickly and easily developing new plant layouts. While other non-interactive algorithms are available, they have several major drawbacks: (1) limited ability to achieve meaningful department shapes; (2) limited ability to set building shapes; (3) little or no conception of the "big picture" (i.e., the ability to "look ahead" as departments are entered); (4) little chance for intelligent intervention from the human along the way, and little "help" from the computer when such chance exists; and (5) limited availability to the person actually doing the layout. Accordingly, this project seeks to overcome these deficiencies while providing block layouts that are actually useable.

CHAPTER II

REVIEW OF CURRENT LITERATURE

Although many analytical techniques have been applied to facility layout, the process still requires a certain subjective skill. As Tompkins and White (23) state,

Facility planning may be likened to painting a picture or playing a musical instrument. There are general guidelines, principles, and techniques that, if followed, may lead to an effective facilities plan, a beautiful piece of art, or a splendid performance. However, one must go beyond an intellectual understanding of guidelines, principles, and techniques and develop a feel for the interrelated, often conflicting, objectives that affect the overall results. Facilities planning then, although becoming more scientific, continues to rely greatly on the experience of planners (pp. 7, 8).

This chapter will examine those techniques and principles. The facilities planner must always remember, however, that his own thoughts, "feel", and intuition are an important and necessary part of the process.

Basic Layout Theory

Objectives of Plant Layout

According to a recent survey (12), respondents reported that clearly stated and understood objectives were the most important factor in the success of a new layout. It is interesting to note that their comments pertaining to

objectives centered not on which particular objectives were most important, but rather on the need to ascertain what management wanted from the facility.

As to typical objectives under which a facility design project may operate, most authors state objectives in terms of minimizing some expense or providing for general order in operations. The list presented by Tompkins and White (23) seems to encompass most factors and is presented here.

1. Support the organization's mission through improved material handling, materials control, and good housekeeping.
2. Effectively utilize people equipment, space, and energy.
3. Minimize capital investment.
4. Provide flexibility.
5. Promote ease of maintenance.
6. Provide for employee safety and job satisfaction (p. 8).

Although not explicitly stated, the objective of "minimized operating expense" is couched in all of these.

Since these objectives cover a broad spectrum of needs, it is evident that the likelihood of any one layout being "best" on all these objectives (plus others) is very, very small. Thus the dependence on the layout planner's judgement in determining which criteria are most important and developing a layout which comes closest to satisfying the most important needs.

Steps in the Layout Process

Although much of the facilities design process is dependent upon the skill and judgement of the analyst, an organized, systematic approach will help produce better layouts, just as adherence to the rules of art and music will produce better paintings and compositions. The basic engineering design process of (1) defining the problem; (2) analyzing the problem; (3) generating alternatives; (4) evaluating the alternatives; (5) selection; and (6) implementation lends itself very well to facilities design. The more specific version follows (adapted from Tompkins and White, 23).

1. Define the objective of the facility.¹ As stated earlier, there is strong consensus that identification of the important objectives and purposes of the facility is crucial.
2. Identify the primary and support activities (departments). This details what functions are necessary to accomplishing the facility's objectives.
3. Determine the interrelationships among all activities. Both qualitative and quantitative assessment is given as to how activities interact with one another.
4. Determine the space requirements of each activity. Equipment, materials, people, and access requirements are taken into consideration.
5. Generate alternative facility plans. Use some method(s) to actually arrive at alternative solutions.

¹Objectives of the facility and those of the layout process (presented earlier), should be kept separate.

6. Evaluate the alternatives. This includes both subjective and objective considerations.
7. Select and implement a plan (pp. 10, 11).

Although not every project will adhere exactly to this approach, the majority will follow it closely.

Review of Selected Layout Techniques

An examination of the steps presented in the previous section show three major functions: (1) preliminary information gathering; (2) actual creation of a layout(s); (3) selection and implementation. The remainder of this thesis will focus on the second function, creation of layouts.

It is in this stage that both the use of method and technique and the creative abilities of the designer must come together at one time. In this chapter the major manual and computer methods of arriving at layouts will be discussed. The algorithm which is the subject of this thesis will be discussed in the next chapter.

Systematic Layout Planning

Systematic Layout Planning (SLP) is the major manual layout technique today. SLP was developed by Richard Muther (11) in the late 1950's. Although it has undergone several revisions and updates, it is still recognized as an efficient layout tool.

SLP is designed to provide a logical, easy-to-use, straightforward approach to integrating the various aspects

of facility design. Organizationally, it breaks the project into four phases: (1) location; (2) overall layout; (3) detail layout; and (4) installation. These are shown in Figure 2. Phase II, overall layout, is where block layouts are developed and where most of the SLP's techniques are employed.

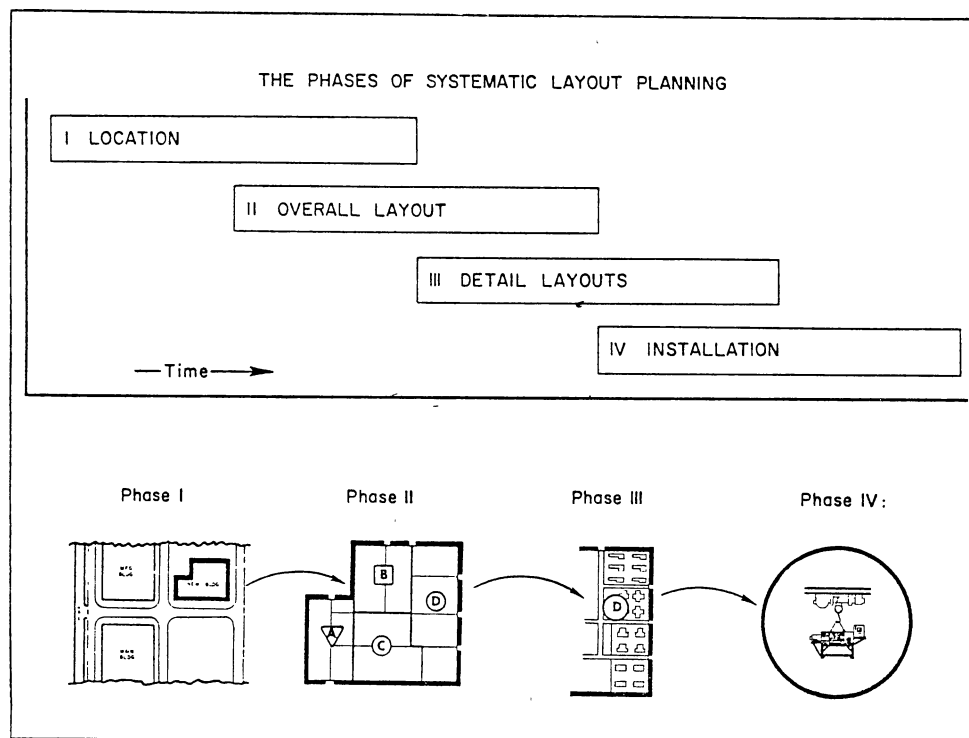


Figure 2. Phases of Systematic Layout Planning
(Source: 11, p. 1-9)

Operationally, SLP use a relatively structured pattern of procedures to guide the analyst toward the desired end product. As shown in Figure 3, this consists of obtaining

input data on area requirements, flow of materials, and activity relationships. At that point, the flow and relationship data is merged into a relationship diagram. Space considerations are then added to obtain a space relationship diagram. Modifying variables are then incorporated to arrive at alternative plans. Finally comes evaluation and selection.

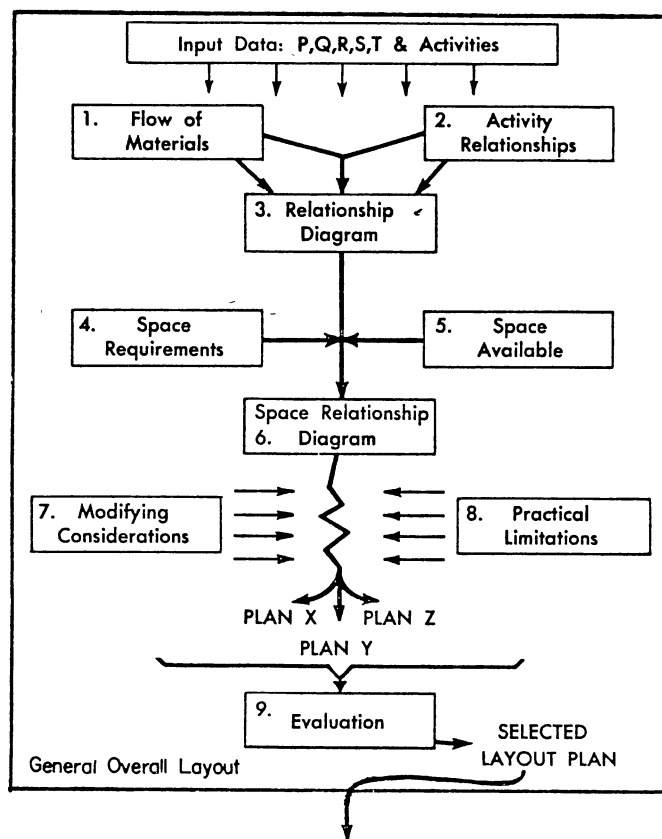


Figure 3. SLP Pattern of Procedures
(Source: 11, p. 2-5)

A major component of SLP is the relationship chart (REL chart). According to Muther (11), the REL chart is "one of the most highly practical and effective tools available for layout planning" (p. 5-2). This is also born out by its prevalence in other layout methods. A "cut-away" REL chart is shown in Figure 4. As can be seen, it rates the relative importance of the relationships between various activities and also provides an easy way of giving a reason for the rating. The five vowels plus "X" provide a six point rating scale.

Because of its comprehensive nature, the REL chart is a major input to the algorithm of this thesis. It is also worth noting that an understanding and familiarity with SLP will help the analyst make the judgments and decisions necessary to use that algorithm. In this way SLP's major drawback -- remembering large quantities of data -- is overcome by the computer and its main advantage -- allowing for high levels of human input -- is retained.

CRAFT

CRAFT (Computerized Relative Allocation of Facilities Technique) was developed in 1963 and became the first commercially available computer aided layout routine (23). It attempts to minimize total transportation cost in a facility, where the cost is defined as the product of volume moved, distance moved, and cost per unit distance per unit load. The validity of CRAFT requires the acceptance of

these assumptions (21, 23).

1. Move costs are independent of the utilization of equipment.
2. Move costs are known with confidence.
3. Move costs are linearly related to the length of the move.

If the assumptions do not hold in the particular project under study, CRAFT should only be used with care.

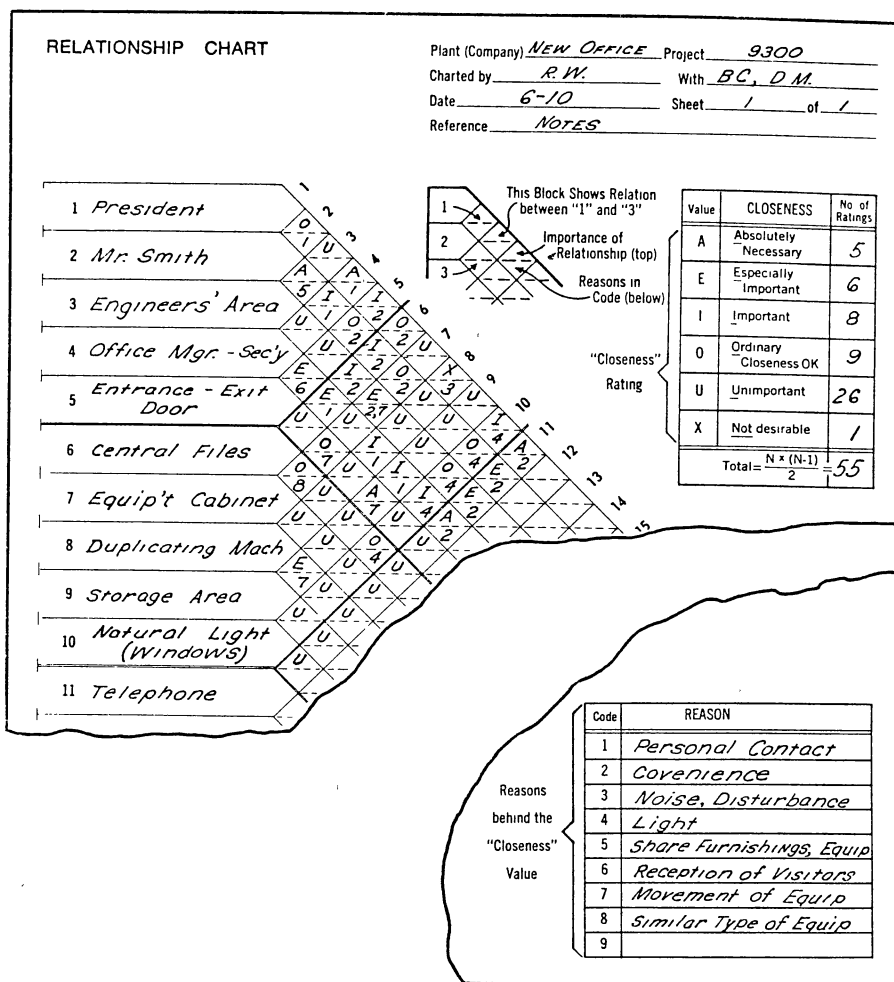


Figure 4. Relationship Chart
 (Source: 11, p. 5-4)

Current computer aided layout techniques can be classified philosophically into two broad categories -- improvement routines or construction routines. CRAFT is an improvement routine -- that is, it takes a layout provided by the user and attempts to improve it based on attempts to minimize the transportation cost. The CRAFT algorithm examines the effects of "switching" the locations of departments which are adjacent to each other or which have the same area. If any such switches give a lower transportation cost, the switch is made and a new layout is generated. This continues until no further switches can be made which reduce the move cost.

