COMPUTERIZED FACILITIES LAYOUT AND DESIGN - A COMPARISON

by

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INTRODUCTION

One of the most important activities of the industrial engineer is facilities layout and design. It has been defined by Zoller and Adendorff (1972) as "The task of assigning relative locations to a set of facilities such that a given level of transaction between these may be carried out with maximum overall efficiency " (p. 116). Facilities layout has been closely related to manufacturing, where the determination of how the manufacturing site, structures, machines and equipment to support production, is of prime consideration in achieving the exterprise's objectives economically and safely.

Though facilities layout has been carried out for many centuries, it was only in the recent decades that a few techniques like template juggling, mathematical models, graphical techniques, computer aided layout, and interactive computer aided layout were developed.

In template juggling, as the name indicates, templates are used to represent departments, machines or activities. The size of templates depends on the scale used to represent the actual size of the departments. The layout planner moves the templates around to get an optimum layout. It is a subjective process and as the complexity of the problem increases the chance of getting a good layout decreases.

Mathematical models are based on minimizing material handling costs. These models predict the location of facilities to reduce transportation costs, often based on very limiting assumptions. Because of their unrealistic built-in assumptions and tedious calculations, these models are rarely used in industry.

Graphical techniques such as spiral, straight line, simplified layout planning and travel charting are a combination of template juggling and mathematical models. They are cumbersome to use, when the number of departments in a facility exceed 15. Hence these techniques are generally used to produce layouts for simple problems (less than 15 departments).

Computer aided layouts are a combination of mathematical models and templates. The computer performs the tedious calculations, moves the departments around and produces graphical layouts. Layouts for large sized problems can be produced by this method (45 departments or more depending on the program). There are a large number of layout programs, used for a variety of problems.

Interactive computer aided layout is the combination of computer aided plant layout programs with interactive computer graphics techniques. The layout planner can easily modify or improve the layouts in a fraction of the time it takes to do it manually. This latest technique of the interaction of the layout planner and computer has advantages beyond any other technique because of the computer's ability to store, change the scale of drawings, overlays (like walls,electrical systems etc.) and its precision in drawing. This technique is relatively new and is gaining popularity in industry. Both interactive or other computer aided layouts as they are used today in industry have one major drawback, and that is, the computer does not understand facilities layout criteria. Hence it serves only an aid and can not be used to develop finalized layouts.

Computerized facilities layout first appeared in the 1960's. It was based on objective analysis, arithmetic calculations and used to work with significantly large and complex layout problems. These have been classified as

1. Construction programs - which lay out from scratch.
2. Improvement programs - which improve an existing layout.

The most commonly used construction layout programs are:

1. CORELAP
2. PLANET
3. ALDEP

Improvement layout programs are:

1. CRAFT
2. COFAD

The next section gives brief details of the data requirements for these programs and of the programs themselves.

Input Data

The input data required to layout a facility may include:

1. Departmental areas
2. From-to chart

3. Relationship chart
4. Move cost chart
5. Initial layout

1. The departmental areas include space for individual work stations and additional area to allow for movement among work station based on machine or element size and flow volume.
2. A from-to chart is a square matrix whose elements represent the volume of flow between departments. The volume may be recorded in any units of movement per unit of time to represent the movement of materials. For example, Figure 1a. gives the number of trips per week via a fork lift truck.
3. A relationship chart is a triangular matrix whose elements represent the qualitative relationship among the departments Figure 1b. Letter codes are used to indicate desirable or undesirable levels of closeness between departments and numbers show the reason why each level of closeness is chosen.
4. A move cost chart is a square matrix whose elements represent the cost of moving one unit of load of material per unit distance between departments. The units are in dollars and it is similar to a from-to chart.
5. An initial layout is the existing layout which indicates the spatial requirements of the departments to be included within the facility to some scale.

From \ To	A	B	C	D	E
A		10	10	40	
B			20	40	
C		15			
D					100
E		5			

A Receiving

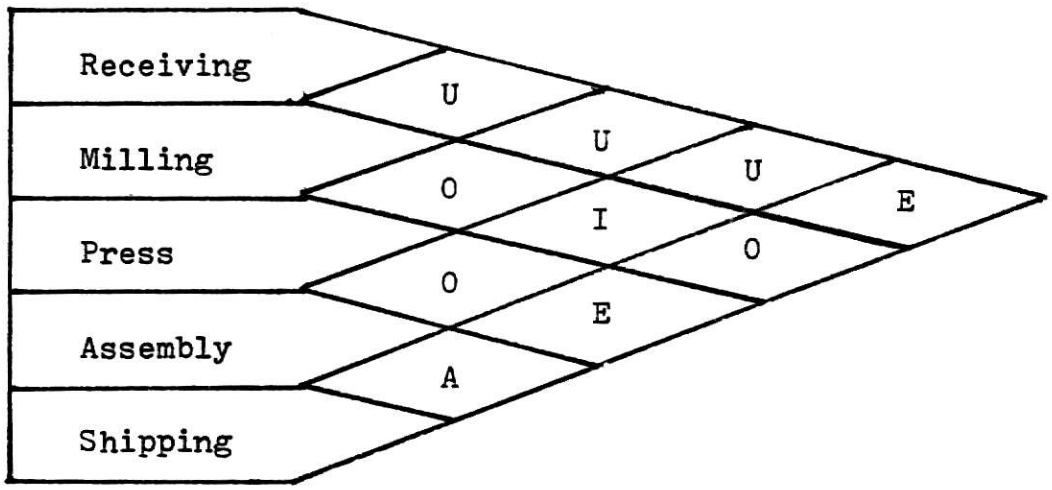
B Milling

C Press

D Assembly

E Shipping

Figure 1a. From-to chart in trips per week. Chart indicates 15 trips per week from press department to milling department.



Value	Closeness
A(6)	Absolutely necessary
E(5)	Especially important
I(4)	Important
O(3)	Ordinary closeness
U(2)	Unimportant
X(1)	Not desirable

Figure 1b. Relationship chart. The chart should be interpreted as "U" relationship between receiving department and the milling, press and assembly departments. And an "E" relationship with the shipping department.

Layout Programs

Construction type layout programs require less input data than the improvement type and can be used to generate layouts for new facilities. Since they can be used for new facilities they do not require an initial layout to be inputted. These programs also have the provision for rating the layouts for the evaluation of the layout planner. One of the drawbacks of these programs is that the layouts produced by them are not ready to be utilized; they have to be "massaged" before implementing them. There are more than 25 different construction programs, but only three of the most popular and readily available programs have been examined in this report.

COmputerized RElationship LAyout Planning (CORELAP). CORELAP was developed by Lee in 1967. The objective of the layout is to place departments close to each other based on their total closeness relationship rating. This is obtained by adding the closeness relationship values (A, E, I, O, U) of each department to those of every other department in turn. In addition to developing a layout, it produces an evaluation score by which the effectiveness of the layout can be judged. The score generated is the sum of products found by multiplying the shortest distance between pairs of departments times a preset value for the closeness desired relationship between those pairs of departments.

The input data required by CORELAP are:

1. Department area requirements
2. Relationship chart
3. Weights for ratings

   Ex: A=729, E=243, I=81, O=27, U=9, X=1

4. Preassignment of any departments to particular plant locations (optional)

The layout process begins by placing the most critical department, that is, the department having the highest sum of the closeness ratings in the center of the layout. The second department entering the layout will be the one having the highest original relationship (A, E, etc) with the department already selected. In case of a tie, it uses the total closeness rating to break the tie. CORELAP grows like a crystal out from the center to develop the layout. After the layout has been prepared CORELAP next calculates distance tables for each pair of departments. The criterion used is shortest path between departments, which is based on the premise that each department will have a dispatch and receiving area on that side of its layout nearest its neighbor. Also no pair of X rated departments are close to each other. Some important characteristics of CORELAP are:

1. Layouts obtained are irregular in shape.
2. The program requires the least detailed inputs compared to other programs.
3. CORELAP evaluates the solution by calculating

distance tables. The shortest path between departments are used as the criteria in the distance calculations.

4. It is limited to 45 departments.
5. It generates only one final layout.

The assumptions underlying CORELAP are:

1. The building shape has not been specified as in a new building type. Its shape is primarily dependent upon the layout arrangement.
2. Layout desired is independent of the material handling equipment to be used.
3. Human judgment used in developing the relationship chart is sufficient for layout planning purposes.
4. For the purpose of scoring the layouts, the flow is assumed to follow the shortest route between originating and receiving departments.

Plant Layout ANalysis and Evaluation Technique (PLANET). PLANET was developed by Deisenroth and Apple in 1972. The objectives of PLANET are to reduce material handling costs, generate alternate layouts and score these layouts. The lower the score the better the layout. The total score is the sum of the products of "flow between cost" and the rectilinear distance between centers of the departments. Flow between cost is the cost of moving the materials between departments without considering the direction of flow.

The input data required by PLANET are:

1. Departmental areas
2. From-to chart
3. Placement priority, that is, the order in which the departments are to be placed in the layout. The range is from one to nine.

Three different selection methods are used by PLANET to generate the layout.

Selection method A: The first pair of departments has the highest placement priority and has the highest flow between cost. The next department has the highest priority of those not yet selected and the highest flow between cost with one of the departments already selected. This procedure continues until all the departments have been selected.

Selection method B: The first pair of departments are selected as in method A but the next department selected is different. It has the highest priority of the unselected departments, and also the highest sum of flow between costs with all unselected departments. This process repeats until all the departments have been selected.

Selection method C: Only one department enters the layout initially. It is the department with the highest priority and highest sum of flow between cost with all other departments. The next department to enter the layout has the highest priority among those yet to be selected and also has the highest sum of flow between costs with all other departments. The process repeats until all the departments have been selected.

Some important characteristics of PLANET are:

1. PLANET does not restrict layout to a building shape, so layouts often have unusual shapes.
2. It is useful to generate initial layouts.
3. It generates three alternate layouts.
4. It allows flexible input data, that is, the input data can be in the form of from-to chart or an extended part list or a penalty chart - Tompkins and Moore (1978).

The assumptions underlying PLANET are:

1. All flows among departments originate and terminate at the centroid of the departments.
2. The direction of flow between departments is not important.

Automated Layout DEsign Program (ALDEP). ALDEP was developed by Seehof and Evans in 1967. The objective of ALDEP is to produce a large number of alternative layouts based on closeness relationships among departments. It also scores the layouts. The higher the score the better the layout. In ALDEP scoring,a value is assigned for closeness to each pair of adjacent departments (A=64, E=16, I=4, O=1, U=0, X=-1024). The computer then determines which departments are adjacent and assigns values to each adjacent pair according to the original relationship chart. The program honors more relationships if the layout has higher score. Therefore a higher score indicates a better layout.

The input data required by ALDEP are:

1. Departmental areas
2. Relationship chart
3. Degree of closeness (the lowest relationship to be searched for placement in the layout, such as , A, E, etc)
4. Sweep width (width of a department in squares)
5. Facility width (depth of the layout in squares)
6. Number of layouts to be generated
7. The number of floors utilized (one, two or three)
8. The variable formats required to print the layout

The process by which ALDEP works is that it selects the first department to enter the layout randomly. The relationship chart is then scanned to determine all departments that have a relationship equal to or more important than the initially specified degree of closeness (A, E, etc). If more than one exists, one of them is randomly selected to enter the layout. If no departments have a relationship equal to or more important than the specified degree of closeness, the second department to enter the layout is selected, the selection procedure is begun again between the second department selected and all unselected departments. Once this department is selected, the next department to enter the layout is determined by the selection procedure between the last department selected and all unselected departments. This process continues until all the departments have been selected.

ALDEP places the first department in the upper left hand corner of the layout. It is made as wide as the initially input "sweep width". As more departments are added it moves down the left hand column until it reaches the facility width, which is the depth of the layout in squares. When the facility width is reached, the computer starts a second column to the right of the first, under the constraint of the sweep width. It generates alternate layouts in the similar way and scores the layouts for evaluation.

Some important characteristics of ALDEP are:

1. It can handle up to three floors.
2. It gives rectangular or square shaped layouts.
3. Locations of departments can be fixed.
4. It has provisions for generating up to 20 alternate layouts.
5. It honors most interrelationships between departments.

The assumptions underlying ALDEP are:

1. The layout is independent of the type of material handling equipment used.
2. Mandatory departmental shapes are not taken into account.
3. It is limited to 53 departments.

The second type of layout programs are known as improvement layouts. These programs are used to improve existing layouts. They use more detailed input data compared to construction type layout programs. Typical input data required for these programs are initial layout, from-to chart, move cost chart. Like the construction layouts, even these layouts are not final and they may have to be modified by the layout planner before they are implemented. There are more than 10 different improvement layouts currently in use but two of the most widely utilized and readily available programs have been considered in this report. The next section gives a brief description of each program.