Because of the path orientation of CRAFT, the user should be aware that the final layout is dependent upon the "potential" provided by the original layout (23). Therefore, several runs using different initial layouts must be made to arrive at a high level of confidence. CRAFT also employs "dummy" departments which may be used to fill building irregularities, represent fixed areas, or locate aisles (23). An example of a CRAFT layout is shown in Figure 5 below.

COFAD

COFAD (Computerized Facilities Design) is basically a modification of CRAFT to allow the use of move costs for a variety of material handling alternatives (21, 23). The user may input information pertaining to different material

handling alternatives for each move, and the algorithm considers those alternatives along with the switching of departments.

LOCATION PATTERN

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	A	A	A	A	A	A	A	C	C	C	I	I	I	I	I	I
2	A					A	A	C		C	I					I
3	A					A	C	C	C	C	I	I	I	I	I	I
4	A					A	C	C	C	H	H	H	H	J	J	J
5	A					A	G	G	G	H			H	J		J
6	A	A	A	A	A	A	G	G	G	H			H	J	J	J
7	B	B	B	B	B	B	G	G	H	H	H	H	H	K	K	K
8	B				B	B	F	F	L	L	L	L	L	L	L	K
9	B				B	F	F	F	L					L	L	L
10	B				B	F		F	L							L
11	B	B	B	B	B	F	F	F	L							L
12	D	D	D	D	E	L	L	L	L	L	L	L	L	L	L	L
13	D		D	E	E	E	L	L	L	L	M	M	M	M	M	M
14	D		D	E		E	M	M	M	M	M					M
15	D		D	E		E	M									M
16	D	D	D	E	E	E	M	M	M	M	M	M	M	M	M	M

Figure 5. CRAFT Layout
(Source: 4, p. 134)

COFAD also has the ability to adjust the flow volumes by a specified percentage in order to test the layout's sensitivity to uncertainties or changes in flow volumes. Since both the layout and the material handling selections are re-evaluated, the user is provided with realistic information to aid in the facility design (23).

Since COFAD is an improvement routine and a modification of CRAFT, the same path dependency of the final layout to the initial layout holds true. Therefore, once

again, several initial layouts should be considered. An example of a typical COFAD output is shown in Figure 6.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G	
2	A									A	G							G	
3	A	A	A	A	A	A	A	A	A	A	G	G	G					G	
4	C	C	C	B	B	B	B	B	B	B	F	F	G	G	G	G	G	G	
5	C		C	C	B					B	F	F	F	F	F	F	F	F	
6	C			C	B	B	B	B	B	B	F	F	F	F	F	F		F	
7	C	C	C	C	B	D	D	D	C	E	E	E	E	E	E	F		F	
8	D	D	D	D	D				D	E					E	F		F	
9	D							D	D	E	E	E	E	E	E	F		F	
10	D	D	D	D	D	D	D	D	H	H	H	H	H	H	H	E	F	F	F

Figure 6. COFAD Layout
(Source: 23, p. 278)

PLANET

PLANET (Plant Layout Analysis and Evaluation Technique) differs from CRAFT and CORELAP in that it is a construction routine rather than an improvement routine. As such, it requires no initial layout be provided by the user, but "builds" its own from scratch.

PLANET operates in three phases to generate a layout (21). In the first, the input data is translated into a form which may be used by the computer. The second involves selecting the order in which departments are to enter the layout. The third phase is determining the placement of departments when they enter the layout.

Besides inputting the area of each department (these were implied by the initial layouts of CRAFT and COFAD) and cost per move data, the user has three methods available for inputting material flow data (21). The first alternative is to input the production sequence for each part to be handled, along with the quantity. Another method is to input the from-to chart directly. The last method is the penalty matrix, which is similar to the REL chart discussed earlier, only instead of rating the need to be close it rates the penalty for being apart.

Additionally, the user must rank each department as to placement order priorities, and select from among three methods of determining the selection order of the departments. The difference between the methods is the way they break ties of placement priorities (21, 23).

As each department enters the layout, it is placed so as to minimize the increase in move cost. However, no consideration is given to the requirements of yet to enter departments or to the shape of departments or the final facility. The user of PLANET should expect to use the layout obtained as an initial layout for manual adjustment, not as a final layout (23).

CORELAP

CORELAP (Computerized Relationship Layout Planning) was the first construction algorithm (21). It uses Muther's REL chart as the primary input to both determine the selection

order and to find the actual placement of departments.

Each department is assigned a total closeness rating (TCR) based upon its relationship to all other departments (A, E, I, O, U, or X). The department with the highest TCR is the first to enter. Subsequent departments enter based upon their relationships to those already entered. Placement is determined so as to maximize the current placement rating, which is the sum of the point values given to satisfied relationships (ex: A=64, E=32, I=16, O=8, U=2, X=-64). As in PLANET, no provision is made during placement for future entering departments.

A special version of CORELAP, called Interactive CORELAP (or SCORE/CORELAP) is also available (4, 8, 9). In this version, the user can make adjustments to the layout produced by CORELAP, and even intervene during the process of department placement. There is a heavy emphasis on being able to ask for a score for the layout at any time in order to assist the designer. However, little proactive information is made available to the user to aid in making intelligent input to the computer process. Nonetheless, the chance for human input is a giant step in the right direction for computer aided layout design.

In both regular and interactive CORELAP, irregular building shapes must be anticipated. Several authors also warn of being too reliant on using the score provided by CORELAP as the sole evaluation measure, suggesting independent judgement as well (4, 23).

ALDEP

ALDEP (Automated Layout Design Program) is a construction routine like PLANET and CORELAP. It differs from these philosophically, however, in that it generates many alternative layouts (and associated scores) rather than attempting to determine the one best layout. In this way the user is given several options.

The first entering department is selected randomly, and the next department is selected based upon having a certain minimum ("must") relationship with the first. If none is found, a department is selected at random. The process is then repeated, comparing all not yet entered departments to the last entered department for those having the "must" value relationship (21). As implied here, ALDEP is driven by a standard REL chart. Although the normal six values (A, E, I, O, U, X) are recognized for scoring purposes, the selection of a minimum relationship as a "must" value effectively divides the relationships into "important" and "unimportant" from the selection process viewpoint (21, 23).

Department placement is accomplished by starting in the upper left corner of a user defined, rectangular building and extending downward, then back up again as departments enter. Figure 7 shows the serpentine pattern that placement follows. The width of the sweep is user specified and should be experimented with to test its effect on layout score and department shapes (23).

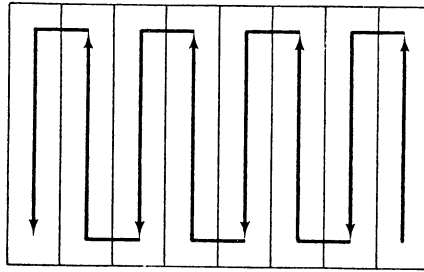


Figure 7. ALDEP Placement Pattern
(Source: 4, p. 104)

ALDEP has good capabilities to fix the location of aisles, docks, elevators, etc., and its "sweep placement" procedure can be made to give realistic department shapes (with proper adjustment of the sweep width). By printing multiple layouts, ALDEP can be a good aid in the "generate alternatives" stage of the layout process.

Summary

Although there are other computerized routines available (COMPROPLAN, IMAGE, LAYOUT, OFFICE, SPACE, SOMI, et al.) those discussed here are the ones of primary interest to the industrial engineer. In general, they are all merely tools for the "generate alternatives" step of the layout design process, presented early in this chapter. Used in that way, they are reasonably effective. A major drawback, however, is their independence from human intervention. As layout design becomes more sophisticated, it should be realized that the computer is best used as a

tool in the designer's hands, not a substitute for the designer. The program described in the next chapter attempts to do just that.

The interested reader is referred to Francis (4), Tompkins (21, 23), and Muther (11) for more information on the methods presented in this chapter.

CHAPTER III

DESCRIPTION OF THE LAYOUT ALGORITHM

Overview of the Program

This chapter describes a computer program which assists the layout planner in developing a new layout. While the programs discussed in the previous chapter actually develop layouts, this program takes the viewpoint that the creativity and subjective judgement of the designer is too valuable a resource to not use to full advantage. The computer, therefore, is used only as a tool to aid the planner, not as a substitute for his skills.

The computer program takes a REL chart as the primary input and uses it to determine an entering order for departments. Then, by examining the relationships among the currently entering department, those already placed in the layout, and departments yet to be placed, the program generates instructions informing the analyst of the important considerations he should consider. In this way, the computer manipulates, analyzes, and edits the data to present the designer with concise, but complete information relevant to placing the department in the layout.

An important aspect of this procedure is the "look ahead" feature it incorporates. Rather than place a depart-

ment completely by its relationship to those departments already in the layout, the requirements of departments not yet entered are also considered. By looking ahead in this way, a placement which seems fine in the immediate context, but which precludes a future requirement from being fulfilled can be avoided.

As an output of the computer program, the designer is given information about the relationships between the entering and current departments, between the entering and future departments, and between future and current departments. By translating this information into "plain English" instructions, the designer is freed from trying to keep track of the data and can therefore concentrate on building a good layout.

The mechanics and details of the program will be described in the remainder of this chapter.

Specific Features of the Program

The specific features of the program will be presented in basically the same order in which they are encountered during program operation. The necessary inputs are listed in Table I below. There are no particular format requirements in the program and complete prompts are given as needed.

Input Requirements

Program Option. The user has two options as to program

operation. Option one is for constructing a new layout completely from scratch. If the user has previously stored a layout on a disk from an earlier session, option two may be chosen. Selection of option two requires the input of the file name under which the layout was stored, but allows for skipping most of the other input information since it is stored with the layout.

TABLE I
INPUT REQUIREMENTS

Required Inputs

Program Option
Number of Departments
Relationship Chart
Department Areas
Square Feet in a Unit Square

Optional Inputs

Department Names
Special Instructions
Building Outline

When working under option two, the computer displays the layout as it was stored and steps through the placement steps in order. However, rather than place each unit square, the program goes straight into its modification mode (discussed later). This scheme provides for easily and

quickly constructing various alternative layouts.

Number of Departments. When prompted, the user inputs the number of departments. Up to 20 are allowed under the current configuration.

Relationship Chart. The relationship chart is entered in response to individual prompts for each relationship pair. The standard A, E, I, O, U, and X scheme of rating relationships is used. If an illegal rating is given, the same prompt is given again to input the correct rating. After input is complete, the REL chart is displayed and corrections are allowed.

Department Areas. The area of each department is entered in number of square feet. There is an individual prompt for each department and corrections are allowed after input is complete.

Unit Square Size. The program uses a grid which contains 680 unit squares (17 x 40) on which the layout is placed. The user must define the number of square feet in each department so the program can assign the correct number of unit squares (21) to each department. If the total number of squares exceeds 600 the user is instructed to redefine the unit square size and is informed as to what the minimum area must be.

Department Names. If the user desires, he may assign names to each department. These will appear on the "tableau

page" listed in the same order as the selection order. The current entering department is listed in red for easy identification. Failure to use this option results in departments being referred to by letter (A, B, C, D, etc.) only.

Special Instructions. Occasionally a department has special requirements such as having a certain shape in order to accommodate equipment or to be placed on a certain wall for necessary exterior access. These considerations are irrelevant to inter-relationships between departments and do not show up in the REL chart.

To relieve the designer from having to remember these special considerations, he is allowed the option of stating these requirements during initial input. Although they do not effect the selection order or scoring processes, they do show up as a part of the instructions for placing the department of interest. The user then has complete placement information before him at one time.

Building Outline. Although strict layout theory dictates designing the building around an optimum layout, in reality the layout often must fit into an existing or already under construction building. When this is the case, the analyst may want to include an outline of the building on the layout grid in order to incorporate that constraint into the layout.

The program provides for two methods of drawing the

building onto the layout. If the building is rectangular, the user simply identifies the upper left corner with the light pen, then specifies the "X" and "Y" dimensions of the building in feet. If the building is irregularly shaped, however, each side must be drawn individually. Again, a corner is identified with the light pen. Then, one side at a time, the designer specifies the direction and distance to draw, until the building is complete. Both methods provide ample opportunity to correct mistakes.

Output and Operations

Selection Order. The portion of the program for determining selection order (and for REL chart input) was taken from a program written for that purpose by Khator and Moodie (6) and published in the March 1983 issue of Industrial Engineering magazine. They first determine a closeness ranking based upon the number of "A" relationships, then E's, and so on. The number one closeness ranked department is the one with the most important relationships, and it becomes the first department in the selection order.

The second department is selected based upon the importance of its relationship to the first. The closeness rank is used to break ties. Subsequent departments are selected based upon the total number of A, then E, the I, etc. relationships with already entered departments. If any departments are tied through each relationship level, the closeness ranking is used to break the tie.

Tableaus of Pertinent Information. In operation, the program goes back and forth between two "pages." The first is the "tableau page," while the second is the "layout page." The tableau page is shown in Figure 8 and will be partially described here and partially described under the subsection on specific placement instructions.