<u>Computerized Relative Allocation of Facilities Technique (CRAFT)</u>. CRAFT was developed by Armour and Buffa in 1963. The objective of CRAFT is to develop a layout which will approach a minimal transportation cost. At end of each iteration CRAFT will print the actual dollars in savings.
The input data required by CRAFT are:

1. From-to chart
2. Move-cost chart

3. An initial layout indicating the area requirements of the departments to be laid out
4. Dummy departments, to make the initial layout a rectangle or square

The CRAFT procedure begins by determining the centroids of the department in the initial layout. Then it calculates the rectilinear distance between department centroids and stores them in the distance chart. The transportation cost for the initial layout is determined by calculating the product of initially inputted from-to, move-cost and distance charts, where the distance chart consists of a matrix containing the rectilinear distances among department centroids. CRAFT next considers departmental interchanges for departments with equal area or having a common border, in order to reduce transportation costs. The interchanges considered depending on the input statement are:

1. Pairwise interchanges
2. Three way interchanges
3. Pairwise followed by three way interchanges
4. Three way followed by pairwise interchanges
5. The best pairwise or three way interchanges.

The transportation cost is approximated for each proposed interchange by internally exchanging the centroids of the interchanged departments. The interchange offering the greatest cost reduction is made, and the actual departmental centroids of the improved layout are calculated. A new distance chart is determined based on these new centroids and transportation cost is obtained for this improved layout. CRAFT continues by a) Considering other departmental interchanges in order to reduce the transportation costs. b) Approximating the transportation costs of the interchanges. c) The above process repeats by selecting the interchange which offers greatest cost reduction.

This process continues until no interchanges in the layout can be found which reduce the transportation cost. Then the model terminates.

Some important characteristic of CRAFT are:

1. Permits fixing specific locations,
2. Input shapes can vary.
3. Costs and savings are printed out.
4. It can check previous iterations.
5. It can evaluate the layouts generated by other layout programs.
6. In the initial layout,dummy departments are fixed to a specific area, with zero flow volumes to other departments. They are used in the initial layout to:
   a) Fill building irregularities (to get rectangular buildings).
   b) Represent fixed areas like stairways, elevators, toilets and aisles.
7. The program does not consider all possible interchanges and a suboptimum layout is reached.

The assumptions underlying CRAFT are:

1. Move costs are costs per unit distance;require the acceptance of the following:
   a) Material handling equipment is selected before the facility is laid out.
   b) Move costs are known before hand.
   c) Move costs are independent of equipment utilization.
   d) Move costs are a linear function of the distance.
2. All flows are rectangular.
3. All flows among departments originate and terminate at department centroids.
4. There are no negative relationships, that is, no departments which should be kept apart.

COmputerized FAcilities Design (COFAD). COFAD was developed by Tompkins and Reed in 1973. The objective of COFAD is to develop a layout and material handling system which approaches the minimal material handling system. COFAD also has provision for comparing alternate material handling systems and for conducting sensitivity analysis on the flow volumes by varying the values of the from-to chart. It prints out the savings in dollars at the end of every iteration for the evaluation of the layout planner.

The input data required by COFAD are:

1. An initial layout indicating the area requirements of the departments to be laid out.

2. A from-to chart for each mobile material handling equipment alternative indicating the volume of flow between departments.
3. A description of which material handling alternatives are feasible for each move, if alternatives are to be evaluated based on straight line or rectilinear distances and if any material handling alternatives are to be fixed to particular moves.
4. The percent change in the from-to chart for the evaluation of solution sensitivity.
5. The data for calculating cost of performing various moves via various material handling alternatives.

The process by which COFAD improves the layout is the same as CRAFT. The next stage in the COFAD process is determination of the best material handling system. To do this, the computer first calculates the costs to perform each move with each of the equipment types based on the assumption of full utilization of the equipment. It then assigns the equipment that has least cost. The computer next calculates the number of pieces of material handling equipment required and apportions the costs for the un-utilized portion of each equipment type to the moves that utilize that type of equipment. It again tries to improve the material handling equipment system by improving the utilization of the equipment that is poorly utilized. If the preceeding process does not result in a change in the layout or material handling system, the program stops, or conducts sensitivity analysis on the flow volumes. If there are changes in the layout then the CRAFT-like procedure is run again until no further improvements are obtained in the layout. Sensitivity analysis is performed on this final layout.

Some important characteristics of COFAD are:

1. It permits fixing departments to specific locations.
2. It has the option of assigning or negating from consideration the assignment of particular material handling equipment types to certain moves.
3. It allows realistic determination of both a layout and material handling system.
4. The steady state solution is obtained by rerunning the model with 90% and 110% of the projected flow volume and checking to see that the solution to these two problems are similar to the original solution.
5. The sensitivity analysis is performed by rerunning the model with variation ranging from 50% to 150% of the projected flow volumes so as to protect against the design of a facility which is inflexible and not capable of meeting the day to day fluctuations.
6. Dummy departments are used to fill building irregularities, to represent fixed areas and to aid in evaluating aisle locations.

The assumptions underlying COFAD are:

1. All moves among departments originate and terminate at the centroid of the departments and follow a rectilinear path.
2. The sensitivity analysis considers only the variations in the total flow volume for a predefined product mix and does not evaluate changes in product mix.

A brief summary of comparison between the five layout programs is given in Table 1.

Literature Review

Muther and McPherson (1970) discussed CRAFT, ALDEP, CORELAP and RMA COMP 1 with respect to their input requirements and output characteristics. They commented that these programs were still in the experimental stage; they required manual adjustment to arrive at a practical layout, and unless the location of an activity is fixed none of the programs honors a shape or configuration requirement for any given activity. They concluded that the programs serve as useful tools to a layout designer and aid in generating alternate layouts. However their arguments were not substantiated by a concrete example. Their work in comparing the layout programs tends to be subjective and incomplete.

Denholm and Brooks (1970) compared CRAFT, CORELAP and ALDEP. They used these layout programs to generate a layout

TABLE 1

Comparison of Layout Programs

	CORELAP	PLANET	ALDEP	CRAFT	COFAD
1.	One final layout	Three alternate layouts	20 alternate layouts	One final layout	One final layout
2.	Based on relationship chart	Based on from-to chart	Based on relationship chart	Based on initial-layout, move cost, and from-to charts	Same as CRAFT plus alternate material handling move-cost chart
3.	Handles one floor	One floor	Three floors	One floor	One floor
4.	Lower the score the better the layout	Lower the score the better the layout	Higher the score the better the layout	Use dollar costs	Use dollar costs
5.	Irregular shaped layouts	Irregular shaped layouts	Regular(square or rectangular) shaped layouts	Regular shaped layouts	Regular shaped layouts
6.	Number of departments limited to 70	Number of departments limited to 99	Number of departments limited to 64	Number of departments limited to 40	Number of departments limited to 40

Comparison of Layout Programs (continued)

	CORELAP	PLANET	ALDEP	CRAFT	COFAD
7.	Departments cannot be fixed to a specific location.	Departments cannot be fixed to specific locations.	Departments can be fixed to a specific location.	Departments can be fixed to a specific location.	Departments can be fixed to to a specific location.
8.	No provision for fixing aisles, toilets, stairwells etc.	No provision for fixing aisles, toilets, stairwells etc.	There is provision for fixing aisles, toilets, etc.	Dummy departments can be used to fix aisles, toilets etc.	Dummy departments can be used to fix aisles, toilets etc.
9.	Initial assignment of the department in the layout is based on total closeness rating.	Initial assignment of the department in the layout is based on total flow between cost and placement priority.	Initial assignment of department in the layout is done randomly.	Initial assignment of department in the layout is based on the interchange having minimum transportation cost.	Same as CRAFT
10.	Rarely used as final optimal layout	Rarely used as final optimal layout	Can be used as final optimal layout	Can be used as final optimal layout	Can be used as final optimal layout
11.	18 percent of the practising engineers use it as reported by Moore's survey (1978)	5 percent	11 percent	25 percent	Not available

for a printed circuit board processing department within a larger manufacturing building. The three programs were provided the same information. The criteria they used for comparison was to minimize material handling cost. The final outputs of CORELAP and ALDEP were later appraised by CRAFT and they concluded that CRAFT generated the best layout with minimum material handling cost.

The Denholm and Brooks study was erroneous on three counts. First, they made no distinction between construction layouts (CORELAP and ALDEP) and improvement layouts (CRAFT). Second, they were improving the existing layout, and hence both CORELAP and ALDEP were inappropriate. Finally, they concluded that CRAFT produces a superior layout compared to the other two,which was misleading. The objective of their study was to minimize material handling cost. Both CORELAP and ALDEP do not consider material handling costs, so comparing them with CRAFT (whose objective is minimizing material handling cost) is erroneous, hence their results are inconclusive.

Moore (1974, 1978) made two surveys and found that computer aided layout was used by more than 57 percent of the practicing engineers (industry and consultants). He listed the most popular layout programs as CORELAP, PLANET, ALDEP and CRAFT. He concluded that a majority of the layout planners used them to:

1. Generate alternate layouts

2. Evaluate the proposed layouts.

He also concluded that in some cases the layout programs provided final optimal layouts which were implemented.

This report attempts to compare the layout programs listed above in terms of the above goals, so as to guide the layout planner to pick the layout program that would give the best solution to the problem.

PROBLEM

The purpose of this study is to test each and compare the five computerized layout programs viz. CORELAP, PLANET, ALDEP, CRAFT and COFAD, in terms of their following objectives.

1. Generate alternate layouts
2. Evaluate the proposed layouts
3. Minimize material handling cost
4. Variation of input quantities in the programs

Four problems have been chosen for this study.

METHOD

The computer programs were obtained from the SHARE program library, Raleigh, North Carolina. The detailed description of the input format and blank input data forms were adopted from Computer aided layout: A user's guide by Tompkins and Moore (1978). The data was converted into the input format required by the programs for the four problems.

Problems

The problems and their input requirements are given as detailed below:

Figure	Problem	Source
2 a,b,c	1	Adopted from, Facilities layout and design by Francis and White Ch.3., Problem #1.
3 a,b,c	2	Example problem - Computer aided layout: A user's guide by Tompkins and Moore
4 a,b,c	3	Problem developed by C. A. Bennett.
5 a,b,c	4	Same as problem 1., Ch. 3., Problem #11.

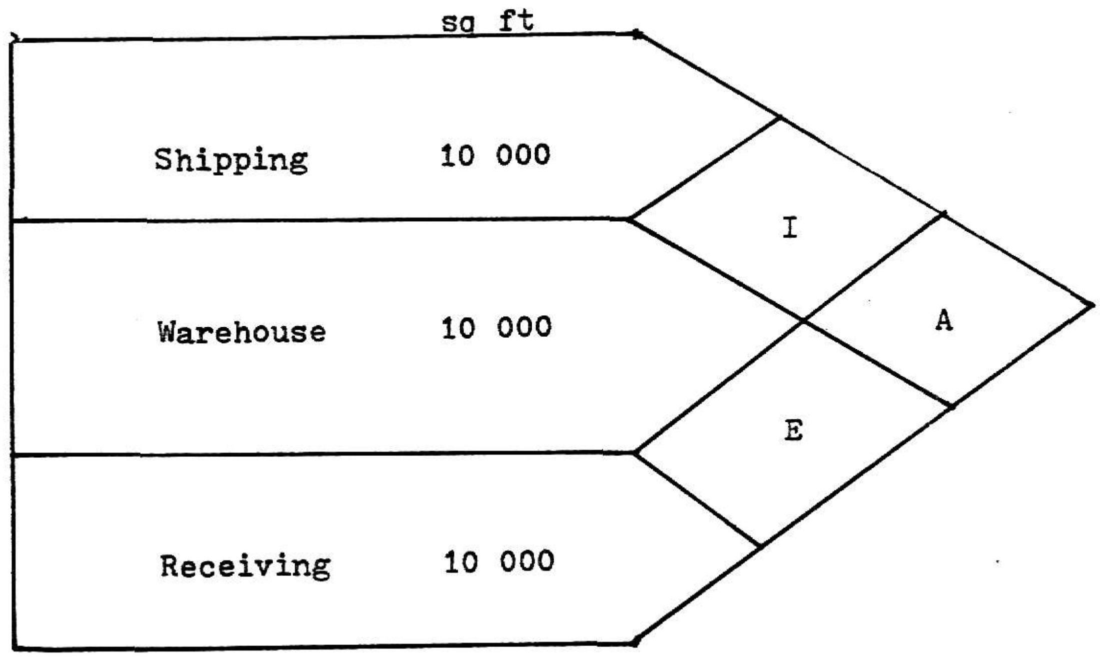


Figure 2a. Problem 1 - Relationship chart for the flow volumes.

To / From	A	B	C
A		1	3
B	1		3
C	4	2	

Legend

A - Shipping
B - Warehouse
C - Receiving

Figure 2b. Problem 1 - From-to chart indicating number of trips per week via an electric platform truck.

To / From	A	B	C
A		1	1
B	1		1
C	1	1	

Figure 2c. Problem 1 - Flow cost chart in dollars per unit moved between departments.

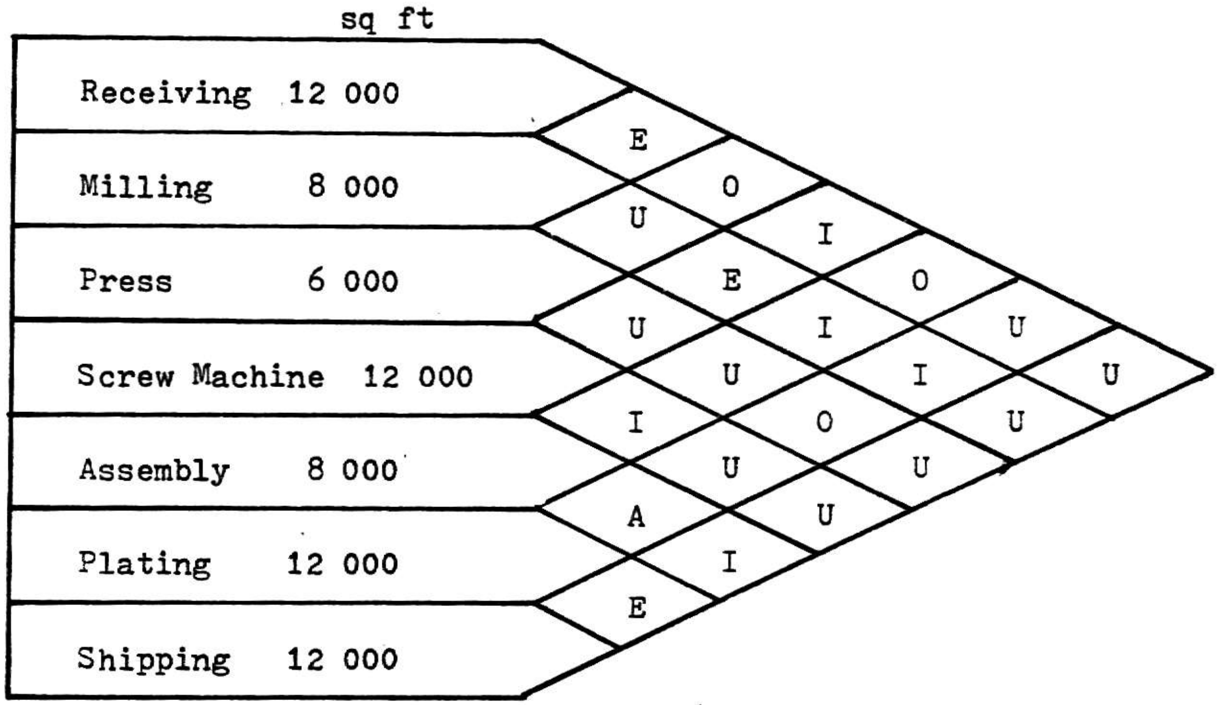


Figure 3a. Problem 2 - Relationship chart for the flow volumes.

To / From	A	B	C	D	E	F	G
A		45	15	25	10	5	
B				30	25	15	
C					5	10	
D		20			35		
E						65	35
F		5			25		65
G							

Legend

A - Receiving
B - Milling
C - Press
D - Screw Machine
E - Assembly
F - Plating
G - Shipping

Figure 3b. Problem 2 - From-to chart indicating number of trips per week via fork truck.

To / From	A	B	C	D	E	F	G
A		1	1	1	1	1	1
B	1		1	1	1	1	1
C	1	1		1	1	1	1
D	1	1	1		1	1	1
E	1	1	1	1		1	1
F	1	1	1	1	1		1
G	1	1	1	1	1	1	

Figure 3c. Problem 2 - Flow cost chart in dollars per unit moved between departments.

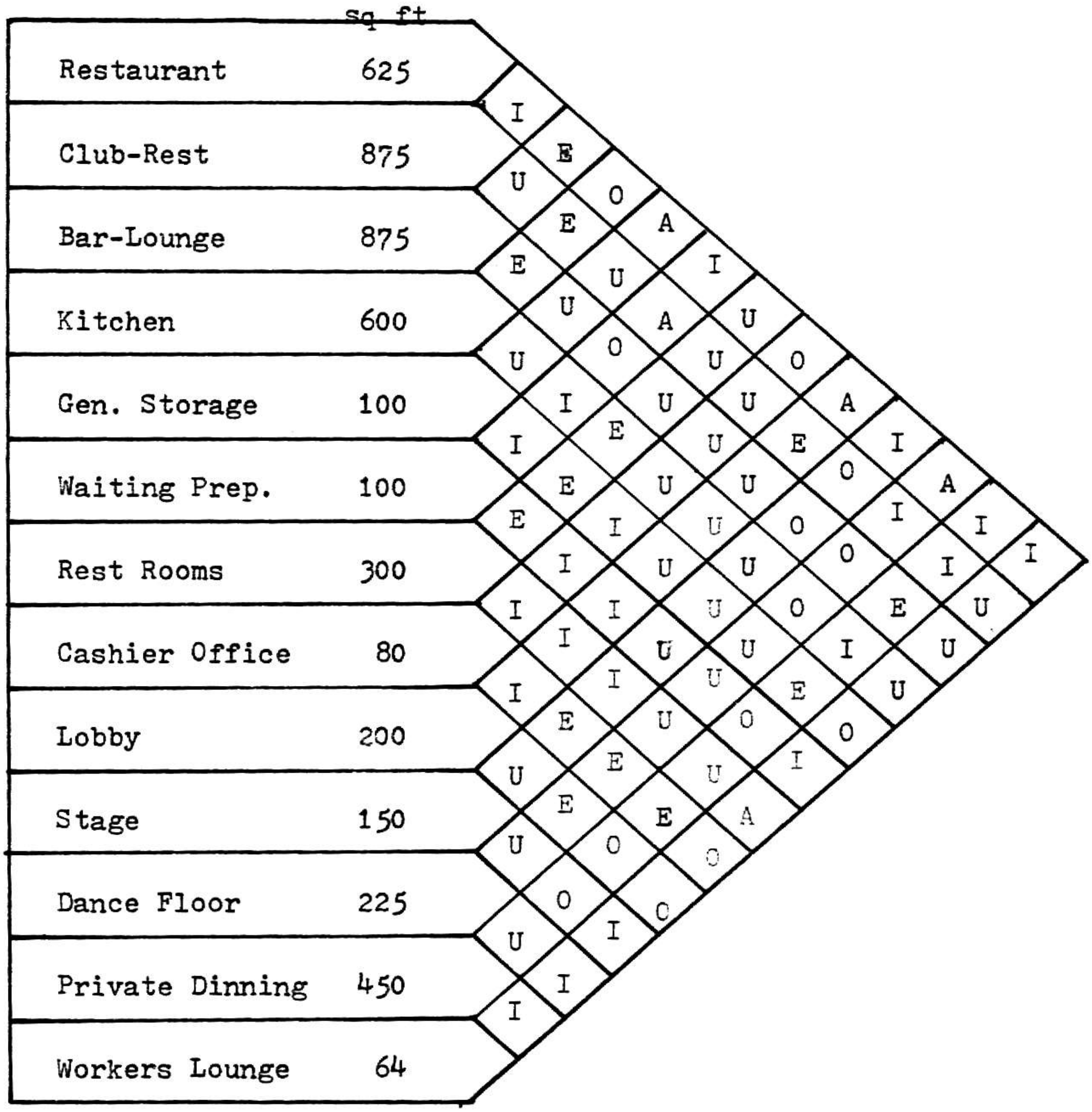


Figure 4a. Problem 3 - Relationship chart for the flow volumes.

To / From	A	B	C	D	E	F	G	H	I	J	K	L	M
A		18	36	9	72	18	0	9	72	18	72	18	18
B			0	36	0	72	0	0	36	9	18	18	0
C				36	0	9	0	0	0	9	9	36	0
D					0	18	36	0	0	0	9	18	0
E						18	36	18	0	0	0	36	9
F							36	18	18	0	0	9	18
G								18	18	18	0	0	72
H									18	36	36	36	9
I										0	36	9	9
J											0	9	18
K												0	18
L													18
M													

Legend
A-Restaurant
B-Club restaurant
C-Bar-lounge
D-Kitchen
E-General storage
F-Waiting preparation
G-Rest rooms
H-Cashier office
I-Lobby
J-Stage
K-Dance floor
L-Private dinning
M-Workers lounge

Figure 4b. Problem 3 - From-to chart indicating number of trips per week.

To / From	A	B	C	D	E	F	G	H	I	J	K	L	M
A		1	1	1	1	1	1	1	1	1	1	1	1
B	1		1	1	1	1	1	1	1	1	1	1	1
C	1	1		1	1	1	1	1	1	1	1	1	1
D	1	1	1		1	1	1	1	1	1	1	1	1
E	1	1	1	1		1	1	1	1	1	1	1	1
F	1	1	1	1	1		1	1	1	1	1	1	1
G	1	1	1	1	1	1		1	1	1	1	1	1
H	1	1	1	1	1	1	1		1	1	1	1	1
I	1	1	1	1	1	1	1	1		1	1	1	1
J	1	1	1	1	1	1	1	1	1		1	1	1
K	1	1	1	1	1	1	1	1	1	1		1	1
L	1	1	1	1	1	1	1	1	1	1	1		1
M	1	1	1	1	1	1	1	1	1	1	1	1	

Figure 4c. Problem 3- Flow cost chart in dollars per unit distance moved.

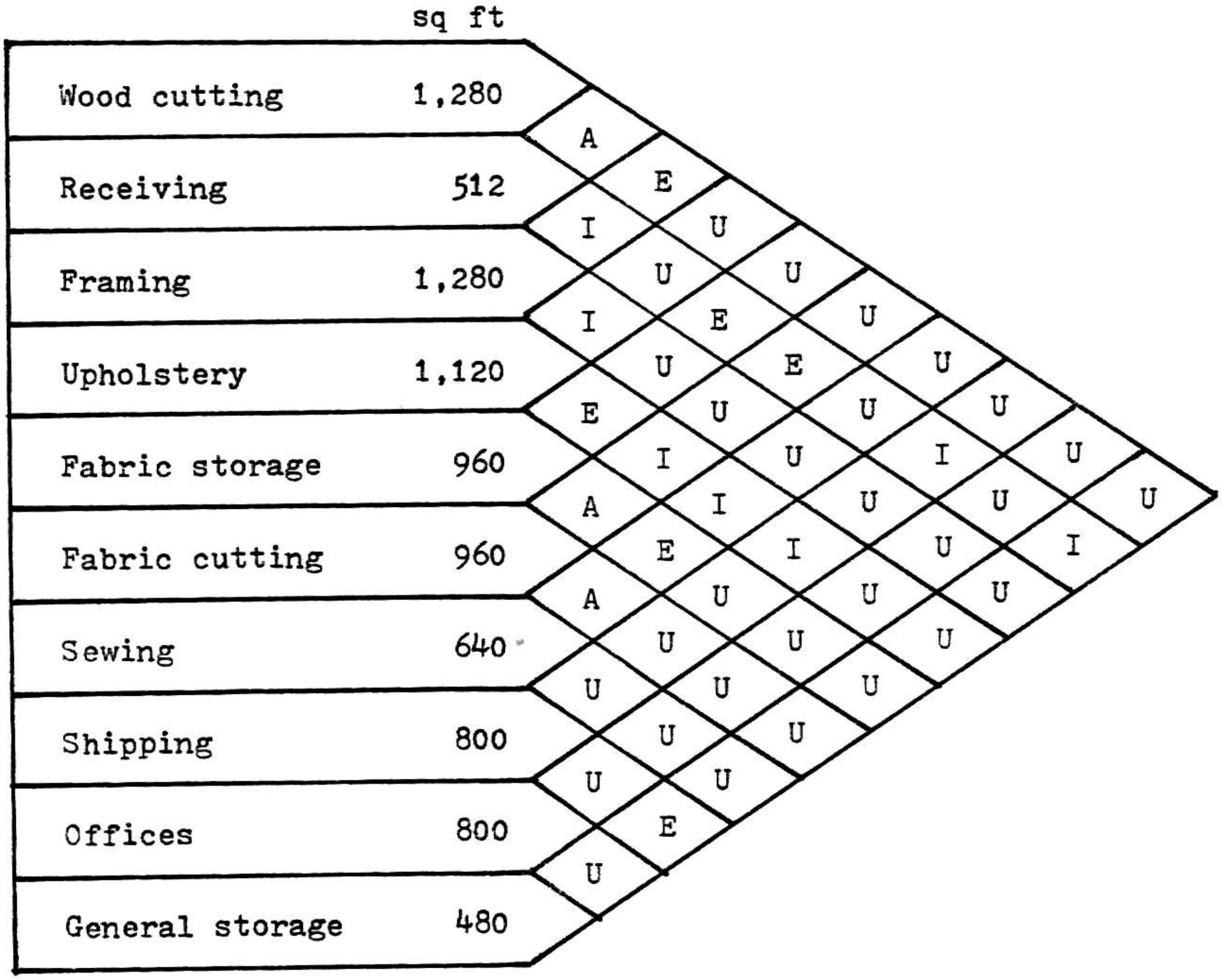


Figure 5a. Problem 4 - Relationship chart for the flow volumes.