TABLEAU NUMBER 2

DEPT NO.	F	E	G	B	D	A	F	PLATING
							E	ASSEMBLY
E	A	*	I	I	I	X	G	SHIPPING
G	E	*					B	MILLING
B	I	*			E	E	D	SCREW MACH
							A	RECEIVING
							C	PRESS

PLACE DEPARTMENT E SUCH THAT IT:

TOUCHES DEPARTMENT(S) F
 LEAVES ROOM FOR DEPT. G TO TOUCH DEPT(S). F
 LEAVES ROOM FOR DEPT. B TO TOUCH DEPT(S). F
 CAN TOUCH DEPARTMENT(S) G AND B AND D WHEN THEY ENTER

HIT 'RETURN' WHEN READY TO CONTINUE

Figure 8. Example Tableau Page

After the selection order of the departments is determined, the REL chart is rearranged from being in sequential order by department to being in selection order, as shown in Figure 9. By arranging the REL chart in this manner, the important relationships are brought into closer proximity to one another. This can be emphasized by "blanking out" the

relatively less important (and more frequent) "O" and "U" relationships. as shown in Figure 10.

Standard REL Chart								Rearranged REL Chart							
DEPT	1	2	3	4	5	6	7	DEPT	6	5	7	2	4	1	3
1	-	E	O	I	O	U	U	6	-	A	E	I	U	U	O
2	E	-	U	E	I	I	U	5	A	-	I	I	I	O	U
3	O	U	-	U	U	O	U	7	E	I	-	U	U	U	U
4	I	E	U	-	I	U	U	2	I	I	U	-	E	E	U
5	O	I	U	I	-	A	I	4	U	I	U	E	-	I	U
6	U	I	O	U	A	-	E	1	U	O	U	E	I	-	O
7	U	U	U	U	I	E	-	3	O	U	U	U	U	O	-

Department Selection Order: 6 5 7 2 4 1 3

Figure 9. REL Chart Re-arranged by Selection Order

Rearranged REL Chart							
DEPT	6	5	7	2	4	1	3
6	-	A	E	I			
5	A	-	I	I	I		
7	E	I	-				
2	I	I		-	E	E	
4		I		E	-	I	
1				E	I	-	
3							-

Figure 10. Selection Order
REL Chart

This rearranged REL chart is then edited into a "tableau" by the program in order to show only the information that is pertinent to the designer at that particular placement stage. Since the REL chart is in the same order as the selection order, all rows above that of the current entering department are for departments already placed and can be eliminated. Therefore, the entering department becomes the first row.

Already placed departments are still represented in the columns of the chart. The last row of the tableau is determined as the last department (in selection order) that has an A, E, I, or X relationship with an already placed or entering department. Departments which have no such relationship are irrelevant at the current step and their rows are left out of the tableau

The first column shown is that of the first department which has an important relationship (A, E, I, or X) with departments represented as rows. The last column is that of the last department which has an important relationship with the entering department.

The result of this process is the tableau shown in Figure 11. As can be seen, three types of information are given by the tableau. First, any important relationship between the entering and already placed departments is shown on the first row. Second, the relationship between subsequent and already placed departments are given in the left side, from the second row down. Third, relationships

between the entering and subsequent departments are given on the right side of the first row. Together, this information allows the designer to place the current department such that both current and future relationships can best be satisfied.

REL Chart							Tableau						
DEPT	6	5	7	2	4	1	3	DEPT	6	5	7	2	4
6		A	E	I				5	A	*	I	I	I
5	A		I	I	I			7	E	*			
7	E	I						2	I	*			E
2	I	I			E	E		Entering department: 5					
4		I		E		I		Already placed department: 6					
1				E	I			Yet to enter departments: 7,2,4					
3													

Figure 11. Tableau Generation from the REL Chart

Specific Placement Instructions. In order to aid the designer in interpreting the tableau, the program takes the data presented there and transforms it into "plain english" instructions. These instructions can take four forms as shown in Figure 12 below. The instructions are generated as a result of where in the tableau relationships are encountered. For example, the first row of the tableau represents relationships between the entering department and

already placed or future departments, and so on as described in the previous section.

DEPT NO.	F	E	G	B	D	A
E	A	*	I	I	I	X
G	E	*				
B	I	*			E	E

PLACE DEPARTMENT E SUCH THAT IT:

TOUCHES DEPARTMENT(S) F
 LEAVES ROOM FOR DEPT. G TO TOUCH DEPT(S). F
 LEAVES ROOM FOR DEPT. B TO TOUCH DEPT(S). F
 CAN TOUCH DEPARTMENT(S) G AND B AND D WHEN THEY ENTER

or

DEPT NO.	E	G	B	D	A
A	X		E	I	*

PLACE DEPARTMENT A SUCH THAT IT:

TOUCHES DEPARTMENT(S) B AND D
 DOES NOT TOUCH DEPT. E

Figure 12. Example Placement Instructions

For convenience to the user, the instructions are repeated on the "layout page," along with the department letter or name and the number of unit squares in the department. These instructions are in a slightly abbreviated form.

Method of Placement. After receiving the placement instructions, the layout planner is ready to actually place

the department in the layout. The program will go to the layout page, where the designer will see the layout grid, a 40 x 17 matrix of small boxes, each one representing a unit square. As the program waits, the designer places successive unit squares onto the grid by touching a light pen to those squares in which he wishes the department placed. In this way, the designer has complete control over the shape of the department and its exact relationship to other departments.

As squares are placed, the computer keeps track of how many and stops allowing placement when the correct number have been placed. Additionally, the program has a special "write protect" feature which prevents placing a square of the entering department on top of any previously placed department square. This prevents any accidental modification during this stage. Modification is allowed, however, as will be explained next.

Method of Modification. One of the important features of this program is the flexibility to modify the layout at almost any time. By doing so, the the computer truly becomes a tool in the hands of the designer, allowing for maximum creativity.

After the completion of each department placement, the user is asked if any modification is desired. An affirmative answer puts the user into the program's modification mode, where he has the option of deleting squares or

adding squares of any letter, without restrictions. He may stay in this mode as long as he wishes. When through modifying, the program returns to the next step in the department placement routine.

After the last department is placed, a special prompt is given which warns that this is the final chance to modify the layout. Again, complete freedom is given to modify in whatever way is desired.

Besides these opportunities lies one other chance for modification. After scoring the layout (to be discussed next), the program gives the option of returning to the layout page for further modification, presumably to correct any deficiencies pointed out by the scoring routine.

The ability to change one's mind and to "massage" the layout is essential to the creative layout design process. This program makes every effort to allow the user complete freedom to do so as often as he likes.

Scoring the Layout. In order to help evaluate the quality, or performance characteristics, of the layout, a scoring routine is provided. The program uses a simple binary scoring algorithm which classifies departments as either "touching" or "not touching". (Contrary to most such algorithms, touching corners count). If a relationship is satisfied, points are awarded according to the importance of the relationship.

The final score is compared to the "perfect" score which would be obtained if all relationships were satisfied

and if the score is less than perfect, the program identifies which relationships were not satisfied. The designer is then given the opportunity to return to the layout grid to make modifications in order to correct deficiencies. This cycle can be repeated as often as desired.

Saving and Recalling a Layout. During the course of a layout design project it is quite likely that the designer will be called upon to work on and modify the layout at several (if not many!) different times. In order to avoid having to input all the data required and construct the layout each time, the user is given the option of saving all pertinent input data as well as the actual layout on a disk. All that is required is a file name to identify that particular layout.

Upon resuming work at the beginning of a new session, the user will select the input option specifying the desire to read a layout from a file. After specifying the file name, all data is loaded. The program then "steps through" each department placement by showing all tableaus and instructions as before, but instead of placing each department in order, all are already on the grid and the program goes directly to the modification option. If a modification is desired it can be made; if not, the program continues until all departments have been worked through. By operating in this way, the designer still has all relationship data and instructions at his fingertips, but

has complete freedom to modify as needed.

General Comments

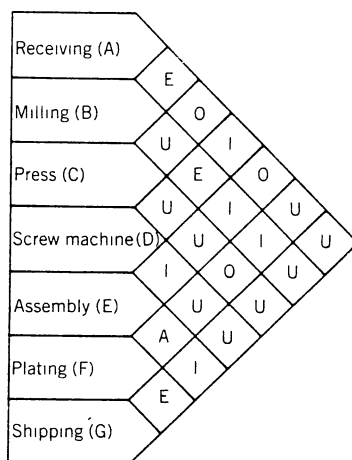
As can be seen, every effort has been made to put the designer in control of the computer and the layout and not vice versa. By allowing the computer to handle and manipulate the data and the designer to be creative without restriction, both more nearly fulfill their proper role.

In order to illustrate and further explain the operation and features of this program, the next chapter will work through an example problem step by step. Extensive use will be made of figures from the actual program output, and specific inputs and options will be presented in more detail. With the information in this chapter and the example in the next, the reader should have a good understanding of the program.

CHAPTER IV

EXAMPLE PROBLEM

In order to further explain the details and operation of the program, the following example is offered. This problem involves seven departments totaling 70,000 square feet, and is taken from the monograph by Tompkins and Moore (21). The relationship chart and department areas are shown in Figure 13. In addition to those factors, we will also assume that the receiving and shipping departments must be on the north or west (top or left) wall because of access requirements with a railroad siding.



Code	Function	Area (square feet)
A	Receiving	12,000
B	Milling	8,000
C	Press	6,000
D	Screw machine	12,000
E	Assembly	8,000
F	Plating	12,000
G	Shipping	12,000

Figure 13. The Problem Parameters
(Source: 23, pp. 241, 244)

This chapter will be broken into three main sections. The first will cover the necessary inputs required for the problem. The second will discuss the major operational issues, specifically the actual department placement. The third section will cover the routines for scoring, evaluating, correcting, and storing the layout. In each section, a narrative will explain what is happening, followed by a figure showing the actual computer transactions.

Program Inputs

After loading the program disk, the user is first confronted with a decision as to which program option to execute. The first is to work on a layout from scratch, the second is to resume work on a layout already stored on a disk. We will choose the first option. Had we chosen the second, we would have been asked to specify a file name for the desired layout, and all input requirements would have been skipped.

The number of departments is entered (up to 19 are allowed), followed by the option of inputting the names of each department. We will take this option. The relationship chart is then entered by responding to a prompt given for each pair of departments, so no difficult format restrictions are required. After the REL chart is completed, it is printed on the screen and the opportunity is given to make changes. We do not need any.

While relationships are fresh in the designer's mind he is asked if there are any special instructions not covered by the REL chart. We have such instructions for Receiving and Shipping (departments 1 and 7), as stated earlier. These are entered free format, other than being limited to one line. The computer now has enough information to calculate the closeness rank and selection order (described in Chapter III). These are labeled and printed to the screen.

The next inputs for the problem are the number of square feet in a unit square and the areas of each department. (Our first entry for the unit square size, 100 square feet, was later rejected as too small, meaning that it would make the layout require more squares than are available on the grid. We are told the minimum size required for this problem and reset the unit square size.) This is followed by prompts for the area of each department. The opportunity is given to change any of these values, but that is not necessary.

The final input required is for the option of defining a building outline. When answered affirmatively, the program moves to the "layout page," where the upper left corner is specified with the light pen. We will define a rectangular building of 75,000 square feet setting an "X" coordinate of 300 (feet) and a "Y" coordinate of 250 in response to prompts. Although the building shows up in bright green on the screen, it shows only faintly when

printed, as seen on subsequent displays of the layout grid. The computer log for these transactions is given in Figure 14.

After completion of the input requirements, the program moves to the "tableau page" described in Chapter III. This page shows all information needed by the designer in order to place the department on the layout grid. This includes the tableau of pertinent relationships, the list of department names (on the screen, the current entering department is shown in red), the "plain English" instructions for placement, and any special instructions. All instructions will be repeated on the "layout page," so there is no worry about remembering them. Tableau page one is shown in Figure 15.