To / From	A	B	C	D	E	F	G	H	I	J
A		2	1						2	
B	6				6	2				2
C	1	2		4					2	
D	1	1	4			4	2	3	2	2
E						5	3		2	
F				4	5		4		2	
G				2	2	4			2	
H					3				2	
I	1	1	1	1	1	1	1	1		1
J				2			1	1	2	

<u>Legend</u>

A - Woodcutting
B - Receiving
C - Framing
D - Upholstery
E - Fabric storage
F - Fabric cutting
G - Sewing
H - Shipping
I - Offices
J - General storage

<u>Figure 5b. Problem 4 - From-to chart indicating number of trips per week via an fork truck</u>.

To / From	A	B	C	D	E	F	G	H	I	J
A		2	2						1	
B	3				2	2				2
C	1	1		5					1	
D	1	1	2			2	2	3	1	1
E						4	3		1	
F				1	3		2		1	
G				4	2	2			1	
H					2				1	
I	1	1	1	1	1	1	1	1		1
J				1			1	2	1	

Figure 5c. Problem 4 - Flow cost chart in dollars per unit moved between departments.

Layouts

Each problem was run on the computer several times by varying the following input quantities in the programs:

CORELAP.

1. The requested unit square side length or element square. [The maximum layout area is 39 x 39. Therefore the unit square side length squared, divided into the total facility area must be less than 1521. If it is not, or no unit square length is input, CORELAP will calculate the unit square area (optional).]
2. Maximum length to width ratio [which precludes the layout becoming long and narrow (optional).]
3. Strict wanted length to width ratio [which specifies the shape of the area available for the layout (optional).]
4. Layout filling ratio [indicates the proportion of the layout area reserved to be filled by actual departments. It should be less than 1; 0.5 is assumed if defaulted.]

PLANET.

1. Number of square feet in a unit square or block size.
2. Department placement priority.

ALDEP.

1. Odd number used as a random number seed.
2. Column sweep width.

3. Number of square feet in a unit square or unit square.

4. Degree of closeness [64 is entered if an "A" relationship is the lowest relationship to be searched for 16 for an "E" relationship, 4 for "I" and 1 for "O".]

CRAFT. The input for initial layouts were changed each time by:

1. Final layout from CORELAP.
2. Final layout from PLANET.
3. Final layout from ALDEP.

COFAD. Problem 2 was run on the computer and the following quantities were incorporated in the input format:

1. Alternate materials handling equipment were utilized
   a) fork lift truck
   b) electric platform truck

2. Sensitivity analysis was performed using 90% and 110% of the flow volumes.

The layouts are given in the results section.

RESULTS

The layout programs were run on the computer, using the different input parameters for each of the four problems. A total of 41 layouts were obtained and the results are classified according to the programs.

CORELAP

The CORELAP outputs show no variation, when the values for fill ratio, maximum length to width ratio and strict wanted length to width ratio were changed. However, when the values for element square were changed, there was some variation in the layouts. CORELAP prints a total score for the final layout, which is of no practical significance. CORELAP assumes the values of element square, filling ratio, maximum length to width ratio and strict wanted length to width ratio, when they are not specified in the input format. In the case of element square it assumes the area of the smallest size department as the area of the element square to calculate blocks. The complete CORELAP solution for problem 3 is given in Figure 8A through Figure 8M.

Table 2 indicates the values of the variables changed and the resulting layouts.

TABLE 2

CORELAP Summary of Results

Problem	Element square sq ft	Fill ratio	Maximum Length to width ratio	Strict Length to width ratio	Figure
1	100	0.5	-	-	6
1	100	0.9	9	2	6
2	6000	0.5	-	-	7
2	6000	0.9	9	2	7
3	64	0.5	-	-	8H
3	64	0.9	9	2	8H
3	25	0.5	-	-	9
4	480	0.5	-	-	10
4	480	0.9	9	2	10
4	4	0.5	-	-	11

Legend

Problem 1

11 - Shipping

12 - Warehouse

13 - Receiving

Problem 2

11 - Receiving

12 - Milling

13 - Press

14 - Screw machine

15 - Assembly

16 - Plating

17 - Shipping

18 or 19 etc - Dummies

Problem 3

11 - Restaurant

12 - Club restaurant

13 - Bar lounge

14 - Kitchen

15 - General storage

16 - Waiting preparation

17 - Rest rooms

18 - Cashier office

19 - Lobby

20 - Stage

21 - Dance floor

22 - Private dinning

23 - Workers lounge

24 or 25 etc - Dummies

Problem 4

11 - Wood utting

12 - Receiving

13 - Framing

14 - Upholstery

15 - Fabric storage

16 - Fabric cutting

17 - Sewing

18 - Shipping

19 - Offices

20 - General storage

21 - Dummies

```
PICTORIAL LAYOUT    NO.  1             PROBLEM NC.1
.........................................................
















                                                 ....
                                                 .11.
                                               .......
                                               .12.13.
                                               .......
```

Figure 6. Problem 1 -CORELAP final output.

```
PICTORIAL LAYOUT    NO.  1          PROBLEM NO.2
..........................................................











                                              .............
                                              .14.11   .13.
                                              .  .........
                                              .  .12.16   .
                                              .............
                                                 .17   .15.
                                                 .........
```

Figure 7. Problem 2 - CORELAP final output.

WEIGHING FACTORS FOR THIS RUN

WEIGHT	R A T I N G VALUE	MEANING
729	7	FOR PRE-ASSIGNING
243	6(=A)	ABSOLUTELY NECESSARY
81	5(=E)	ESPECIALLY IMPORTANT
27	4(=I)	IMPORTANT
9	3(=O)	ORDINARY CLOSENESS
1	2(=U)	UNIMPORTANT
-729	1(=X)	UNDESIRABLES

Figure 8A . Problem 3 - CORELAP output, page 1.

```
PROBLEM NUMBER    1                                        PROBLEM NO.3

PARAMETERS

N= 13
ELEMENT SQUARE SIDE=  0
MAXIMUM LENGTH TO WIDTH RATIO=  0
STRICT WANTED LENGTH TO WIDTH RATIO = 0.0
LAYOUT FILLING RATIO=.0
PLOT/PUNCH OPTION=1     PARTIAL LAYOUT OPTION(IOPT)=0


DATA

DEPARTMENT  DIRECTION   RELATION CHARTS
NO      AREA   N W S E

11       625   0 0 0 0   0416146441114
12       875   0 0 0 0   4066145446634
13       875   0 0 0 0   1603136444634
14       600   0 0 0 0   6630661111113
15       100   0 0 0 0   1116041111113
16       100   0 0 0 0   4436401111136
17       300   0 0 0 0   6561110563364
18        80   0 0 0 0   4441113063343
19       200   0 0 0 0   4441116604461
20       150   0 0 0 0   1641113340641
21       225   0 0 0 0   1661113346041
22       450   0 0 0 0   1331136464404
23        64   0 0 0 0   4443364311140
```

Figure 8B. Problem 3 - CORELAP output, page 2.

```
TOTAL AREA=     4644

NO SHAPE PARAMETER GIVEN RATIO=1 ASSUMED

NO FILLING RATIO SPECIFIED.FILLRA=0.50 IS ASSUMED

NO ELEMENT SQUARE SIDE SPECIFIED

GIVEN ELEMENT SQUARE TOO SMALL

ELEMENT SQUARE=     64

TOTAL NUMBER OF ELEMENT SQUARES NEEDED FOR LAYOUT IS 145

40 COLUMNS AND 40 ROWS ARE RESERVED FOR LAYOUT
```

Figure 8C. Problem 3 - CORELAP output, page 3.

DEPARTMENTAL DATA

NO	NUMBER OF UNIT SQUARES	BLOCK WIDTH	BLOCK LENGTH	TCR
11	10	3	4	37
12	14	4	4	53
13	14	4	4	45
14	9	3	3	36
15	2	1	2	22
16	2	1	2	35
17	5	2	3	45
18	1	1	1	37
19	3	1	3	42
20	2	1	2	35
21	4	2	2	37
22	7	3	3	40
23	1	1	1	38

Figure 8D. Problem 3 - CORELAP output, page 4.

ORDERED NARAY AND REL-CHART

NO	UNITS	LENGTH	WIDTH	TCR
12	14	4	4	53
13	14	4	4	45
17	5	2	3	45
19	3	1	3	42
22	7	3	3	40
23	1	1	1	38
11	10	3	4	37
21	4	2	2	37
18	1	1	1	37
14	9	3	3	36
20	2	1	2	35
16	2	1	2	35
15	2	1	2	22

NO	12	13	17	19	22	23	11	21	18	14	20	16	15
11	4	1	6	4	1	4	0	1	4	6	1	4	1
12	0	6	5	4	3	4	4	6	4	6	6	4	1
13	6	0	6	4	3	4	1	6	4	3	4	3	1
14	6	3	1	1	1	3	6	1	1	0	1	6	6
15	1	1	1	1	1	3	1	1	1	6	1	4	0
16	4	3	1	1	3	6	4	1	1	6	1	0	4
17	5	6	0	6	6	4	6	3	3	1	3	1	1
18	4	4	3	6	4	3	4	3	0	1	3	1	1
19	4	4	6	0	6	1	4	4	6	1	4	1	1
20	6	4	3	4	4	1	1	6	3	1	0	1	1
21	6	6	3	4	4	1	1	0	3	1	6	1	1
22	3	3	6	6	0	4	1	4	4	1	4	3	1
23	4	4	4	1	4	0	4	1	3	3	1	6	3

<u>Figure 8E. Problem 3 - CORELAP output, page 5</u>.

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	22	22	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	13	13	22	22	22	18	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	13	13	13	13	19	19	19	0
0	0	0	0	0	0	0	0	0	0	0	0	0	13	13	13	13	17	17	0	0
0	0	0	0	0	0	0	0	0	0	0	21	21	13	13	13	13	17	17	0	0
0	0	0	0	0	0	0	0	0	0	0	21	21	12	12	12	12	17	11	11	11
0	0	0	0	0	0	0	0	0	0	0	20	20	12	12	12	12	23	11	11	11
0	0	0	0	0	0	0	0	0	0	0	0	0	12	12	12	12	0	11	11	11
0	0	0	0	0	0	0	0	0	0	0	0	0	12	12	14	14	14	11	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	16	16	14	14	14	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	15	15	14	14	14	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8F. Problem 3 - CORELAP output, page 6.

LAYOUT NO. 1 PROBLEM NO.3

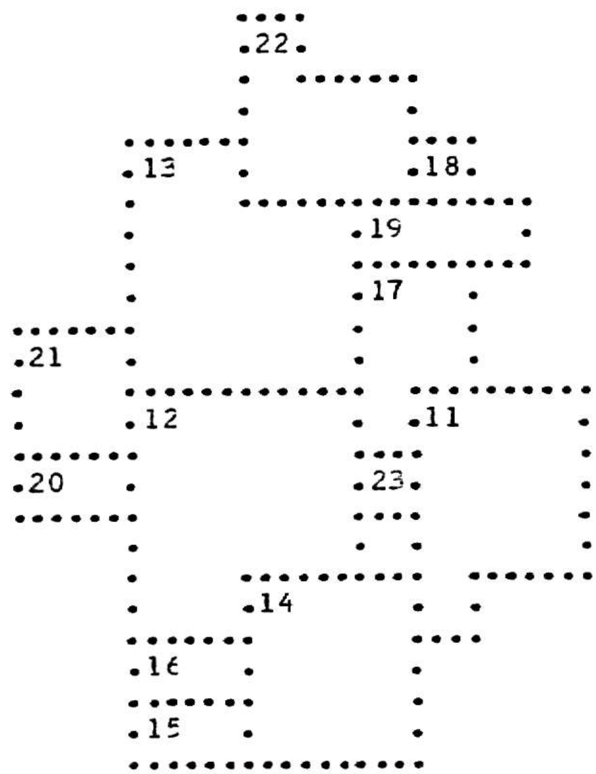


Figure 8G. Problem 3 - CORELAP final output, page 7.

CRDER TABLE

VICTOR	WITH	REL TO WINNER	PLACING RATING	BOUNDARY LENGTH	PRE-ASSIGNED	NO ROOM
12	0	0	0	0	0	0
13	6	12	243	4	0	0
21	6	12	486	2	0	0
14	6	12	243	3	0	0
20	6	12	486	3	0	0
17	6	13	324	3	0	0
11	6	14	729	3	0	0
16	6	14	270	3	0	0
15	6	14	270	3	0	0
19	6	17	270	3	0	0
22	6	17	252	4	0	0
23	6	16	81	3	0	0
18	6	19	270	2	0	0

Figure 8H. Problem 3 - CORELAP output, page 8.

DISTANCE TABLE

6 RATING (16 PAIRS)

FROM	TO	DISTANCE
11	17	0
11	14	0
12	13	0
12	21	0
12	14	0
12	20	0
13	17	0
13	21	0
14	16	0
14	15	0
17	19	0
18	19	0
19	22	0
20	21	0
17	22	1
16	23	5

Figure 8I. Problem 3 - CORELAP output, page 9.

DISTANCE TABLE

4 RATING (21 PAIRS)

FROM	TO	DISTANCE
11	23	0
12	23	0
12	16	0
13	19	0
15	16	0
17	23	0
18	22	0
11	12	1
13	20	2
11	19	2
13	23	2
13	18	2
12	19	3
11	18	3
11	16	4
22	23	4
21	22	5
12	18	5
19	21	6
20	22	7
19	20	8

Figure 8J. Problem 3 - CORELAP output, page 11.

DISTANCE TABLE

3 RATING (13 PAIRS)

FROM	TO	DISTANCE
13	22	0
14	23	1
17	18	1
12	22	3
13	14	3
17	21	4
13	16	4
17	20	5
18	23	5
15	23	6
16	22	8
18	21	3
18	20	10

Figure 8K. Problem 3 - CORELAP output, page 12.

DISTANCE TABLE

1 RATING (27 PAIRS)

FROM	TO	DISTANCE
12	15	1
11	13	2
14	17	2
16	20	3
19	23	3
15	20	4
16	21	4
11	22	4
14	20	4
20	23	4
11	15	5
15	21	5
11	21	5
13	15	5
11	20	5
14	19	5
14	21	5
21	23	5
16	17	6
14	22	6
14	18	7
15	17	7
16	19	9
15	22	9
15	19	10
16	18	11
15	18	12

TOTAL SCORE FOR THIS RUN IS 574

Figure 8L. Problem 3 - CORELAP output, page 13.

PICTORIAL LAYOUT NO. 1 PROBLEM NO.3

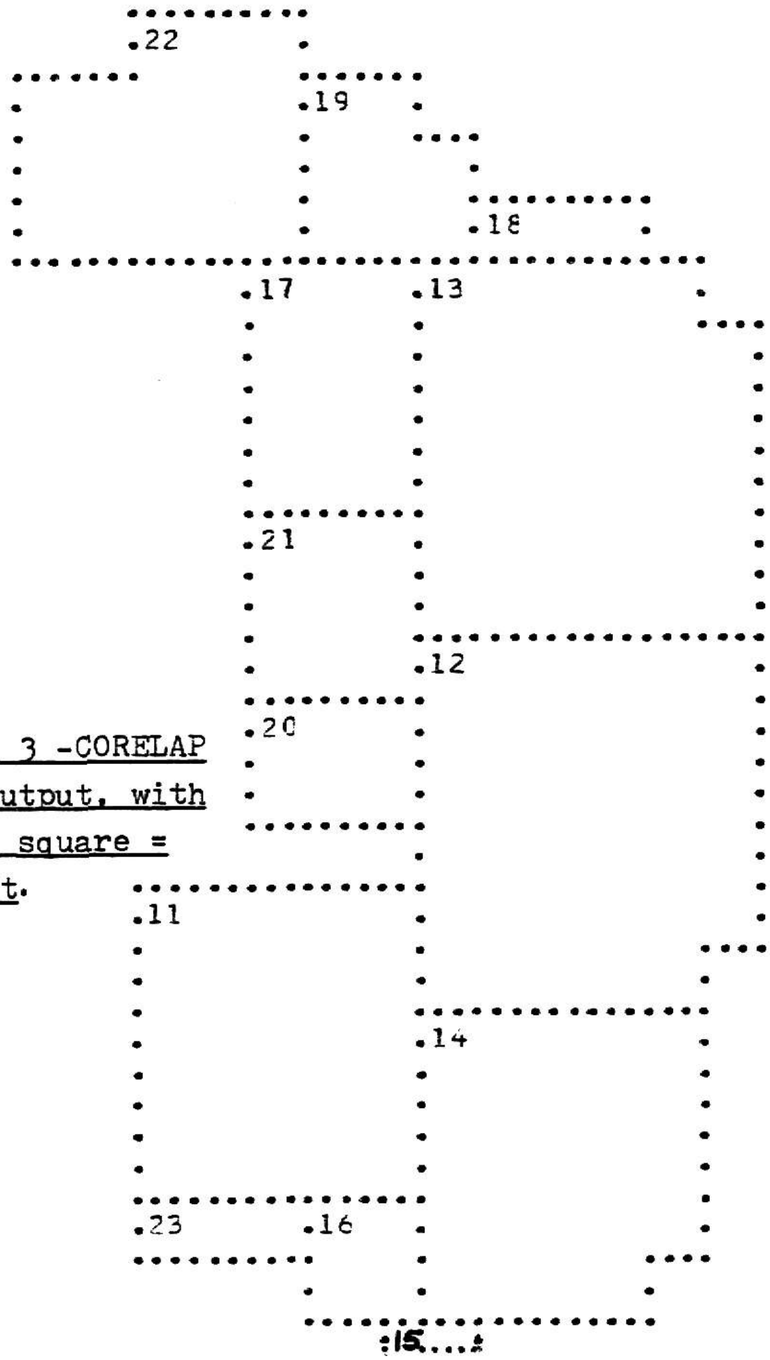


Figure 9. Problem 3 -CORELAP final output, with element square = 25 sq ft.

```
PICTCRIAL LAYLUT    NC.   1          PRCBLEM NC.4
......................................................

                                 .......
                                 .19   .
                              ...................
                              .18   .11      .13.
                              ................  .
                              .20.14.15   .12.  .
                              ....  ..........  .
                                 .  .17.16   .  .
                                 ...............
```

Figure 10. Problem 4 - CORELAP final output.

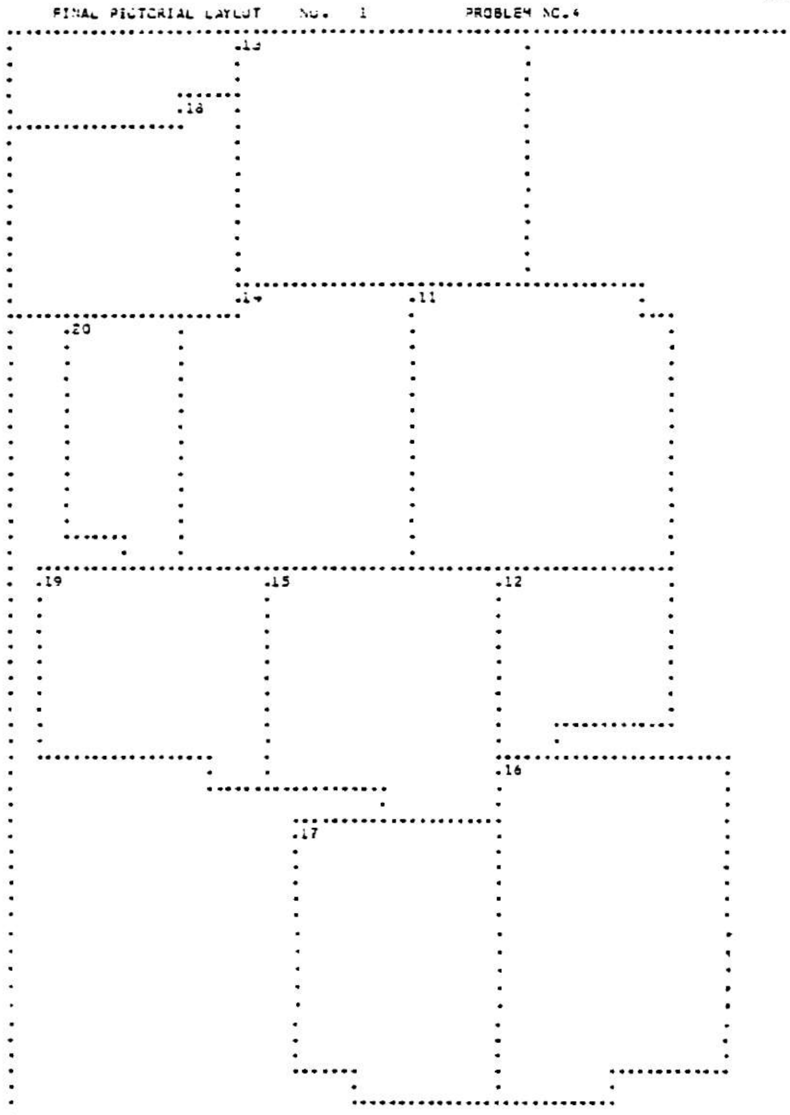


Figure 11. Problem 4 - CORELAP final output, with element square = 16 sq ft.

PLANET

The outputs of PLANET indicate that the layout obtained is dependent upon placement priority and block size. There is considerable variation in the layouts obtained by changing the values of these two quantities. PLANET calculates the number of blocks required for each department based on the input block size and rounds off the values to the nearest integer. If the block size and department area are not divisible exactly, then the layouts obtained may not conform to the actual department areas. The scores are useful for comparing the results of the three alternate layouts, but are of no use when judging layouts obtained by varying either placement priority or block size. The complete PLANET solution for Problem 2 is given in Figure 15A through Figure 15G.

Table 3 gives the values for placement priority and block size for the problems and the resulting figures.

TABLE 3

PLANET Summary of Results

Problem	Block size sq ft	Placement priority	Figure	Lowest score
1	500	01	12	18
2	200	A02 G02	13	69
2	500	A02 G02	14	40
2	500	01	15F	41
3	25	G02 H02 M02	16	126
3	30	G02 H02 M02	17	117
3	30	01	18	108
4	32	01	19	147
4	32	H02 I02	20	148
4	64	H02 I02	21	106

A lower score means a better layout.

A02 G02 H02 - Departments A, G and H have a placement priority of 02 (others have 01).

01 - All departments have a placement priority of 01.

H02 I02 - Departments H and I have a placement priority of 02 (others have 01).

Legend

Problem 1

- A - Shipping
- B - Warehouse
- C - Receiving

Problem 2

- A - Receiving
- B - Milling
- C - Press
- D - Screw machine
- E - Assembly
- F - Plating
- G - Shipping
- H,I,J - Dummies

Problem 3

- A - Restaurant
- B - Club restaurant
- C - Bar lounge
- D - Kitchen
- E - General storage
- F - Waiting preparation
- G - Rest rooms
- H - Cashier office
- I - Lobby
- J - Stage
- K - Dance floor
- L - Private dinning
- M - Workers lounge
- N,O,P - Dummies

Problem 4

- A - Woodcutting
- B - Receiving
- C - Framing
- D - Upholstary
- E - Fabric storage
- F - Fabric cutting
- G - Sewing
- H - Shipping
- I - Offices
- J - General storage
- K,L,M - Dummies

BS - Block size

PP - Placement priority

```
LAYOUT            COST          18.

                                  A  A  A  A  A  C  C  C  C  C
                                  A  A  A  A  A  C  C  C  C  C
                                  A  A  A  A  A  C  C  C  C  C
                                  A  A  A  A  A  C  C  C  C  C
                                                 B  B  B  B  B
                                                 B  B  B  B  B
                                                 B  B  B  B  B
                                                 B  B  B  B  B

PLACEMENT WAS  A  C  B
```

Figure 12. Problem 1 - PLANET final output with, BS= 500 sq ft and PP=01 for all departments.