When the designer is finished examining the tableau page, he simply hits return (as instructed) and the program moves to the "layout page". At the bottom of the page are all instructions, as well as information as to the name, letter, and number of unit squares of the current entering department. Although the user is not restricted as to placement of the squares, he will presumably put them adjacent to one another, in a feasible shape, and within the building outline if he has used one. After the correct number of squares have been placed, the program automatically goes to the modification option. If taken, the user is given the chance to add or delete squares of any department, as often as needed. The progressive evolution of the layout

PLANT LAYOUT PROGRAM
 SCHOOL OF INDUSTRIAL ENGINEERING
 OKLAHOMA STATE UNIVERSITY

```

ENTER:
      1 FOR WORKING ON A LAYOUT FROM SCRATCH
      2 FOR WORKING ON A LAYOUT FILED ON DISK
? 1
NO. OF DEPARTMENTS? 7

DO YOU WANT TO INPUT NAMES FOR DEPARTMENTS (Y/N)? Y

Please limit names to 10 characters

  DEPT. 1 IS ? RECEIVING
  DEPT. 2 IS ? MILLING
  DEPT. 3 IS ? PRESS
  DEPT. 4 IS ? SCREW MACH
  DEPT. 5 IS ? ASSSEMBLY
  DEPT. 6 IS ? PLATING
  DEPT. 7 IS ? SHIPPING

GET READY TO ENTER REL CHART
PERMISSIBLE RELATIONSHIPS ARE: A, E, I, O, U(OR SPACE) AND X

ENTER RELATIONSHIP BETWEEN

      DEPARTMENT 1 AND DEPARTMENT 2 ? E
      DEPARTMENT 1 AND DEPARTMENT 3 ? O
      DEPARTMENT 1 AND DEPARTMENT 4 ? I
      DEPARTMENT 1 AND DEPARTMENT 5 ? O
      DEPARTMENT 1 AND DEPARTMENT 6 ? U
      DEPARTMENT 1 AND DEPARTMENT 7 ? U

ENTER RELATIONSHIP BETWEEN

      DEPARTMENT 2 AND DEPARTMENT 3 ? U
      DEPARTMENT 2 AND DEPARTMENT 4 ? E
      DEPARTMENT 2 AND DEPARTMENT 5 ? I

ENTER RELATIONSHIP BETWEEN

      DEPARTMENT 6 AND DEPARTMENT 7 ? E
  
```

Figure 14. Example Problem Inputs

ARE THERE ANY SPECIAL INSTRUCTIONS (Y/N)? Y

ENTER NUMBER OF THE DEPARTMENT? 1

ENTER INSTRUCTIONS ON THIS LINE? PLACE ON OUTSIDE WALL

ANY OTHER DEPARTMENTS? ENTER NUMBER (OR 0 TO STOP)? 7

ENTER INSTRUCTIONS ON THIS LINE? PLACE ON OUTSIDE WALL

ANY OTHER DEPARTMENTS? ENTER NUMBER (OR 0 TO STOP)? 0

CLOSENESS RANK OF THE DEPARTMENTS:

6 5 2 4 1 7 3

SELECTION ORDER OF THE DEPARTMENTS:

6 5 7 2 4 1 3

HOW MANY SQ. FEET IN A UNIT SQUARE? 100

INPUT THE AREAS OF EACH DEPARTMENT

1	AREA = ?	12000
2	AREA = ?	8000
3	AREA = ?	6000
4	AREA = ?	12000
5	AREA = ?	8000
6	AREA = ?	12000
7	AREA = ?	12000

DO YOU WANT TO CHANGE ANY AREAS (Y/N)? N

UNIT SQUARE IS TOO SMALL FOR THE GRID

MAKE UNIT SQUARE AT LEAST 117 SQUARE FEET

HOW MANY SQ. FEET IN A UNIT SQUARE? 1000

DO YOU WANT TO CHANGE ANY AREAS (Y/N)? N

DO YOU WANT TO DEFINE A BUILDING (Y/N)? Y

Figure 14. Continued

TABLEAU NUMBER 1

DEPT NO.	F	E	G	B	F	PLATING
					E	ASSEMBLY
F	*	A	E	I	G	SHIPPING
					B	MILLING
					D	SCREW MACH
					A	RECEIVING
					C	PRESS

PLACE DEPARTMENT F SUCH THAT IT:

TOUCHES NOTHING SPECIAL
CAN TOUCH DEPARTMENT(S) E AND G AND B WHEN THEY ENTER

HIT 'RETURN' WHEN READY TO CONTINUE?

Figure 15. Tableau Page One

is given in Figures 16, 17, and 18 by showing the placement of the third, fifth, and seventh departments and their associated tableau pages.

Program Scoring, Evaluation, Correction,
and Storage

After the final department is placed and all modification is completed, the user has the option of scoring the layout. This procedure takes about 25 seconds. A closeness matrix is printed to the screen showing which departments were classified as touching and not touching. The user may intervene to manually change this if he wishes. When satisfied with the closeness matrix, the layout score is computed, displayed, and compared to the perfect score obtained if all relationships were satisfied. If any A, E,

TABLEAU NUMBER 3

DEPT NO.	F	E	G	B	D	
G	E	I	*			F PLATING
B	I	I	*		E	E ASSEMBLY
D		I	*	E		G SHIPPING
						B MILLING
						D SCREW MACH
						A RECEIVING
						C PRESS

PLACE DEPARTMENT G SUCH THAT IT:

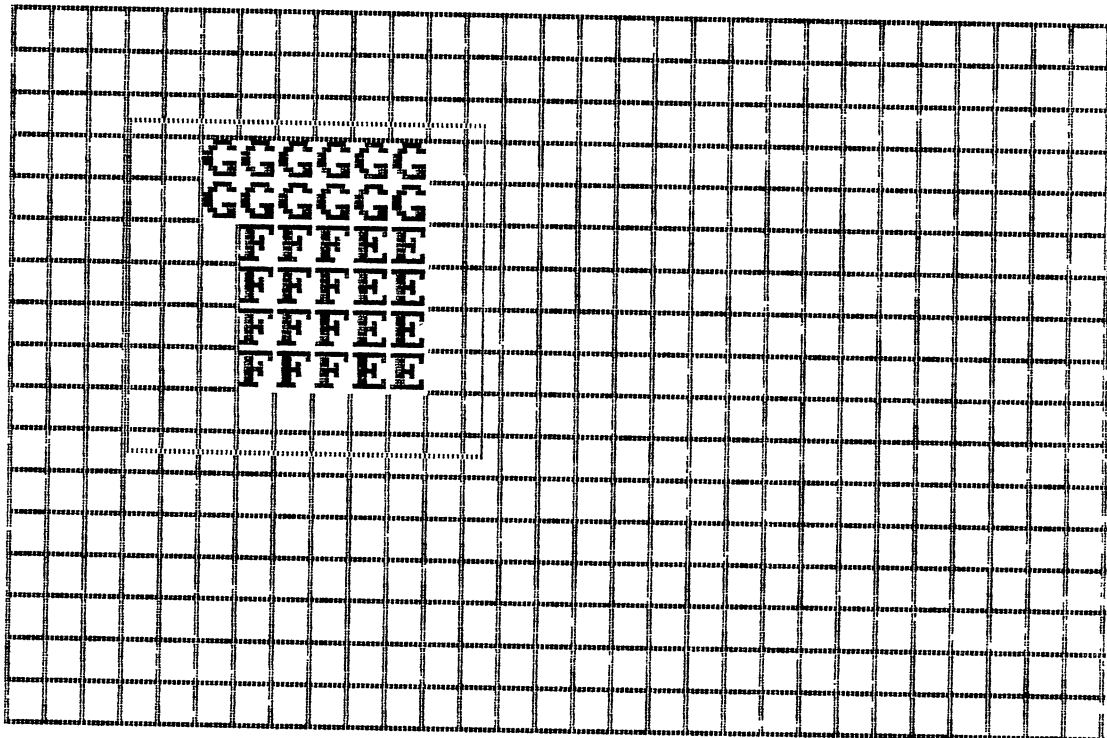
TOUCHES DEPARTMENT(S) F AND E
 LEAVES ROOM FOR DEPT. B TO TOUCH DEPT(S). F AND E
 LEAVES ROOM FOR DEPT. D TO TOUCH DEPT(S). E

SPECIAL INSTRUCTIONS

PLACE ON OUTSIDE WALL

HIT "RETURN" WHEN READY TO CONTINUE?

Figure 16. Layout Evolution, Step 3



TOUCH F, E
 LEAVE ROOM FOR B TO TOUCH F, E
 LEAVE ROOM FOR D TO TOUCH E, E

PLACE ON OUTSIDE WALL
 DO YOU WANT TO MODIFY? (Y/N)

Figure 16. Continued

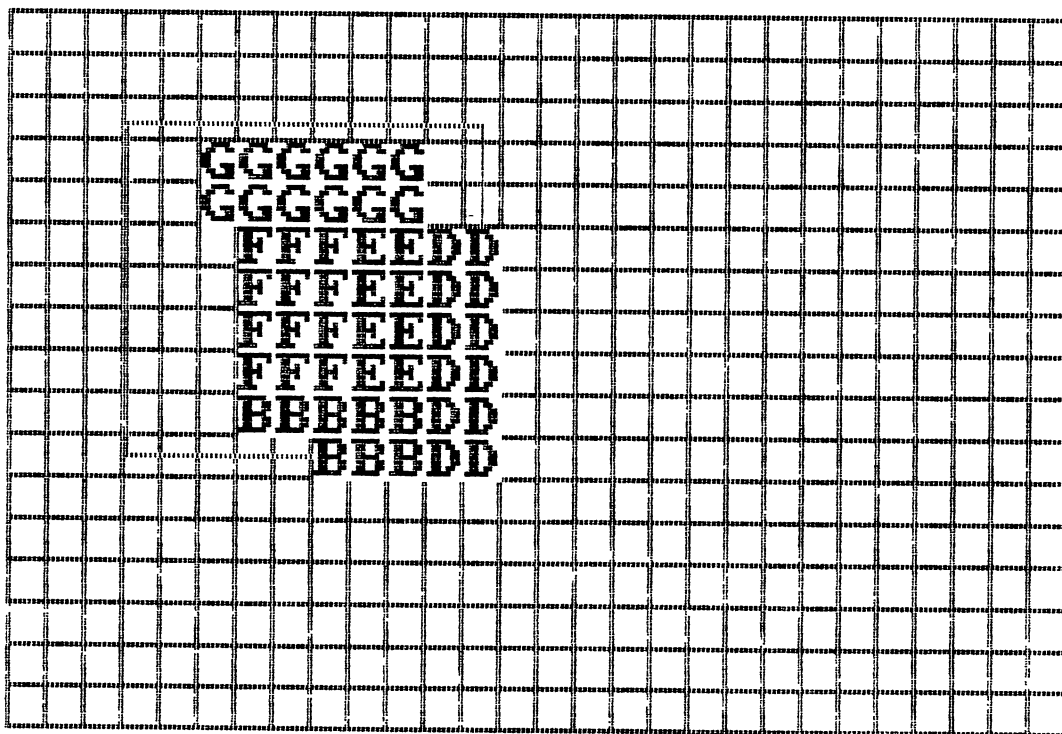
TABLEAU NUMBER 5

DEPT NO.	E	G	B	D	A	C	F	PLATING
							E	ASSEMBLY
D	I		E	*	I		G	SHIPPING
A			E	*			B	MILLING
							D	SCREW MACH
							A	RECEIVING
							C	PRESS

PLACE DEPARTMENT D SUCH THAT IT:

TOUCHES DEPARTMENT(S) E AND B
 LEAVES ROOM FOR DEPT. A TO TOUCH DEPT(S). B
 CAN TOUCH DEPARTMENT(S) A WHEN IT ENTERS

HIT 'RETURN' WHEN READY TO CONTINUE?



TOUCH E, B
 LEAVE ROOM FOR A TO TOUCH B
 ALLOW FOR A TO TOUCH D

Figure 17. Layout Evolution, Step 5

TABLEAU NUMBER 7

DEPT NO.

C

- F PLATING
- E ASSEMBLY
- G SHIPPING
- B MILLING
- D SCREW MACH
- A RECEIVING
- C PRESS

PLACE DEPARTMENT C SUCH THAT IT:

TOUCHES NOTHING SPECIAL

HIT 'RETURN' WHEN READY TO CONTINUE?

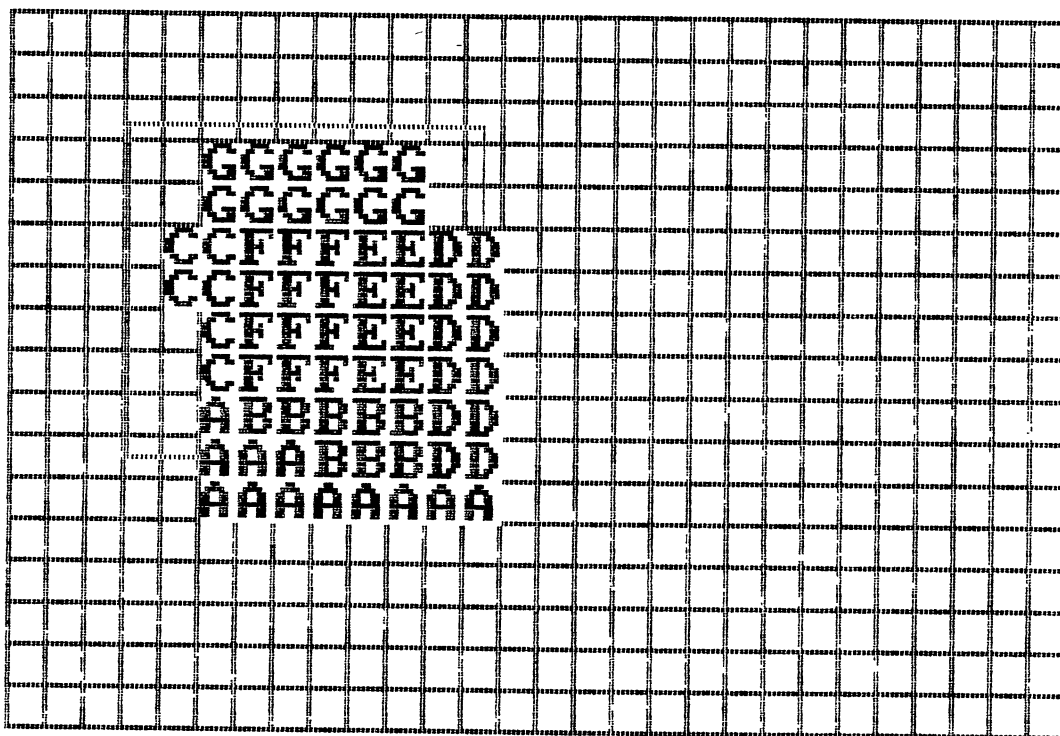


Figure 18. Layout Evolution, Step 7

I, O, or X relationships are not satisfied, they are identified and displayed as shown in Figure 19.

WANT TO EVALUATE A LAYOUT CONFIGURATION? (Y/N)? Y

WANT TO CHANGE CLOSENESS RELATIONSHIP VALUES? (Y/N)
(DEFAULT VALUES ARE: A=8, E=4, I=2, O=1, U=0, X=-8)? N

Please wait . . .