LAYOUT COST 69.

				D	D	C	C											A
D	D	D	D	D	D	C	D			B	B	B	B	A	A	A	A	A
D	D	D	D	D	D	D	C	B	B	B	B	B	B	A	A	A	A	A
D	D	D	D	D	D	C	C	B	B	B	B	B	B	A	A	A	A	A
D	D	D	D	D	D	C	C	B	B	B	B	B	B	A	A	A	A	A
D	D	D	D	D	D	C	C	B	B	B	B	B	B	A	A	A	A	A
D	D	D	D	D	C	C	C	B	B	B	B	B	B	A	A	A	A	A
D	D	D	D	D	D	C	C	B	B	B	B	B	B	A	A	A	A	A
E	E	E	E	E	E	E	F	F	F	F	F	F	F	F	F	G	G	G
E	E	E	E	E	E	E	F	F	F	F	F	F	F	F	F	G	G	G
E	E	E	E	E	E	E	F	F	F	F	F	F	F	F	F	G	G	G
E	E	E	E	E	E	E	F	F	F	F	F	F	F	F	F	G	G	G
	E	E	E	E	E	E	F	F	F	F	F	F	F			G	G	G
	E	E	E	E	E	E	F	F	F	F	F	F	F			G	G	G
							F	F	F	F	F	F	F	F		G	G	G
									C	C	C	C	C			G	G	G
									C	C	C	C	C					
									C	C	C	C	C					
									C	C	C	C	C					
									C	C	C	C	C					
									C	C	C	C	C					

PLACEMENT WAS E F D B C G A

Figure 13. Problem 2 - PLANET final output with BS=200 sq ft and PP=02 for departments A and G.

```
LAYOUT            COST          40.

                                          G  G  G  G  G  G
                                          G  G  G  G  G  G
                                          G  G  G  G  G  G
                                          G  G  G  G  G  G
                              E  E  E  E  F  F  F  F  F  F
                              E  E  E  E  F  F  F  F  F  F
                              E  E  E  E  F  F  F  F  F  F
                     D  D  D  E  E  E  E  F  F  F  F  F  F
                     D  D  D  D  B  B  B  B  C  C  C
                     D  D  D  D  B  B  B  B  C  C  C
                     D  D  D  D  B  B  B  B  C  C  C
                     D  D  D  D  B  B  B  B  C  C  C
                     D  D  D  D  D  A  A  A  A
                                 A  A  A  A  A
                                 A  A  A  A  A
                                 A  A  A  A  A
                                 A  A  A  A  A

PLACEMENT WAS  E  F  B  D  C  G  A
```

Figure 14. Problem 2 - PLANET final output with, BS=500 sq ft and PP=02 for departments A and G.

3 JUN 80

PROBLEM NO.2

NUMBER OF DEPARTMENTS = 7

UNIT BLOCK SIZE = 500.00

INPUT DATA IS IN THE FORM OF A FROM-TO CHART.

THE TYPE OF SELECTION METHOD USED'

TYPE 1 A LAYOUT WILL BE PRINTED ONLY AFTER THE LAST ITERATIO

TYPE 2 A LAYOUT WILL BE PRINTED ONLY AFTER THE LAST ITERATIO

TYPE 3 A LAYOUT WILL BE PRINTED ONLY AFTER THE LAST ITERATIO

Figure 15A. Problem 2 - PLANET output, page 1.

INPUT DATA FOR DEPARTMENT
BLOCK ALLOCATIONS

DEPARTMENT SYMBOL	REQUIRED AREA	NUMBER OF BLOCKS	PRIORITY	REMARKS
A	12000.	24	1	
B	8000.	16	1	
C	6000.	12	1	
D	12000.	24	1	
E	8000.	16	1	
F	12000.	24	1	
G	12000.	24	1	

7 DEPARTMENTS AVAILABLE FOR ARRANGEMENT.

Figure 15B. Problem 2 - PLANET output, page 2.

NORMALIZED FROM-TO CHART

A	B	C	D	E	F	G
.0	0.69231	0.23077	0.38462	0.15385	0.07692	0.0
.0	0.0	0.0	0.46154	0.38462	0.23077	0.0
.0	0.0	0.0	0.0	0.07692	0.15385	0.0
.0	0.30769	0.0	0.0	0.53846	0.0	0.0
.0	0.0	0.0	0.0	0.0	1.00000	0.53846
.0	0.07692	0.0	0.0	0.38462	0.0	1.00000
.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 15C. Problem 2 - PLANET output, page 3.

NORMALIZED FLOW-BETWEEN COST CHART

A	B	C	D	E	F	G
	0.6923	0.2308	0.3846	0.1538	0.0769	0.0
923	0.0	0.0	0.7692	0.3846	0.3077	0.0
.308	0.0	0.0	0.0	0.0769	0.1538	0.0
.846	0.7692	0.0	0.0	0.5385	0.0	0.0
.538	0.3846	0.0769	0.5385	0.0	1.3846	0.5385
.769	0.3077	0.1538	0.0	1.3846	0.0	1.0000
	0.0	0.0	0.0	0.5385	1.0000	0.0

Figure 15D. Problem 2 - PLANET output, page 4.

```
LAYOUT          COST         43.

                     C  C  B  B  B  B  B

                     C  C  C  B  B  B  E  E  E  E  F  F  F  F  F

                     C  C  C  B  B  B  E  E  E  E  F  F  F  F  F

                     C  C  C  B  B  B  E  E  E  E  F  F  F  F  F

                     C  A  A  B  B  C  E  E  E  E  F  F  F  F  F

                        A  A  A  A  D  D  D  D  D  G  G  G  G  G

                        A  A  A  A  D  D  D  D  D  G  G  G  G  G

                        A  A  A  A  D  D  D  D  D  G  G  G  G  G

                        A  A  A  A  A  D  D  D  D  G  G  G  G  G

                        A  A  A  A  A  D  D  D  D  G  G  G  G

PLACEMENT WAS  E  F  G  D  B  A  C
```

Figure 15E. Problem 2 - PLANET output, page 5 with BS=500 sq ft PP=01 for all departments. Alternate layout #1

```
            LAYOUT        COST       41.

                                        E E E E F F F F F F
                                        E E E E F F F F F F
                                        E E E E F F F F F F
                                  D D D D E E E E F F F F F F
                                  D D D D B B B B G G G G G
                                  D D D D B B B B G G G G G
                                  D D D D B B B B G G G G G
                                  D D D D B B B B G G G G G
                                  D D D D A A A A G G G G
                                        A A A A A C C C
                                        A A A A A C C C
                                        A A A A A C C C
                                        A A A A A C C C
PLACEMENT WAS  E  F  G  B  D  A  C
```

Figure 15F. Problem 2 - PLANET output, page 6.
Alternate layout #2.

```
LAYOUT          COST        42.

                              E  E  E  E  F  F  F  F  F  F
                              E  E  E  E  F  F  F  F  F  F
                              E  E  E  E  F  F  F  F  F  F
                     D  D  D  E  E  E  E  F  F  F  F  F  F
                     D  D  D  D  B  B  B  B  G  G  G  G
                     D  D  D  D  B  B  B  B  G  G  G  G
                     D  D  D  D  B  B  B  B  G  G  G  G  G
                     D  D  D  D  B  B  B  B  G  G  G  G  G
                     D  D  D  D  D  A  A  G  G  G  G  G  G
                              A  A  A  A  A  C  C  C
                              A  A  A  A  A  C  C  C
                              A  A  A  A  A  C  C  C
                              A  A  A  A  A  C  C  C
                              A  A

PLACEMENT WAS  E  F  B  D  G  A  C
```

Figure 15G. Problem 2 - PLANET output, page 7.
Alternate layout #3.

```
LAYOUT          COST          126.

                        B B B
      D D D D D B B B B B B
E E F D D D D D B B B B B B A
  E F F D D D D B B B B B B A
  E M F D D D D B B B B B B A
      M D D D D B B B B B B A
      M D D J J J K K K B B A
    L L L L J J J K K K   G G
    L L L L I I I K K K   G G
    L L L L I I C C C C C G G
      L L L I I C C C C C C G
      L L L I H C C C C C C
            H H C C C C C C
                C C C C C C
                C C C C C C

PLACEMENT WAS  J K B C G I H L A D F M E
```

<u>Figure 16. Problem 3 - PLANET final output with, BS=25 sq ft and PP=02 for departments G, H and M.</u>

LAYOUT COST 128.

										C	C	C
			G	G	H	H	C	C	C	C	C	C
	G	G	G	G	H	I	C	C	C	C	C	C
	G	G	G	I	I	I	C	C	C	C	C	C
	G	G	G	I	I	I	C	C	C	C	C	C
	L	L	L	L	L	I	C	C	C	C	C	C
	L	L	L	L	J	J	J	K	K	K	C	C
	L	L	L	L	J	J	J	K	K	K		
		L	L	L	L			K	K	K		
		L	D	D	D	D	B	B	B	B	B	
E	F	F	D	D	D	D	B	B	B	B	B	B
E	E	F	D	D	D	D	B	B	B	B	B	B
	E	F	D	D	D	D	B	B	B	B	B	B
	M	M	D	D	D	D	B	B	B	B	B	B
		M	D	D	D	D	B	B	B	B	B	B
			A	A	A	A	A					
			A	A	A	A	A					
			A	A	A	A	A					
			A	A	A	A	A					
			A	A	A	A	A					

PLACEMENT WAS J K C B D F E L I A M H G

Figure 17. Problem 3 - PLANET final output with, BS=30 sq ft and PP=02 for departments G, H and M.

```
LAYOUT            COST          117.

            C  C  C  C  C     H  H
            C  C  C  C  C     H  I  I
            C  C  C  C  C  C  I  I  I
            C  C  C  C  C  C  I  I  L  L
            C  C  C  C  C  C  L  L  L  L  G  G
      J  J  J  K  K  K  K  C  L  L  L  L  G  G
         J  J  K  K  K  K     L  L  L  L  G  G
            B  B  B  B  B  D  D  D  D  L  G
            B  B  B  B  B  D  D  D  D  M  M
            B  B  B  B  B  D  D  D  D  F  E  E
            B  B  B  B  B  D  D  D  D  F  F  E
            B  B  B  B  B  D  D  D  D  A
            B  B  B  B     A  A  A  A  A
                           A  A  A  A  A
                           A  A  A  A  A
                           A  A  A  A  A

PLACEMENT WAS  J  K  C  B  D  F  E  L  I  A  M  H  G
```

Figure 18. Problem 3 - PLANET final output with BS=30 sq ft and PP=01 for all departments.

```
        LAYOUT           COST          147.

              H   H   H   H   H           J   J   J
              H   H   H   H   H       J   J   J   J
              H   H   H   H   H       J   J   J   J
              H   H   H   H   H       J   J   J   J
              H   H   H   H   H       D   D   D   D   D           C   C   C   C
              I   I   I   I   I   D   D   D   D   D   D   C   C   C   C   C   C
              I   I   I   I   I   D   D   D   D   D   D   C   C   C   C   C   C
              I   I   I   I   I   D   D   D   D   D   D   C   C   C   C   C   C
              I   I   I   I   I   D   D   D   D   D   D   C   C   C   C   C   C
              I   I   I   I   I   D   D   D   D   D   D   C   C   C   C   C   C
          E   E   E   E   E   E   F   F   F   F   F   F   C   C   C   C   C   C
          E   E   E   E   E   E   F   F   F   F   F   F   B   B   B   B   A   A
          E   E   E   E   E   E   F   F   F   F   F   F   B   B   B   B   A   A
          E   E   E   E   E   E   F   F   F   F   F   F   B   B   B   B   A   A
          E   E   E   E   E   E   F   F   F   F   F   F   B   B   B   B   A   A
                                  G   G   G   G   G                       A   A
                                  G   G   G   G   G                       A   A
                                  G   G   G   G   G
                                  G   G   G   G   G

PLACEMENT WAS E   F   G   D   I   C   B   A   J   H
```

Figure 19. Problem 4 - PLANET final output with BS=32 sq ft and PP=01 for all departments.

```
LAYOUT         COST       148.

                  C C C C C C C
                  C C C C C C C I I I I I H H
                  C C C C C C C I I I I I H H
                  C C C C C C C I I I I I H H
                    C C C C C C I I I I I H H
                    C C C C C C I I I I I H H
            J J J D D D D D D D F F F F F F G
            J J J D D D D D D D F F F F F F G
            J J J D D D D D D D F F F F F F G
            J J J D D D D D D D F F F F F F G
            J J J D D D D D D D F F F F F F G
                A A A A A B B B B E E E E E
                A A A A A A B B B E E E E E
                A A A A A A B B B E E E E E
                A A A A A A B B B E E E E E
                  A A A A A B B B E E E E E
                  A A A A A A     E E E E E
                  A A A A A A
PLACEMENT WAS D F E B G C A J I H
```

Figure 20. Problem 4 - PLANET final output with, BS=32 sq ft and PP=02 for departments H and I.

```
LAYOUT          COST       106.

                                       C  C  C  C  C
                                 A  A  C  C  C  C  C
                           A  A  A  A  C  C  C  C  C
                           A  A  A  A  C  C  C  C  C
                           A  A  A  A  C  C  C  C  C
                           A  A  A  A  C  D  D  C  D  J  J
                           B  B  B  B  A  D  D  C  C  J  J
                           B  B  B  B  A  D  D  C  C  J  J
                        E  E  E  E  E  F  F  F  F  F  J  J
                        E  E  E  E  E  F  F  F  F  F
                        E  E  E  E  E  F  F  F  F  F
                              I  I  I  I  G  G  G
                        H  H  H  I  I  I  G  G  G
                        H  H  H  I  I  I  G  G  G
                        H  H  H  I  I  I  G
                        H  H  H  H
PLACEMENT WAS  E  F  G  D  B  C  A  J  I  H
```

Figure 21. Problem 4 - PLANET final output with, BS=64 and PP=02 for departments H and I.