Just a little longer . . .

TOTAL SCORE FOR THE GIVEN LAYOUT CONFIGURATION = 32

PERFECT SCORE = 33

UNSATISFIED RELATIONSHIPS

RELATIONSHIP	VALUE
A, E	0

WANT TO TRY ANY MODIFICATIONS ON THIS LAYOUT (Y/N)? N

WANT TO STORE THIS LAYOUT ON A DISK (Y/N)? Y
SPECIFY THE DRIVE AND THE FILENAME (EX -- B:LAYOUT) ? B:LA
DO YOU WANT TO SAVE BUILDING (Y/N)? N

Figure 19. Scoring, Evaluation, and Saving the Layout

After this evaluation, the user has the option of returning to the layout grid to modify the layout. When he is satisfied with the layout he also is given the oppor-

tunity to store the layout on a floppy disk for future work or reference. This procedure stores not only the layout, but also all input data. A filename must be provided. If a drive other than the current default drive is desired as the target drive, it must be specified also, as in the example.

Sometimes, it may be desirable to erase the current building outline so as to be able to draw another which more closely fits the layout. If so, respond "no" when asked if "you want to store the current building outline."

Example Summary

This completes the example problem demonstration. As the reader can see, the inputs are very straight forward and, in fact, difficult to "mess up". Ample opportunity is given in critical areas to change one's mind or correct errors. For a problem of this size, total execution time is about 15 to 30 minutes, depending upon how familiar the designer is with the problem and the relationship constraints.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

FOR FURTHER STUDY

Summary

The facility layout process involves a combination of objective and subjective considerations. Objectively, the layout planner attempts to establish relationships between the various departments involved in the project. He then tries to employ some methodology for placing the departments so as to satisfy as many relationships as possible. While several other computer algorithms have been developed which attempt to optimally place departments in the layout using some logic scheme, they are unable to incorporate the necessary subjective considerations required to obtain a good layout.

Because facility layout is as much an art as a science, the best layouts can only be obtained with substantial input from the planner who understands the requirements of the facility under design. Instead of excluding the designer from the planning process, as most computer algorithms do, he should be included at each stage. Doing this requires using the computer as a tool to aid the planner, rather than as a substitute for his skills, knowledge, and judgement.

This thesis has developed such a tool. By inputting the basic data pertaining to the layout project, the planner relieves himself from the task of trying to keep track of the many relationships, special considerations and constraints involved. He is then free to utilize his subjective and creative skills more effectively in order to obtain a better layout in less time than would otherwise be possible. This project has accomplished that objective.

Recommendation for Further Study

As would be expected with any project of this type, there are some areas for improvement, development and further study. In hopes of encouraging such efforts, the following suggestions are offered.

The first such suggestion would be a more objective method (or perhaps option) for determining the REL chart relationships. Tompkins (23) offers factors which could be used in determining the relationships between departments. These factors are:

1. Organizational relationships, influenced by span of control and reporting relationships.
2. Flow relationships, including the flow of materials, people, equipment, information, and money.
3. Control relationships, including centralized versus decentralized materials control, real time versus bath inventory control, shop floor control, and levels of automation and integration.
4. Environmental relationships, including safety considerations and temperature, noise, fumes, humidity, and dust.

5. Process relationships other than those considered above, such as floor loadings, requirements for water treatment, chemical processing, and special services (pp. 66, 67).

By developing a rating scheme for evaluating the importance of each factor to each relationship, and weighting each factor according to its relative importance, each relationship could be found in a more deterministic manner. A dissertation by Webb (26) utilizes such an approach, and could be adapted to this program.

Another possible area for development would be some form of automatic placement of departments as a result of information in the tableau. Of course, this would tend toward reducing the opportunity for human interaction, which is one of the primary advantages of this algorithm. Nonetheless, a good placement routine (again, perhaps as an option) could be useful to the designer as long as ample opportunity for modification was allowed.

A third area which could be explored would be to incorporate a more sophisticated scoring and evaluation routine. The binary scoring (touch, no touch) method currently used is among the simplest available. Other possibilities would include distance between centers of each department (21), shortest path between all departments (21), or SLPCALC (9). These (and other) methods take into account the total spatial relationship between all departments, not just whether or not they are adjacent. By doing so, departments which do not touch borders but are close together can receive some credit, while departments which do

touch but whose centers are far apart may receive less than full credit. It should be possible to fairly easily include such a scoring method in this program.

It is hoped that this project and these recommendations will encourage others to do work in the field of facility layout using the microcomputer. As computer technology and understanding matures, man will learn to make better use of the computer as a workhorse at times, as a tool at times, and -- most importantly -- know when each is appropriate.

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APPENDIX
PROGRAM LISTING

```

10 ' *** create and store rel chart
20 '     and determine selection order
30 '
40 KEY OFF
50 SCREEN 0,0,0
60 WIDTH 80
70 COLOR 6,8,8
80 DEFINT I-N
90 FOR I=1 TO 10
100 PRINT
110 IF I<>5 THEN 160
120 PRINT TAB(20) "PLANT LAYOUT PROGRAM"
130 PRINT TAB(14) "SCHOOL OF INDUSTRIAL ENGINEERING"
140 PRINT TAB(17) "OKLAHOMA STATE UNIVERSITY"
150 PRINT TAB(14) "*****"
160 NEXT I
170 DIM IR(20),NE(20),IS(20),IC(20,20),REL$(20,20),AREA%(20),NSQR(20),
    GRD%(6002)
180 DIM DL$(21),LAY$(25,40),SP%(20),INST$(20),SP2%(20),INST2$(20),L$(21)
190 DIM N(9),NLAY(20,40),DNAME$(20),BX(50),BY(50)
200 B$ = " "
210 C$=","
220 PK=0
230 GOSUB 2990 ' *** SELECT INPUT OPTION
240 IF IO <> 2 THEN GOTO 260 ELSE GOSUB 8960 ' *** READ STORED LAYOUT
250 OLD = 1 : GOTO 500
260 ' *** READ REL CHART
270 INPUT " NO. OF DEPARTMENTS"; ND
280 IF ND < 20 THEN 310
290 PRINT " PROBLEM SIZE IS TOO BIG, NO. OF DEPARTMENTS SHOULD BE < 20"
300 GOTO 2970 ' *** GO TO END
310 PRINT
320 INPUT " DO YOU WANT TO INPUT NAMES FOR DEPARTMENTS (Y/N)"; A$
330 IF A$ = "N" THEN GOTO 350
340 IF A$ = "Y" THEN GOSUB 9510 ELSE GOTO 320

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```

350 PRINT " GET READY TO ENTER REL CHART"
360 PRINT " PERMISSIBLE RELATIONSHIPS ARE: A, E, I, O, U(OR SPACE) AND X
370 RESTORE 2940
380 FOR I = 1 TO ND-1
390 PRINT
400 PRINT " ENTER RELATIONSHIP BETWEEN"
410 PRINT
420 FOR J = I+1 TO ND
430 PRINT TAB(10) "DEPARTMENT";I;"AND DEPARTMENT";J;
440 INPUT R$(I,J)
450 GOSUB 3090          ' *** VALID RELATIONSHIP CHECK
460 IF IG <> 0 THEN 430
470 R$(J,I) = R$(I,J)
480 NEXT J
490 NEXT I
500 FOR I = 1 TO ND
510 ID(I) = I
520 R$(I,I) = "S"
530 NEXT I
540 PRINT
550 GOSUB 3190          ' *** PRINT REL CHART
560 PRINT
570 INPUT " WANT TO CHANGE ANY RELATIONSHIPS? (Y/N)";A#
580 IF A# = "N" THEN 790
590 IF A# <> "Y" THEN 570
600 IF NDONE = 0 THEN GOTO 670      ' INITIALIZE THE GRID
610 FOR K = 1 TO 18
620 FOR L = 1 TO 40
630 LAY$(K,L) = ""
640 NEXT L
650 NEXT K
660 NDONE = 0
670 PRINT:INPUT " ENTER FROM AND TO DEPARTMENTS SEPARATED BY A COMMA";I,J
680 IF I < 0 OR I > ND THEN 710
690 IF J < 0 OR J > ND THEN 710

```

```

700 GOTO 730
710 PRINT " INVALID DEPARTMENT NUMBER"; I; "OR"; J
720 GOTO 670
730 INPUT " ENTER NEW RELATIONSHIP (A,E,I,O,U,X)"; R$(I,J)
740 GOSUB 3090          ' *** RELATIONSHIP VALID?
750 IF IG <> 0 THEN 730
760 R$(J,I) = R$(I,J)
770 GOSUB 3190
780 GOTO 570
790 IF ID = 2 THEN INPUT "ANY CHANGES TO SPECIAL INSTRUCTIONS(Y/N)"; A$:GOTO 810
800 PRINT : INPUT " ARE THERE ANY SPECIAL INSTRUCTIONS (Y/N)"; A$
810 IF A$ = "N" THEN GOTO 830
820 IF A$ = "Y" THEN GOSUB 6920 ELSE GOTO 800
830 IF NDONE = 0 THEN GOTO 890          ' **** INITIALIZE LAY$(X,Y)
840 FOR K = 1 TO 18
850 FOR L = 1 TO 40
860 LAY$(K,L) = ""
870 NEXT L
880 NEXT K
890 FOR I = 1 TO ND
900 FOR J = 1 TO ND
910 GOSUB 3300          ' *** FIND OUT RELATIONSHIP TYPE
920 IF K = 0 THEN 940
930 NR(I,K) = NR(I,k) + IN
940 NEXT J
950 NEXT I
960 '
970 ' *** RANK DEPARTMENTS ON THE BASIS OF A,E,I, AND X VALUES
980 '
990 FOR I = 1 TO ND-1
1000 J = ID(I)
1010 FOR K = 1 TO 4
1020 NH(K) = NR(J,K)
1030 NEXT K
1040 FOR K = 1+I TO ND

```

```

1050 L = ID(K)
1060 FOR M = 1 TO 4
1070 IF NH(M) > NR(L,M) THEN 1170
1080 IF NH(M) = NR(L,M) THEN 1160
1090 FOR N = 1 TO 4
1100 NH(N) = NR(L,N)
1110 NEXT N
1120 IT = ID(I)
1130 ID(I) = ID(K)
1140 ID(K) = IT
1150 GOTO 1170
1160 NEXT M
1170 NEXT K
1180 NEXT I
1190 PRINT
1200 PRINT " CLOSENESS RANK OF THE DEPARTMENTS:"
1210 PRINT
1220 FOR I = 1 TO ND
1230 J = ID(I)
1240 PRINT J;
1250 IR(J) = I
1260 NEXT I
1270 PRINT
1280 *
1290 * *** SFLECTION ORDER OF DEPARTMENTS
1300 *
1310 FOR K = 1 TO ND
1320 NE(K) = 0 :NEXT K
1330 I = ID(1)
1340 IS(1) = I
1350 NE(I) = 1
1360 NS = 1
1370 FOR II = 2 TO ND
1380 FOR M = 1 TO ND
1390 FOR N = 1 TO 4

```



```

1400 MR(M,N) = 0
1410 NEXT N
1420 NEXT M
1430 FOR I = 1 TO ND
1440 IF NE(I) >= 1 THEN 1510
1450 FOR JJ = 1 TO NS
1460 J = IS(JJ)
1470 GOSUB 3300          ' *** FIND OUT RELATIONSHIP TYPE
1480 IF K = 0 THEN 1500
1490 MR(I,K) = MR(I,K) + IN
1500 NEXT JJ
1510 NEXT I
1520 FOR J = 1 TO 4
1530 NH(J) = -999
1540 NEXT J
1550 DN = 0
1560 FOR J = 1 TO ND
1570 IF NE(J) >= 1 THEN 1690
1580 FOR K = 1 TO 4
1590 IF NH(K) > MR(J,K) THEN 1690
1600 IF NH(K) = MR(J,K) THEN 1660
1610 DN = J
1620 FOR L = 1 TO 4
1630 NH(L) = MR(J,L)
1640 NEXT L
1650 GOTO 1690
1660 NEXT K
1670 IF IR(DN) <= IR(J) THEN 1690
1680 DN = J
1690 NEXT J
1700 IS(II) = DN
1710 NE(DN) = II
1720 NS = NS + 1
1730 NEXT II
1740 PRINT

```

```

1750 PRINT " SELECTION ORDER OF THE DEPARTMENTS:"
1760 PRINT
1770 FOR I = 1 TO ND
1780 PRINT IS(I);
1790 NEXT I
1800 PRINT:PRINT
1810 GOTO 3490          ' *** CONTINUE DATA INPUT
1820 SCREEN 0,0,0
1830 WIDTH 80 : COLOR 2
1840 PRINT:PRINT:INPUT " WANT TO EVALUATE A LAYOUT CONFIGURATION? (Y/N)";A$
1850 IF A$ = "N" THEN 2820
1860 IF A$ <> "Y" THEN 1820
1870 PRINT
1880 PRINT " WANT TO CHANGE CLOSENESS RELATIONSHIP VALUES? (Y/N)"
1890 PRINT " (DEFAULT VALUES ARE: A=8,E=4,I=2,O=1,U=0,X=-8)";
1900 INPUT A$
1910 IF A$ = "Y" THEN 1990
1920 IF A$ = "N" THEN 1950
1930 PRINT " ANSWER Y OR N"
1940 GOTO 1900
1950 RESTORE 2950
1960 READ NA,NY,NI,NO,NU,NX
1970 GOTO 2060
1980 PRINT
1990 PRINT " ENTER CLOSENESS VALUES FOR A,E,I,O,U AND X (SEPARATED BY COMMAS)"
2000 INPUT NA,NY,NI,NO,NU,NX
2010 PRINT
2020 PRINT " A=";NA, "E=";NY, "I=";NI, "O=";NO, "U=";NU, "X=";NX
2030 INPUT " DO YOU WANT TO CHANGE ANY VALUES? (Y/N)"; A$
2040 IF A$ = "Y" THEN 1990
2050 IF A$ <> "N" THEN 2030
2060 FOR I = 1 TO ND
2070 FOR J = 1 TO ND
2080 LL$ = R$(I,J)
2090 IF LL$ = "U" THEN VA = NU : GOTO 2160

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```

2100 IF LL$ = "O" THEN VA = NO : GOTO 2160
2110 IF LL$ = "I" THEN VA = NI : GOTO 2160
2120 IF LL$ = "E" THEN VA = NY : GOTO 2160
2130 IF LL$ = "A" THEN VA = NA : GOTO 2160
2140 IF LL$ = "X" THEN VA = NX : GOTO 2160
2150 GOTO 2170
2160 IV(I,J) = VA : IV(J,I) = VA
2170 NEXT J
2180 NEXT I
2190 IF PR = 0 THEN 2230
2200 PRINT: INPUT " WANT TO EVALUATE A NEW LAYOUT? (Y/N)"; A$
2210 IF A$ = "N" THEN 2700
2220 IF A$ <> "Y" THEN 2200
2230 FOR I = 1 TO ND
2240 FOR J = 1 TO ND
2250 IC (I,J) = 0
2260 NEXT J
2270 NEXT I
2280 GOSUB 7080          ' *** CALL SCORING SUBROUTINE
2290 GOTO 2450
2300 PRINT              ' LINES 2300 - 2440 CURRENTLY DISABLED
2310 INPUT " ENTER DEPARTMENT NUMBER (0 TO STOP)"; IM
2320 PRINT
2330 IF IM > 0 AND IM <= ND THEN 2370
2340 IF IM = 0 THEN 2450
2350 PRINT " INVALID DEPARTMENT NUMBER"; IM
2360 GOTO 2280
2370 INPUT "          ENTER NEIGHBORING DEPARTMENT(0 TO STOP)"; TZ
2380 IF TZ > 0 AND TZ <= ND THEN 2420
2390 IF TZ = 0 THEN 2280
2400 PRINT TAB(10) "INVALID DEAPRTMENT NUMBER"; TZ
2410 GOTO 2370
2420 IC(IM,TZ) = 1
2430 IC(TZ,IM) = 1
2440 GOTO 2370

```

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2450 PRINT:PRINT " CLOSENESS MATRIX"
2460 GOSUB 3390
2470 FOR I = 1 TO ND
2480 PRINT I,
2490 FOR J = 1 TO ND
2500 PRINT IC(I,J);
2510 NEXT J
2520 PRINT
2530 NEXT I
2540 PRINT
2550 INPUT " WANT TO CHANGE ANY CLOSENESS VALUE (Y/N)"; A$
2560 IF A$ = "N" THEN 2700
2570 IF A$ <> "Y" THEN 2550
2580 INPUT " ENTER TWO DEPARTMENT NUMBERS (SEPARATED BY A COMMA)"; IM,TZ
2590 IF IM < 1 OR IM > ND THEN 2660
2600 IF TZ < 1 OR TZ > ND THEN 2660
2610 PRINT " ENTER THEIR CLOSENESS VALUE"
2620 INPUT " (1 IF CLOSE, 0 OTHERWISE)"; VA
2630 IF VA = 0 OR VA = 1 THEN 2680
2640 PRINT " INVALID CLOSENESS RELATIONSHIP VALUE"
2650 GOTO 2610
2660 PRINT " INVALID DEPARTMENT"; IM; "OR"; TZ
2670 GOTO 2580
2680 IC(IM,TZ) = VA
2690 GOTO 2550
2700 PRINT
2710 SC = 0
2720 FOR I = 1 TO ND
2730 FOR J = I+1 TO ND
2740 IF IC(I,J) < 1 THEN 2760
2750 SC = SC + IV(I,J)
2760 NEXT J
2770 NEXT I
2780 PRINT " TOTAL SCORE FOR THE GIVEN LAYOUT CONFIGURATION =";
2790 COLOR 3 :PRINT SC : COLOR 2

```

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2800 GOSUB 8300      ' *** DETERMINE PERFECT SCORE
2810 PRINT
2820 INPUT " WANT TO TRY ANY MODIFICATIONS ON THIS LAYOUT (Y/N)";A$
2830 IF A$ <> "N" THEN 2880
2840 INPUT " WANT TO STORE THIS LAYOUT ON A DISK (Y/N)";A$
2850 IF A$ = "N" THEN 2970
2860 IF A$ <> "Y" THEN 2840 ELSE GOSUB 8680      ' *** STORE LAYOUT
2870 GOTO 2970
2880 IF A$ <> "Y" THEN 2820
2890 SCREEN 1:COLOR B,0:PUT (1,1),GRD%,PSET : GOTO 6520
2900 FR = 1
2910 GOSUB 2990
2920 GOTO 560
2930 DATA 12000,8000,6000,12000,8000,12000,12000
2940 DATA E,O,I,X,U,U,U,E,I,I,U,U,U,O,U,I,U,U,A,I,E
2950 DATA B,4,2,1,0,-B
2960 DATA A,B,C,D,E,F,G,H,I,J,K,L,M,N,O,P,Q,R,S,T
2970 END
2980 '
2990 ' *** INPUT PROGRAM OPTION -- SUBROUTINE FROM LINE 230
3000 '
3010 PRINT " ENTER:"
3020 PRINT TAB(8) "1 FOR WORKING ON A LAYOUT FROM SCRATCH"
3030 PRINT TAB(8) "2 FOR WORKING ON A LAYOUT FILED ON DISK"
3040 INPUT ID
3050 IF ID > 0 AND ID < 3 THEN 3080
3060 PRINT "INVALID OPTION -- ENTER 1 OR 2"
3070 GOTO 3040
3080 RETURN
3090 ' *** CHECK FOR VALID RELATIONSHIP (FROM LINE 450 OR 740)
3100 IG = 0
3110 L$ = R$(I,J)
3120 IF L$ = " " THEN R$(I,J) = "U" : GOTO 3170
3130 IF L$ = "U" OR L$ = "O" OR L$ = "I" THEN 3170
3140 IF L$ = "E" OR L$ = "A" OR L$ = "X" THEN 3170

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3150 PRINT " INVALID RELATIONSHIP";L$
3160 IG = 1
3170 RETURN
3180 ' *** DISPLAY REL CHART (FROM LINE 550)
3190 PRINT " RELATIONSHIP MATRIX"
3200 GOSUB 3390
3210 FOR I = 1 TO ND
3220 PRINT I,
3230 FOR J = 1 TO ND
3240 PRINT B$;R$(I,J);B$;
3250 NEXT J
3260 PRINT
3270 NEXT I
3280 PRINT
3290 RETURN
3300 ' *** FIND OUT A,E,I, OR X RELATIONSHIP (FROM LINE 910 OR 1470)
3310 K = 0
3320 IN = 1
3330 E$ = R$(I,J)
3340 IF E$ = "A" THEN K = 1 : GOTO 3380
3350 IF E$ = "E" THEN K = 2 : GOTO 3380
3360 IF E$ = "I" THEN K = 3 : GOTO 3380
3370 IF E$ = "X" THEN K = 4 : IN = -1
3380 RETURN
3390 ' *** PRINT DEPARTMENT HEADINGS
3400 PRINT
3410 PRINT " DEPT NO. ";
3420 FOR I = 1 TO ND
3430 PRINT I;
3440 NEXT I
3450 PRINT:PRINT
3460 RETURN
3470 '
3480 ' *** INPUT DEPARTMENT AREAS (TRANSFERED FROM LINE 1810)
3490 '

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```

3500 IF OLD = 0 THEN GOTO 3540
3510 FOR I = 1 TO ND
3520 NS = AREA%(I) / USQR% : NSQR(I) = INT (NS) :NEXT I
3530 GOTO 3900
3540 PRINT: INPUT " HOW MANY SQ. FEET IN A UNIT SQUARE";USQR%
3550 IF MINSQ% <> 0 THEN GOTO 3580
3560 RESTORE 2930
3570 PRINT: PRINT " INPUT THE AREAS OF EACH DEPARTMENT":PRINT
3580 TOTSQ = 0
3590 FOR I = 1 TO ND
3600 IF MINSQ% <> 0 THEN GOTO 3620
3610 PRINT I, :PRINT "AREA = " :INPUT AREA%(I)
3620 NS = AREA%(I) / USQR%
3630 TOTSQ = TOTSQ + NS
3640 NSQR(I) = INT(NS)
3650 NEXT I
3660 '
3670 PRINT:INPUT " DO YOU WANT TO CHANGE ANY AREAS (Y/N)";A$
3680 IF A$ = "N" THEN 3840
3690 IF A$ <> "Y" THEN GOTO 3670
3700 PRINT:INPUT " INPUT DEPARTMENT NUMBER";I
3710 IF I < 1 OR I > ND THEN GOTO 3700
3720 INPUT " INPUT CORRECT AREA ";AREA%(I)
3730 NS = AREA%(I)/USQR%
3740 TOTSQ = TOTSQ - NSQR(I)
3750 NSQR(I) = INT(NS)
3760 TOTSQ = TOTSQ + NSQR(I)
3770 PRINT:INPUT " ANY OTHER CHANGES (ENTER DEPT. # OR 0 TO STOP)"; I
3780 IF I > 0 AND I < ND THEN GOTO 3720
3790 IF I <> 0 THEN GOTO 3770
3800 FOR J = 1 TO ND
3810 PRINT J,AREA%(J) : NEXT J
3820 GOTO 3670
3830 '
3840 IF TOTSQ <= 600 GOTO 3910

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3850 PRINT:PRINT " UNIT SQUARE IS TOO SMALL FOR THE GRID"
3860 MINSQ% = (USQR% * TOTSQ) / 600
3870 PRINT:PRINT " MAKE UNIT SQUARE AT LEAST";MINSQ%;"SQUARE FEET"
3880 GOTO 3540
3890 *
3900 IF BLDSV$ = "Y" THEN GOTO 3970
3910 PRINT : INPUT " DO YOU WANT TO DEFINE A BUILDING (Y/N)";A$
3920 IF A$ = "N" THEN GOTO 3970
3930 IF A$ = "Y" THEN GOSUB 7520 ELSE GOTO 3910
3940 SCREEN 0,0,0
3950 WIDTH 80 : COLOR 6
3960 *
3970 * *** CONVERT REL CHART TO REL CHART BY SELECTION ORDER
3980 *
3990 FOR K = 1 TO ND
4000 I = IS(K)
4010 SP2%(K) = SP%(I) : INST2$(K) = INST$(I) * TAKE CARE OF SPC. INST.
4020 FOR L = 1 TO ND
4030 J = IS(L)
4040 REL$(K,L) = R$(I,J)
4050 IF REL$(K,L) = "O" OR REL$(K,L) = "U" OR REL$(K,L) = "S" THEN REL$(K,L) = " "
4060 NEXT L
4070 NEXT K
4080 *
4090 FOR I = 1 TO ND+1
4100 J = ND + 1
4110 REL$(I,J) = " "
4120 REL$(J,I) = " "
4130 NEXT I
4140 *
4150 GOTO 4310
4160 * *** PRINT NEW REL CHART *** CURRENTLY DISABLED
4170 *
4180 PRINT : PRINT " DEPT NO. ";
4190 FOR I = 1 TO ND

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```

4200 PRINT IS(I);
4210 NEXT I
4220 PRINT:PRINT
4230 FOR I = 1 TO ND
4240 PRINT IS(I),
4250 FOR J = 1 TO ND
4260 PRINT B$;REL$(I,J);B$;
4270 NEXT J
4280 PRINT
4290 NEXT I
4300 PRINT
4310 NEXTENT = 1
4320 *
4330 * *** DELIMIT MATRIX
4340 *
4350 * *** SELECT FIRST AND LAST COLUMNS
4360 *
4370 FOR L = 1 TO ND
4380 FOR K = NEXTENT TO ND
4390 IF REL$(K,L) <> " " THEN GOTO 4420
4400 NEXT K
4410 NEXT L
4420 FRSTCOL% = L
4430 *
4440 FOR K = NEXTENT+1 TO ND
4450 IF REL$(NEXTENT,K) = " " THEN LASTCOL% = K-1 : GOTO 4480
4460 NEXT K
4470 LASTCOL% = K
4480 IF LASTCOL% < NEXTENT + 2 AND NEXTENT+2 <= ND THEN LASTCOL% = NEXTENT + 2
4490 *
4500 * *** SELECT LAST ROW
4510 *
4520 FOR K = NEXTENT + 1 TO ND
4530 FOR L = FRSTCOL% TO NEXTENT-1
4540 IF REL$(K,L) <> " " GOTO 4570