ALDEP

ALDEP output indicates that it not only generates a large number of alternate layouts but also produces variable layouts by changing the input values of any of the four quantities. The input quantities that can be changed are unit square, sweep width, random number and degree of closeness. ALDEP prints a score and the highest score gives the best layout. ALDEP calculates blocks for each department based on unit square. If the departmental areas are not exactly divisible by unit square, the final layout obtained may have under-or oversized departments. Also when the unit square is changed the input format statement has to be changed. The complete ALDEP solution with five alternate layouts for problem 2 is given in Figure 26A through Figure 26H.

Table 15 gives the values for the four quantities, scores obtained and the resulting layouts for the four problems.

TABLE 4

ALDEP Summary of Results

Problem	Unit square sq ft	sweep width	Random number	Degree of closeness	Highest score	Figure
1	1000	1	0931	01	40	22
1	1000	2	0931	01	168	23
1	1000	1	0931	64	160	24
1	1000	1	0397	01	136	25
2	400	2	0931	01	250	26 E
2	400	3	0931	01	258	27
2	400	2	0931	64	210	28
2	400	2	0397	01	250	26
3	25	3	0931	01	430	29
3	25	4	0931	01	406	30
3	25	3	0931	64	326	31
3	25	3	0397	01	360	32
4	64	3	0931	01	536	33
4	64	4	0931	01	592	34
4	64	3	0931	64	536	35
4	64	3	0397	01	528	36

* The higher score indicates a better layout.

Legend

Problem 1

1 - Shipping

2 - Warehouse

3 - Receiving

Problem 2

1 - Receiving

2 - Milling

3 - Press

4 - Screw machine

5 - Assembly

6 - Plating

7 - Shipping

8 or 9 etc - Dummies

Problem 3

1 - Restaurant

2 - Club restaurant

3 - Bar lounge

4 - Kitchen

5 - General storage

6 - Waiting preparation

7 - Rest rooms

8 - Cashier office

9 - Lobby

10 - Stage

11 - Dance floor

12 - Private dinning

13 - Workers lounge

14 or 15 etc - Dummies

Problem 4

1 - woodcutting

2 - Receiving

3 - Framing

4 - Upholstery

5 - Fabric storage

6 - Fabric cutting

7 - Sewing

8 - Shipping

9 - Offices

10 - General storage

11 - Dummies

SW - Sweep Width

US - Unit Square

RN - Random Number

DC - Degree of Closeness

```
TRIAL LAYOUT     2   SCORE =     40

 0  0
 0  0

                                        TOP FLOOR

 0  0  0  0  0  0  0  0
 0  1  2  2  3  3  0  0
 0  1  2  2  3  3  0  0
 0  1  1  2  3  3  0  0
 0  1  1  2  3  3  0  0
 0  1  1  2  2  3  0  0
 0  1  1  2  2  3  0  0
 0  0  0  0  0  0  0  0

                                     GROUND FLOOR

 0  0
 0  0

                                    TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET THE
    111   113                                NECESSARY RELATIONSHIPS.
    113   111
```

Figure 22. Problem 1 - ALDEP final output with SW=1 US=1000 sq ft RN=0931 DC=01.

```
TRIAL LAYOUT    1   SCORE =  100


 0  0
 0  0

                                 TOP FLOOR


 0  0  0  0  0  0  0  0
 0  1  1  3  3  3  3  0
 0  1  1  3  3  3  3  0
 0  1  1  2  2  3  3  0
 0  1  1  2  2  0  0  0
 0  1  1  2  2  0  0  0
 0  2  2  2  2  0  0  0
 0  0  0  0  0  0  0  0
                              GROUND FLOOR


 0  0
 0  0
                             TERRACE LEVEL


UNDER THE RULES FOR EVALUATION, THIS LAYOUT SATISFIES ALL NECESSARY
RELATIONSHIPS.
```

<u>Figure 23. Problem 1 - ALDEP final output with,</u>
<u>SW=2 US=1000 sqft RN=0931 DC=01</u>.

```
TRIAL LAYOUT    1   SCORE =  160

 0  0
 0  0

                              TOP FLOOR

 0  0  0  0  0  0  0  0
 0  1  3  3  2  2  0  0
 0  1  3  3  2  2  0  0
 0  1  1  3  2  2  0  0
 0  1  1  3  2  2  0  0
 0  1  1  3  3  2  0  0
 0  1  1  3  3  2  0  0
 0  0  0  0  0  0  0  0

                           GROUND FLOOR

 0  0
 0  0

                          TERRACE LEVEL

UNDER THE RULES FOR EVALUATION, THIS LAYOUT SATISFIES ALL NECESSARY
RELATIONSHIPS.
```

Figure 24. Problem 1 - ALDEP final output with SW=1 US=1000sq ft RN=0931 DC=064.

```
TRIAL LAYOUT    3  SCORE =  136

 0  0
 0  0

                                 TOP FLOOR

 0  0  0  0  0  0  0  0
 0  2  1  1  3  3  0  0
 0  2  1  1  3  3  0  0
 0  2  2  1  3  3  0  0
 0  2  2  1  3  3  0  0
 0  2  2  1  1  3  0  0
 0  2  2  1  1  3  0  0
 0  0  0  0  0  0  0  0

                              GROUND FLOOR

 0  0
 0  0

                             TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET THE
    112    113                              NECESSARY RELATIONSHIP.
    113    112
```

Figure 25. Problem 1 - ALDEP final output with SW=1 US=1000 sq ft RN=0397 DC=01.

DEPARTMENT	REQUIRES AREA	NO. SQUARES
111	12000.000	30
112	8000.000	20
113	6000.000	15
114	12000.000	30
115	8000.000	20
116	12000.000	30
117	12000.000	30

DEPTS AVAILABLE FOR RANDOM PLACEMENT= 7

Figure 26A. Problem 2 - ALDEP output, page 1.

DECODE MATRIX

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
111	0	16	1	4	1	0	0																								
112	16	0	0	16	4	4	0																								
113	1	0	0	0	0	1	0																								
114	4	16	0	0	4	0	0																								
115	1	4	0	4	0	64	4																								
116	0	4	1	0	64	0	16																								
117	0	0	0	0	4	16	0																								

Figure 26B. Problem 2 - ALDEP output, page 2.

```
FACILITIES LAYOUT - DESIGN PROGRAM

STARTING NEW JOB. RUN CODE = REP2


          INPUT MATRIX
111   S
112   E S
113   O U S
114   I E U S
115   O I U I S
116   U I O U A S
117   U U U U I E S
```

Figure 26C. Problem 2 - ALDEP output, page 3.

TRIAL LAYOUT 1 SCORE = 242

0	0
0	0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	1	2	2	2	2	4	4	5	5	6	6	6	6	7	7	7	7	0
0	1	1	2	2	2	2	4	4	5	5	6	6	6	6	7	7	7	7	0
0	1	1	2	2	2	2	4	4	5	5	6	6	6	6	7	7	7	7	0
0	1	1	2	2	2	2	4	4	5	5	6	6	6	6	7	7	7	7	0
0	1	1	2	2	2	2	4	4	5	5	6	6	6	6	7	7	7	7	0
0	1	1	1	1	4	4	4	4	5	5	6	6	3	3	7	7	7	7	0
0	1	1	1	1	4	4	4	4	5	5	6	6	3	3	7	7	7	7	0
0	1	1	1	1	4	4	4	4	5	5	6	6	3	3	3	7	0	7	0
0	1	1	1	1	4	4	4	4	5	5	6	6	3	3	3	3	0	0	0
0	1	1	1	1	4	4	4	4	5	5	6	6	3	3	3	3	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0	0
0	0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET NECESSARY RELATIONSHIP.

111	113
111	115
112	115
112	116
113	111
115	111
115	112
115	117
116	112
117	115

Figure 26D. Problem 2 - ALDEP output, page 4, with, SW=2 US=400 sq ft RN=0931 DC=01 Alternate layout #1.

TRIAL LAYOUT 2 SCORE = 250

0	0
0	0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	3	3	1	1	1	1	4	4	4	4	6	6	6	6	7	7	7	7	0
0	3	3	1	1	1	1	4	4	4	4	6	6	6	6	7	7	7	7	0
0	3	3	1	1	1	2	4	4	4	4	6	5	6	6	7	7	7	7	0
0	3	3	1	1	2	2	4	4	4	4	5	5	6	6	7	7	7	7	0
0	3	3	1	1	2	2	4	4	4	4	5	5	6	6	7	7	7	7	0
0	3	3	1	1	2	2	4	4	4	4	5	5	6	6	7	7	7	7	0
0	3	3	1	1	2	2	4	4	4	4	5	5	6	6	7	7	7	7	0
0	1	3	1	1	2	2	2	4	5	4	5	5	6	6	6	7	0	7	0
0	1	1	1	1	2	2	2	2	5	5	5	5	6	6	6	6	0	0	0
0	1	1	1	1	2	2	2	2	5	5	5	5	6	6	6	6	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0	0
0	0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET NECESSARY RELATIONSHIP.

111	115
112	116
113	116
115	111
115	117
116	112
116	113
117	115

Figure 26E. Problem 2 - ALDEP output, page 5. Alternate layout #2.

TRIAL LAYOUT 3 SCORE = 108

0 0
0 0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	5	5	1	1	1	1	4	4	4	4	6	6	6	6	7	7	7	7	0
0	5	5	1	1	1	1	4	4	4	4	6	6	6	6	7	7	7	7	0
0	5	5	1	1	1	1	4	4	4	4	6	3	6	6	7	7	7	7	0
0	5	5	1	1	1	1	4	4	4	4	3	3	6	6	7	7	7	7	0
0	5	5	1	1	1	1	4	4	4	4	3	3	6	6	7	7	7	7	0
0	5	5	1	1	2	2	2	2	4	4	3	3	6	6	7	7	7	7	0
0	5	5	1	1	2	2	2	2	4	4	3	3	6	6	7	7	7	7	0
0	5	5	1	1	2	2	2	2	4	4	3	3	6	6	6	7	0	7	0
0	5	5	1	1	2	2	2	2	4	4	3	3	6	6	6	6	0	0	0
0	5	5	1	1	2	2	2	2	4	4	3	3	6	6	6	6	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0 0
0 0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET NECESSARY RELATIONSHIP.

111	113
112	115
112	116
113	111
114	115
115	112
115	114
115	116
115	117
116	112
116	115
117	115

Figure 26F. Problem 2 - ALDEP output, page 6. Alternate layout #3.

TRIAL LAYOUT 4 SCORE = 172

0	0
0	0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	2	2	1	1	1	1	6	6	6	6	4	4	4	4	7	7	7	7	0
0	2	2	1	1	1	1	6	6	6	6	4	4	4	4	7	7	7	7	0
0	2	2	1	1	1	1	6	6	6	6	4	5	4	4	7	7	7	7	0
0	2	2	1	1	1	1	6	6	6	6	5	5	4	4	7	7	7	7	0
0	2	2	1	1	1	1	6	6	6	6	5	5	4	4	7	7	7	7	0
0	2	2	1	1	3	3	6	6	6	6	5	5	4	4	7	7	7	7	0
0	2	2	1	1	3	3	6	6	6	6	5	5	4	4	7	7	7	7	0
0	2	2	1	1	3	3	3	6	5	6	5	5	4	4	4	7	0	7	0
0	2	2	1	1	3	3	3	3	5	5	5	5	4	4	4	4	0	0	0
0	2	2	1	1	3	3	3	3	5	5	5	5	4	4	4	4	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0	0
0	0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET NECESSARY RELATIONSHIP.