```

```

4550 NEXT L
4560 LASTROW% = K-1 : GOTO 4590
4570 NEXT K
4580 LASTROW% = K
4590 '
4600 ' *** DISPLAY TABLEAU
4610 '
4620 PRINT
4630 SCREEN 0,1
4640 WIDTH 80
4650 COLOR 3,8,8
4660 GOSUB 6030
4670 PRINT : PRINT " TABLEAU NUMBER" NEXTENT: PRINT : PRINT "DEPT NO.      ";
4680 FOR I = FRSTCOL% TO LASTCOL%
4690 PRINT B$;DL$(I);B$;
4700 NEXT I
4710 PRINT:PRINT
4720 FOR I = NEXTENT TO LASTROW%
4730 PRINT B$;"      " DL$(I),
4740 FOR J = FRSTCOL% TO LASTCOL%
4750 IF J = NEXTENT THEN COLOR 2 : PRINT B$;"*";B$;:COLOR 3 : GOTO 4790
4760 IF REL$(I,J) = "X" THEN COLOR 4,8,8
4770 PRINT B$;REL$(I,J);B$;
4780 COLOR 3,8,8
4790 NEXT J
4800 PRINT
4810 NEXT I
4820 PRINT
4830 IF LBL = 1 THEN GOSUB 9610      ' *** DEPARTMENT NAMES
4840 '
4850 ' *** DEVELOP INSTRUCTIONS FOR TABLEAU PAGE
4860 '
4870 PRINT:PRINT
4880 PRINT " PLACE DEPARTMENT " DL$(NEXTENT) " SUCH THAT IT:"
4890 PRINT

```

```

4900 NN=0
4910 PRINT "      TOUCHES";
4920 FOR I = FRSTCOL% TO NEXTENT-1
4930 IF REL$(NEXTENT,I) = " " OR REL$(NEXTENT,I) = "X" THEN GOTO 4970
4940 IF NN = 1 THEN PRINT " AND " DL$(I); : GOTO 4970
4950 PRINT " DEPARTMENT(S) " DL$(I);
4960 NN = 1
4970 NEXT I
4980 IF NN = 0 THEN PRINT " NOTHING SPECIAL";
4990 PRINT
5000 '
5010 NN = 0
5020 FOR I = FRSTCOL% TO NEXTENT-1
5030 IF REL$(NEXTENT,I) <> "X" THEN GOTO 5070
5040 IF NN = 1 THEN GOTO 5060
5050 PRINT "      DOES NOT TOUCH DEPT " DL$(I);:NN=1 : GOTO 5070
5060 PRINT ", " DL$(I);
5070 NEXT I
5080 IF NN = 1 THEN PRINT
5090 '
5100 FOR I = NEXTENT+1 TO LASTROW%
5110 NN = 0
5120 FOR N = FRSTCOL% TO NEXTENT-1
5130 IF REL$(I,N) = " " OR REL$(I,N) = "X" THEN GOTO 5170
5140 IF NN = 1 THEN PRINT " AND " DL$(N); : GOTO 5170
5150 PRINT "      LEAVES ROOM FOR DEPT. "DL$(I)" TO TOUCH DEPT(S). " DL$(N);
5160 NN = 1
5170 NEXT N
5180 IF NN = 1 THEN PRINT
5190 NEXT I
5200 '
5210 NN = 0
5220 FOR I = NEXTENT+1 TO LASTCOL%
5230 IF REL$(NEXTENT,I) = " " OR REL$(NEXTENT,I) = "X" THEN GOTO 5270
5240 IF NN <> 0 THEN PRINT " AND " DL$(I) ; : GOTO 5260

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```

5250 PRINT "      CAN TOUCH DEPARTMENT(S) " DL$(I);
5260 NN = NN + 1
5270 NEXT I
5280 IF NN = 1 THEN PRINT " WHEN IT ENTERS" : GOTO 5300
5290 IF NN > 1 THEN PRINT " WHEN THEY ENTER"
5300 PRINT:PRINT
5310 IF SP2%(NEXTENT) = 1 THEN GOSUB 7010
5320 INPUT " HIT 'RETURN' WHEN READY TO CONTINUE";DUM
5330 '
5340 ' *** GRAPHICS PORTION *****
5350 '
5360 SCREEN 1
5370 COLOR 8,0
5380 KEY OFF
5390 '
5400 ' *** DRAW GRID
5410 '
5420 IF NDONE = 1 THEN PUT (1,1),GRD%,PSET : GOTO 5540
5430 FOR I = 7 TO 320 STEP 8
5440 LINE (I,7)-(I,143),2
5450 NEXT
5460 FOR J = 7 TO 150 STEP 8
5470 LINE (7,J)-(320,J),2
5480 NEXT
5490 IF OLD = 0 THEN GOTO 5540
5500 GOSUB 9300          ' *** FILL IN OLD LAYOUT
5510 '
5520 ' *** INSTRUCTIONS FOR GRID
5530 '
5540 LOCATE 20,1
5550 NN = 0
5560 FOR I = FRSTCOL% TO NEXTENT-1
5570 IF REL$(NEXTENT,I) = " " OR REL$(NEXTENT,I) = "X" THEN GOTO 5600
5580 IF NN = 0 THEN PRINT "TOUCH " DL$(I); :NN = 1 : GOTO 5600
5590 PRINT ", " DL$(I) ;

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5600 NEXT I
5610 IF NN = 1 THEN PRINT
5620 '
5630 NN = 0
5640 FOR I = FRSTCOL% TO NEXTENT-1
5650 IF REL$(NEXTENT,I) <> "X" THEN GOTO 5690
5660 IF NN = 1 THEN GOTO 5680
5670 PRINT "DO NOT TOUCH " DL$(I) ; : NN = 1 :GOTO 5690
5680 PRINT ", " DL$(I);
5690 NEXT I
5700 IF NN = 1 THEN PRINT
5710 '
5720 FOR I = NEXTENT+1 TO LASTROW%
5730 NN = 0
5740 FOR N = FRSTCOL% TO NEXTENT-1
5750 IF REL$(I,N) = " " OR REL$(I,N) = "X" THEN GOTO 5790
5760 IF NN = 1 THEN PRINT " ," DL$(N); : GOTO 5790
5770 PRINT "LEAVE ROOM FOR " DL$(I) " TO TOUCH " DL$(N);
5780 NN = 1
5790 NEXT N
5800 IF NN = 1 THEN PRINT
5810 NEXT I
5820 '
5830 NN = 0
5840 FOR I = NEXTENT + 1 TO LASTCOL%
5850 IF REL$(NEXTENT,I) = " " OR REL$(NEXTENT,I) = "X" THEN GOTO 5890
5860 IF NN = 1 THEN PRINT " ," DL$(I);:GOTO 5890
5870 PRINT "ALLOW FOR " DL$(I);
5880 NN = 1
5890 NEXT I
5900 IF NN = 1 THEN PRINT " TO TOUCH " DL$(NEXTENT) ;
5910 IF SP2%(NEXTENT)=1 THEN PRINT: PRINT INST2$(NEXTENT);
5920 LOCATE 25,2 : KK = IS(NEXTENT)
5930 IF LBL = 1 THEN PRINT DNAME$(KK);" (" ;DL$(NEXTENT);" " ;NSQR(KK);"UNIT S
QUARES";

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5940 IF LBL = 1 THEN GOTO 5960
5950 PRINT "DEPT. " DL$(NEXTENT), NSQR(KK) "UNIT SQUARES";
5960 I = NEXTENT
5970 *
5980 GOTO 6290
5990 *
6000 *
6010 * *** SELECT DEPARTMENT LETTER (SUBROUTINE CALLED FROM LINE 4660)
6020 *
6030 FOR I = 1 TO ND
6040 IF IS(I) = 1 THEN DL$(I) = "A" : GOTO 6240
6050 IF IS(I) = 2 THEN DL$(I) = "B" : GOTO 6240
6060 IF IS(I) = 3 THEN DL$(I) = "C" : GOTO 6240
6070 IF IS(I) = 4 THEN DL$(I) = "D" : GOTO 6240
6080 IF IS(I) = 5 THEN DL$(I) = "E" : GOTO 6240
6090 IF IS(I) = 6 THEN DL$(I) = "F" : GOTO 6240
6100 IF IS(I) = 7 THEN DL$(I) = "G" : GOTO 6240
6110 IF IS(I) = 8 THEN DL$(I) = "H" : GOTO 6240
6120 IF IS(I) = 9 THEN DL$(I) = "I" : GOTO 6240
6130 IF IS(I) = 10 THEN DL$(I) = "J" : GOTO 6240
6140 IF IS(I) = 11 THEN DL$(I) = "K" : GOTO 6240
6150 IF IS(I) = 12 THEN DL$(I) = "L" : GOTO 6240
6160 IF IS(I) = 13 THEN DL$(I) = "M" : GOTO 6240
6170 IF IS(I) = 14 THEN DL$(I) = "N" : GOTO 6240
6180 IF IS(I) = 15 THEN DL$(I) = "O" : GOTO 6240
6190 IF IS(I) = 16 THEN DL$(I) = "P" : GOTO 6240
6200 IF IS(I) = 17 THEN DL$(I) = "Q" : GOTO 6240
6210 IF IS(I) = 18 THEN DL$(I) = "R" : GOTO 6240
6220 IF IS(I) = 19 THEN DL$(I) = "S" : GOTO 6240
6230 IF IS(I) = 20 THEN DL$(I) = "T" : GOTO 6240
6240 NEXT I
6250 RETURN
6260 *
6270 * *** LOCATE DEPARTMENTS ON GRID WITH PEN (FROM LINE 5980)
6280 *

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6290 IF OLD = 0 THEN GOTO 6320
6300 FOR J = 1 TO 2000 : NEXT J
6310 GOTO 6420
6320 FOR J = 1 TO NSQR(IS(I))
6330 PEN ON
6340 IF PEN(3) = 0 THEN GOTO 6330
6350 R = PEN(8)
6360 C = PEN(9)
6370 IF LAY$(R,C) <> "" THEN GOTO 6330
6380 LOCATE R,C
6390 PRINT DL$(I) : LAY$(R,C) = DL$(I)
6400 NEXT J
6410 '
6420 GET (1,1)-(319,144),GRD%
6430 NDDNE = 1
6440 PEN OFF
6450 NEXTENT = NEXTENT + 1
6460 IF NEXTENT <= ND THEN GOTO 6580
6470 '
6480 ' *** MODIFICATION ROUTINES
6490 '
6500 ' *** PROMPTS AND INPUTS
6510 '
6520 LOCATE 25,1 : INPUT; "  FINAL MODIFICATION? (Y/N)      ";A$
6530 IF A$ <> "N" THEN GOTO 6550 ELSE LOCATE 25,1
6540 INPUT; "GET PRINTOUT, THEN RETURN      ";DUM : GOTO 1820
6550 IF A$ = "Y" THEN FINAL% = 1 : GOTO 6650
6560 LOCATE 25,1 : PRINT "ANSWER Y OR N      ";
6570 FOR J = 1 TO 1000: NEXT J : GOTO 6520
6580 LOCATE 25,1
6590 '
6600 INPUT; "DO YOU WANT TO MODIFY? (Y/N)      ";A$
6610 IF A$ = "N" THEN GOTO 4370
6620 IF A$ = "Y" THEN GOTO 6650
6630 LOCATE 25,1 : INPUT;"  MODIFY?      (Y OR N)      ";A$ : GOTO 6610

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6640 GOTO 4370
6650 LOCATE 25,1 : INPUT; " ADD OR DELETE (A/D) ";A$
6660 IF A$ = "A" THEN LOCATE 25,1:INPUT;" ENTER DEPT. LETTER ";D$
6670 IF A$ = "D" THEN D$ = " "
6680 LOCATE 25,1 : INPUT; " HOW MANY SQUARES ";NS
6690 "
6700 " *** ACTUAL MODIFICATION WITH PEN
6710 "
6720 FOR I = 1 TO NS
6730 PEN ON
6740 IF PEN(3) = 0 THEN GOTO 6730
6750 FOR J = 1 TO 50 : NEXT J
6760 R1 = PEN(8) : C2 = PEN(9)
6770 LOCATE R1,C2
6780 PRINT D$ : IF D$ = " " THEN DD$ = ""
6790 IF D$ <> " " THEN DD$ = D$
6800 LAY$(R1,C2) = DD$
6810 FOR J = 1 TO 200 : NEXT J
6820 NEXT I
6830 GET (1,1)-(319,144),GRD%
6840 PEN OFF
6850 LOCATE 25,1 : INPUT; " ADD, DELETE, OR CONTINUE?(A,D,C)";A$
6860 IF A$ = "A" THEN GOTO 6660
6870 IF A$ = "D" THEN GOTO 6670
6880 IF A$ <> "C" THEN GOTO 6850
6890 IF A$ = "C" AND FINAL% = 0 THEN GOTO 4370 ELSE LOCATE 25,1
6900 INPUT; " GET PRINTOUT, THEN RETURN ";DUM : FINAL% = 0 : GOTO 1820
6910 "
6920 " *** SPECIAL INSTRUCTIONS SUBROUTINE (FROM LINE 820)
6930 "
6940 PRINT : INPUT " ENTER NUMBER OF THE DEPARTMENT";DN
6950 IF DN < 1 OR DN > ND THEN GOTO 6940
6960 SP%(DN) = 1
6970 PRINT : INPUT " ENTER INSTRUCTIONS ON THIS LINE";INST$(DN)
6980 PRINT: INPUT " ANY OTHER DEPARTMENTS? ENTER NUMBER (OR 0 TO STOP)";DN

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6990 IF DN = 0 THEN RETURN
7000 GOTO 6950
7010 *
7020 * *** SPECIAL INSTRUCTIONS OUTPUT FOR TABLEAU PAGE (FROM LINE 5310)
7030 *
7040 COLOR 2 : PRINT "      SPECIAL INSTRUCTIONS"
7050 COLOR 4 : PRINT : PRINT "      " INST2*(NEXTENT) : PRINT:PRINT
7060 COLOR 3
7070 RETURN
7080 *
7090 * *** SCORING SUBROUTINE (CALLED FROM LINE 2280)
7100 *
7110 * *** CONVERT LETTERS TO NUMBERS IN LAYOUT
7120 *
7130 PRINT:PRINT:COLOR 7:PRINT "      Please wait . . ."
7140 RESTORE 2960
7150 L$(1) = ""
7160 FOR I = 2 TO ND + 1
7170 READ L$(I) : NEXT          * *** READS LETTERS FROM DATA LINE 2960
7180 FOR I = 1 TO 17
7190 FOR J = 1 TO 40
7200 FOR K = 1 TO ND + 1
7210 IF LAY$(I,J) = L$(K) THEN GOTO 7230
7220 NEXT K
7230 NLAY(I,J) = K - 1
7240 NEXT J
7250 NEXT I
7260 *
7270 PRINT:PRINT:PRINT:COLOR 7:PRINT "      Just a little longer . . .":COLOR 2
7280 PRINT:PRINT
7290 *
7300 * *** IDENTIFY SURROUNDING SQUARES
7310 *
7320 FOR I = 2 TO 16
7330 FOR J = 2 TO 39 STEP 2

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7340 IF NLAY(I,J) = 0 THEN GOTO 7490
7350 K = I + 1   : L = I - 1
7360 M = J + 1   : N = J - 1
7370 N1 = NLAY(I,J)
7380 N(2) = NLAY(I,M) : N(3) = NLAY(I,N)
7390 N(4)=NLAY(K,J) : N(5)=NLAY(L,J)
7400 N(6)=NLAY(K,M) : N(7)=NLAY(K,N)
7410 N(8)=NLAY(L,M) : N(9)=NLAY(L,N)
7420 *
7430 * *** IF ADJOINING SQUARE DIFFERENT, TAKE NOTE
7440 *
7450 FOR II = 2 TO 9
7460 IF N1 <> N(II) THEN IC(N1,N(II)) = 1 : IC(N(II),N1) = 1
7470 NEXT II
7480 *
7490 NEXT J
7500 NEXT I
7510 RETURN
7520 *
7530 * *** DEFINING A BUILDING SUBROUTINE (FROM LINE 3930)
7540 *
7550 * *** DRAW GRID
7560 *
7570 SCREEN 1 : COLOR 8,0
7580 FOR I = 7 TO 320 STEP 8
7590 LINE (I,7)-(I,143),2
7600 NEXT
7610 FOR J = 7 TO 150 STEP 8
7620 LINE (7,J)-(320,J),2
7630 NEXT
7640 LSIDE! = SQR(USQR%)           * *** CALCULATE LENGTH OF A SIDE
7650 PFERFT! = 8/LSIDE!           * *** CALCULATE POINTS PER FOOT
7660 NDONE = 1
7670 IF OLD = 0 THEN GOTO 7740
7680 FOR I = 2 TO 18

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7690 FOR J = 2 TO 40
7700 IF LAY$(I,J) = "" THEN GOTO 7720
7710 LOCATE I,J : PRINT LAY$(I,J)
7720 NEXT J
7730 NEXT I
7740 '
7750 ' *** DRAW BUILDING
7760 '
7770 PT = 0 : LOCATE 20,1 : PRINT " LOCATE A CORNER WITH PEN"
7780 PEN ON
7790 IF PEN(3) = 0 THEN GOTO 7780
7800 FOR J = 1 TO 100 : NEXT J
7810 X% = PEN(1) : Y% = PEN(2)
7820 PEN OFF
7830 PSET (X%,Y%),1 :PRINT: INPUT " IS THAT OK ";A$
7840 IF A$ = "N" THEN PSET (X%,Y%),0 : GOTO 7770
7850 IF A$ <> "Y" THEN GOTO 7830
7860 PT = PT + 1 : BX(PT) = X% : BY(PT) = Y%
7870 LOCATE 22,1 : PRINT " "
7880 LOCATE 20,1 : INPUT " IS THE BUILDING RECTANGULAR";A$
7890 IF A$ = "N" THEN GOTO 8060
7900 IF A$ <> "Y" THEN GOTO 7880
7910 PRINT: INPUT " WHAT IS THE 'X' DIMENSION (FT)";XFT
7920 INPUT; " WHAT IS THE 'Y' DIMENSION (FT)";YFT
7930 XPTS% = INT(PPERFT! * XFT) : YPTS% = INT(PPERFT! * YFT)
7940 X2% = X% + XPTS% : Y2% = Y% + YPTS%
7950 LINE (X%,Y%)-(X2%,Y2%),1,B
7960 LOCATE 25,1 :INPUT; " IS THAT BUILDING OK";A$
7970 IF A$ <> "N" THEN GOTO 8020
7980 LINE (X%,Y%)-(X2%,Y2%),0,B
7990 LOCATE 22,1 : PRINT " "
8000 LOCATE 23,1 : PRINT " "
8010 LOCATE 25,1 : PRINT " "
8020 IF A$ <> "Y" THEN GOTO 7960
8030 PT = PT + 1 : BX(PT) = X2% : BY(PT) = Y2%
";
";
"; : PSET(X%,Y%),1:GOTO 7880

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```

8040 GET (1,1)-(319,144),GRD%
8050 RETURN
8060 LOCATE 20,1 : PRINT "
8070 LOCATE 22,1:PRINT "*"; : INPUT " WHICH DIRECTION (U,D,L,R, STOP)";DIR%
8080 LOCATE 22,1 : PRINT " "
8090 IF DIR% <> "STOP" THEN GOTO 8130 ELSE LOCATE 25,1
8100 INPUT; " GOOD BUILDING? (Y/N) ";A%
8110 IF A% = "N" THEN CLS :GOTO 7570
8120 IF A% <> "Y" THEN GOTO 8090 ELSE GET (1,1)-(319,144),GRD% : RETURN ' *****
8130 PRINT "*";: INPUT; " HOW MANY FEET " ; FT
8140 LOCATE 23,1 : PRINT " ";
8150 '
8160 PTS = INT(PPERFT! * FT)
8170 XX% = X% : YY% = Y%
8180 IF DIR% = "U" THEN Y% = Y% - PTS : GOTO 8230
8190 IF DIR% = "D" THEN Y% = Y% + PTS : GOTO 8230
8200 IF DIR% = "L" THEN X% = X% - PTS : GOTO 8230
8210 IF DIR% = "R" THEN X% = X% + PTS : GOTO 8230
8220 GOTO 8070
8230 LINE -(X%,Y%),1
8240 LOCATE 25,1 : INPUT; " IS THAT OK ";A%
8250 IF A% = "Y" THEN PT = PT + 1 : BX(PT) = X% : BY(PT) = Y%
8260 IF A% = "Y" THEN LOCATE 25,1 : PRINT " "; : GOTO 8070
8270 IF A% <> "N" THEN GOTO 8240
8280 LINE -(XX%,YY%),0 : LOCATE 25,1 : PRINT " ";
8290 X% = XX% : Y% = YY% : GOTO 8070
8300 '
8310 ' *** DETERMINE PERFECT SCORE SUBROUTINE (FROM LINE 2800)
8320 '
8330 PFTSC = 0
8340 FOR I = 1 TO ND
8350 FOR J = I+1 TO ND
8360 IF IV(I,J) < 0 THEN GOTO 8380
8370 PFTSC = PFTSC + IV(I,J)
8380 NEXT J

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8390 NEXT I
8400 PRINT:COLOR 4 :PRINT " PERFECT SCORE =" PFTSC : PRINT
8410 *
8420 * *** IDENTIFY UNSTATISFIED RELATIONSHIPS
8430 *
8440 COLOR 3
8450 N = 0
8460 FOR I = 1 TO ND
8470 FOR J = I+1 TO ND
8480 IF IC(I,J) = 1 AND IV(I,J) >= 0 THEN GOTO 8620 * *** TOUCH AND NOT "X"
8490 IF IC(I,J) = 1 AND IV(I,J) < 0 THEN GOTO 8510 * *** TOUCH AND IS "X"
8500 IF IV(I,J) <= 0 THEN GOTO 8620 * ** DON'T NEED TO TOUCH
8510 IF N = 1 THEN GOTO 8540
8520 PRINT " UNSATISFIED RELATIONSHIPS"
8530 PRINT:PRINT " RELATIONSHIP VALUE"
8540 RESTORE 2960
8550 FOR K = 1 TO I : READ DI$
8560 NEXT K
8570 RESTORE 2960
8580 FOR L = 1 TO J : READ DJ$
8590 NEXT L
8600 PRINT:PRINT " " DI$ ", " DJ$, ,R$(I,J)
8610 N = 1
8620 NEXT J
8630 NEXT I
8640 COLOR 2
8650 RETURN
8660 *
8670 * *** SUBROUTINE TO STORE LAYOUT (CALLED FROM LINE 2860)
8680 *
8690 INPUT " SPECIFY THE DRIVE AND THE FILENAME (EX --- B:LAYOUT) ";FILNM$
8700 OPEN FILNM$ FOR OUTPUT AS #1
8710 WRITE #1, ND,LBL,PT
8720 IF PT > 1 THEN INPUT "DO YOU WANT TO SAVE BUILDING (Y/N)";BLDSV$
8730 IF PT <= 1 THEN GOTO 8800

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8740 IF BLDSV# <> "Y" AND BLDSV# <> "N" THEN GOTO 8720
8750 WRITE #1, BLDSV#
8760 IF BLDSV# = "N" THEN GOTO 8800
8770 FOR J = 1 TO PT
8780 WRITE #1, BX(J), BY(J)
8790 NEXT J
8800 FOR I = 2 TO 18
8810 FOR J = 2 TO 40
8820 WRITE #1, LAY$(I,J)
8830 NEXT J
8840 NEXT I
8850 FOR I = 1 TO ND
8860 FOR J = I TO ND
8870 WRITE #1, R$(I,J),R$(J,I)
8880 NEXT J
8890 WRITE #1, AREA$(I), SP$(I), INST$(I), INST2$(I)
8900 IF LBL = 1 THEN WRITE #1, DNAME$(I)
8910 NEXT I
8920 WRITE #1, USOR%
8930 CLOSE #1
8940 RETURN
8950 '
8960 ' *** SUBROUTINE TO READ AND DISPLAY LAYOUT (FROM LINE 240)
8970 '
8980 INPUT " SPECIFY THE DRIVE AND FILENAME (EX -- B:LAYOUT) ";FILNM#
8990 OPEN FILNM# FOR INPUT AS #1
9000 INPUT #1, ND,LBL,PT
9010 IF PT <= 1 THEN GOTO 9070
9020 INPUT #1, BLDSV#
9030 IF BLDSV# = "N" THEN GOTO 9070
9040 FOR J = 1 TO PT
9050 INPUT #1, BX(J), BY(J)
9060 NEXT J
9070 FOR I = 2 TO 18
9080 FOR J = 2 TO 40

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9090 INPUT #1, LAY$(I,J)
9100 NEXT J
9110 NEXT I
9120 FOR I = 1 TO ND
9130 FOR J = I TO ND
9140 INPUT #1, R$(I,J), R$(J,I)
9150 NEXT J
9160 INPUT #1, AREA$(I), SP$(I), INST$(I), INST2$(I)
9170 IF LBL = 1 THEN INPUT #1, DNAME$(I)
9180 NEXT I
9190 INPUT #1, USQR%
9200 CLOSE #1
9210 RETURN
9220 '
9230 SCREEN 1 : COLOR B,0 : KEY OFF
9240 FOR I = 7 TO 320 STEP 8
9250 LINE (I,7)-(I,143),2
9260 NEXT I
9270 FOR J = 7 TO 150 STEP 8
9280 LINE (7,J)-(320,J),2
9290 NEXT J
9300 '
9310 ' *** SUBROUTINE TO FILL IN OLD LAYOUT (FROM LINE 5500)
9320 '
9330 FOR I = 2 TO 18
9340 FOR J = 2 TO 40
9350 IF LAY$(I,J) = "" THEN GOTO 9370
9360 LOCATE I,J : PRINT LAY$(I,J)
9370 NEXT J
9380 NEXT I
9390 NDONE = 1
9400 IF PT <= 1 THEN GOTO 9480
9410 IF BLDSV$ = "N" THEN GOTO 9480
9420 IF PT > 2 THEN GOTO 9440
9430 LINE (BX(1),BY(1))-(BX(2),BY(2)),1,B : GOTO 9480

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```

9440 PSET (BX(1),BY(1)),1
9450 FOR J = 2 TO PT
9460 LINE -(BX(J),BY(J)),1
9470 NEXT J
9480 '
9490 RETURN
9500 '
9510 ' SUBROUTINE TO INPUT DEPARTMENT NAMES (FROM LINE 340)
9520 '
9530 LBL = 1
9540 PRINT: PRINT " Please limit names to 10 characters":PRINT
9550 FOR I = 1 TO ND
9560 PRINT "   DEPT."; I; "IS ";
9570 INPUT DNAME$(I)
9580 NEXT I
9590 PRINT
9600 RETURN
9610 '
9620 ' *** SUBROUTINE TO PLACE NAMES ON INFO PAGE (FROM LINE 4830)
9630 '
9640 FOR I = 1 TO ND
9650 J = 3 + I
9660 LOCATE J,45
9670 IF I = NEXTENT THEN COLOR 4
9680 PRINT DL$(I);B$;B$;DNAME$(IS(I))
9690 COLOR 3
9700 NEXT I
9710 RETURN

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VITA²

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