111	114
111	115
112	114
112	115
112	116
114	111
114	112
115	111
115	112
115	117
116	112
116	117
117	115
117	116

Figure 26G. Problem 2 - ALDEP output, page 7. Alternate layout 4.

```
TRIAL LAYOUT   19   SCORE =   66

C  0
0  0

                              TOP FLOOR

0  0  0  0  0  0  0  0  0  0  0  C  0  0  C  0  0  0  0  0
0  6  6  2  2  2  2  1  1  3  3  4  4  4  4  7  7  7  7  0
C  6  6  2  2  2  2  1  1  3  3  4  4  4  4  7  7  7  7  0
0  6  6  2  2  2  2  1  1  3  3  4  4  4  5  7  7  7  7  0
0  6  6  2  2  2  2  1  1  3  3  4  4  5  5  7  7  7  7  0
C  6  6  2  2  2  2  1  1  3  3  4  4  5  5  7  7  7  7  0
0  6  6  6  6  1  1  1  1  3  3  4  4  5  5  7  7  7  7  0
0  6  6  6  6  1  1  1  1  3  3  4  4  5  5  7  7  7  7  0
0  6  6  6  6  1  1  1  1  4  3  4  4  5  5  5  7  0  7  0
0  6  6  6  6  1  1  1  1  4  4  4  4  5  5  5  5  0  0  0
C  6  6  6  6  1  1  1  1  4  4  4  4  5  5  5  5  0  0  0
C  0  0  0  0  0  0  0  0  0  0  C  0  0  C  0  0  0  0  0

                           GROUND FLOOR

C  0
0  0

                           TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYCUT CDES NOT MEET
     111   115                              NECESSARY RELATIONSHIP.
     112   114
     112   115
     113   116
     114   112
     115   111
     115   112
     115   116
     116   113
     116   115
     116   117
     117   116
```

Figure 26H. Problem 2 - ALDEP output, page 8. Alternate layout #5.

TRIAL LAYOUT 2 SCORE = 258

0	0
0	0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	3	3	3	2	2	2	2	2	2	6	6	6	6	6	6	0	0	0	0
0	3	3	3	2	2	2	4	2	2	5	6	6	6	6	6	7	0	0	0
0	3	3	3	2	2	2	4	4	4	5	5	5	6	6	6	7	7	7	0
0	3	3	3	2	2	2	4	4	4	5	5	5	6	6	6	7	7	7	0
0	3	3	3	2	2	2	4	4	4	5	5	5	6	6	6	7	7	7	0
0	1	1	1	1	1	1	4	4	4	5	5	5	6	6	6	7	7	7	0
0	1	1	1	1	1	1	4	4	4	5	5	5	6	6	6	7	7	7	0
0	1	1	1	1	1	1	4	4	4	5	5	5	6	6	6	7	7	7	0
0	1	1	1	1	1	1	4	4	4	5	4	4	6	7	7	7	7	7	0
0	1	1	1	1	1	1	4	4	4	4	4	4	7	7	7	7	7	7	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0	0
0	0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET THE NECESSARY RELATIONSHIP.

111	115
113	116
115	111
115	117
116	113
117	115

Figure 27. Problem 2 - ALDEP final output with SW=3 US=400 sq ft RN=0931 DC=01.

TRIAL LAYOUT 4 SCORE = 210

0 0
0 0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	4	4	1	1	1	1	2	2	7	7	5	5	5	5	6	6	3	3	0
0	4	4	1	1	1	1	2	2	7	7	5	5	5	5	6	6	3	3	0
0	4	4	1	1	1	1	2	2	7	7	5	5	5	5	6	6	3	3	0
0	4	4	1	1	1	1	2	2	7	7	5	5	5	5	6	6	3	3	0
0	4	4	1	1	1	1	2	2	7	7	5	5	5	5	6	6	3	3	0
0	4	4	4	4	1	1	2	2	7	7	7	7	6	6	6	6	3	3	0
0	4	4	4	4	1	1	2	2	7	7	7	7	6	6	6	6	3	3	0
0	4	4	4	4	1	1	2	2	7	7	7	7	6	6	6	6	0	3	0
0	4	4	4	4	1	1	2	2	7	7	7	7	6	6	6	6	0	0	0
0	4	4	4	4	1	1	2	2	7	7	7	7	6	6	6	6	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0 0
0 0

TERRACE LEVEL

UNDER THE RULES FOR EVALUATION, THIS LAYOUT SATISFIES ALL THE NECESSARY RELATIONSHIP.

Figure 28. Problem 2 - ALDEP final output with SW=2 US=400 sq ft RN=0931 DC=064.

TRIAL LAYOUT 6 SCORE = 430

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	3	3	3	2	2	2	2	2	2	4	4	5	5	5	5	11	11	11	11	0
0	3	3	3	2	2	2	2	2	2	4	4	4	6	6	6	11	11	11	11	0
0	3	3	3	2	2	2	2	2	2	4	4	4	6	12	12	10	10	10	11	0
0	3	3	3	2	2	2	1	1	2	4	4	4	12	12	12	10	10	10	13	0
0	3	3	3	2	2	2	1	1	1	4	4	4	12	12	12	9	9	9	13	0
0	3	3	3	2	2	2	1	1	1	4	4	4	12	12	12	9	9	9	13	0
0	3	3	3	2	2	2	1	1	1	4	4	4	12	12	12	9	9	8	0	0
0	3	3	3	2	2	2	1	1	1	4	4	4	12	12	12	7	8	8	0	0
0	3	3	3	2	3	3	1	1	1	4	1	1	12	7	7	7	7	7	0	0
0	3	3	3	3	3	3	1	1	1	1	1	1	7	7	7	7	7	7	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0 0
0 0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET NECESSARY RELATIONSHIP.

101 106
101 108
101 109
101 113
102 106
102 107
102 108
102 109
102 110
102 111
102 112
102 113
103 104
103 106
103 107
103 108
103 109
103 110
103 111
103 112
103 113
104 103
104 113
105 113

Figure 29. Problem 3 - ALDEP final output with SW=3 US=25 sq ft RN=0931 DC=01.

TRIAL LAYOUT 12 SCORE = 406

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	3	3	3	3	1	1	1	1	1	1	1	1	7	8	8	8	9	9	9	0
0	3	3	3	3	1	1	1	1	1	1	1	1	7	7	7	7	9	9	9	0
0	3	3	3	3	1	1	2	2	1	1	1	1	7	7	7	7	9	9	10	0
0	3	3	3	3	2	2	2	2	4	1	1	1	12	7	7	7	10	10	10	0
0	3	3	3	3	2	2	2	2	4	4	4	4	12	12	12	12	10	10	11	0
0	3	3	3	3	2	2	2	2	4	4	4	4	12	12	12	12	11	11	11	0
0	3	3	3	3	2	2	2	2	4	4	4	4	12	12	12	12	11	11	11	0
0	3	3	3	3	2	2	2	2	4	4	4	4	12	12	12	12	13	11	11	0
0	3	3	3	2	2	2	2	2	4	4	4	4	12	6	6	6	13	13	0	0
0	2	2	2	2	2	2	2	2	4	4	4	5	5	5	5	6	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0	0
0	0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET NECESSARY RELATIONSHIP.

101	106
101	108
101	109
101	113
102	106
102	107
102	108
102	109
102	110
102	111
102	112
102	113
103	104
103	106
103	107
103	108
103	109
103	110
103	111
103	112
103	113
104	103
104	106
104	113

Figure 30. Problem 3 - ALDEP final output with SW=4 US=25 sq ft RN=0931 DC=01.

TRIAL LAYOUT 9 SCORE = 326

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	2	2	12	12	12	12	4	4	9	9	1	1	1	11	3	3	3	3	0	0
0	2	2	8	8	12	12	4	4	9	9	1	1	11	11	3	3	3	3	0	0
0	2	2	8	2	12	12	4	4	9	9	1	1	11	11	3	3	3	3	0	0
0	2	2	2	2	12	12	4	4	9	9	1	1	11	11	3	3	3	3	0	0
0	2	2	2	2	12	12	4	4	6	6	1	1	11	11	3	13	3	3	3	0
0	2	2	2	2	12	12	4	4	6	6	1	1	7	7	13	13	3	3	3	0
0	2	2	2	2	12	12	4	4	5	5	1	1	7	7	10	10	3	3	3	0
0	2	2	2	2	12	12	4	4	5	5	1	1	7	7	10	10	3	3	3	0
0	2	2	2	2	4	4	4	4	1	1	1	1	7	7	10	10	3	3	3	0
0	2	2	2	2	4	4	4	4	1	1	1	1	7	7	7	7	3	3	3	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0	0
0	0

TERRACE LEVEL

UNDER THE RULES FOR EVALUATION, THIS LAYOUT SATISFIES ALL NECESSARY RELATIONSHIP.

Figure 31. Problem 3 - ALDEP final output with SW=3 US=25 sq ft RN=0931 DC=064.

TRIAL LAYOUT 6 SCORE = 360

TOP FLOOR

C	0	0	0	0	0	0	0	0	0	0	0	0	0	C	C	0	0	0	C	C
C	3	3	2	2	2	2	1	1	1	1	4	5	5	5	8	8	9	9	0	0
0	3	3	2	2	2	2	1	1	1	1	4	4	6	5	7	8	9	9	C	0
C	3	3	2	3	2	2	1	1	1	1	4	4	6	6	7	7	9	9	0	0
0	3	3	3	3	2	2	1	1	1	1	4	4	12	6	7	7	9	9	0	C
C	3	3	3	3	2	2	1	1	1	1	4	4	12	12	7	7	10	10	13	0
0	3	3	3	3	2	2	2	2	1	1	4	4	12	12	7	7	10	10	13	0
0	3	3	3	3	2	2	2	2	1	1	4	4	12	12	7	7	10	10	13	C
C	3	3	3	3	2	2	2	2	4	1	4	4	12	12	12	7	11	11	11	0
0	3	3	3	3	2	2	2	2	4	4	4	4	12	12	12	12	11	11	11	0
C	3	3	3	3	2	2	2	2	4	4	4	4	12	12	12	12	11	11	11	0
C	0	0	0	0	0	0	0	0	0	0	0	0	0	C	C	0	0	0	0	0

GROUND FLOOR

C	0
C	0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET THE NECESSARY RELATIONSHIP.

101	106
101	107
101	108
101	109
101	113
102	106
102	107
102	108
102	109
102	110
102	111
102	112
102	113
103	104
103	106
103	107
103	108
103	109
103	110
103	111
103	112
103	113
104	103
104	113

Figure 32. Problem 3 - ALDEP final output with SW=3 US=25 sq ft RN=0397 DC=01.

```
TRIAL LAYOUT     7   SCORE =   536

 0  0
 0  0

                              TOP FLOOR

 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  1  1  1  9  9  9  9 10 10  4  4  4  4  4  0
 0  1  1  1  9  9  9 10 10 10  4  4  4  4  4  0
 0  1  1  1  9  9  9 10 10 10  4  4  5  4  4  0
 0  1  1  1  9  9  9  8  8  8  5  5  5  4  4  0
 0  1  1  1  3  3  3  8  8  8  5  5  5  4  4  0
 0  1  1  1  3  3  3  8  8  8  5  5  5  7  7  0
 0  1  1  2  3  3  3  8  8  8  5  5  5  7  7  0
 0  2  2  2  3  3  3  6  6  8  6  5  5  7  7  0
 0  2  2  2  3  3  3  6  6  6  6  6  6  7  7  0
 0  2  3  3  3  3  3  6  6  6  6  6  6  7  7  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0

                           GROUND FLOOR

 0  0
 0  0

                          TERRACE LEVEL


UNDER THE RULES FOR EVALUATION, THIS LAYOUT SATISFIES ALL
                                   NECESSARY   RELATIONSHIP.
```

Figure 33. Problem 4 - ALDEP final output with SW=3 US=64 sq ft RN=0931 DC=01.

TRIAL LAYOUT 3 SCORE = 592

0	0
0	0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	4	4	4	4	5	5	5	5	5	6	6	6	9	9	0
0	4	4	4	4	5	5	5	5	6	6	6	6	9	9	0
0	4	4	4	4	5	5	5	5	6	6	6	6	9	9	0
0	4	4	4	4	2	2	5	5	6	6	6	6	9	9	0
0	4	4	3	3	2	2	2	2	7	7	7	7	9	9	0
0	3	3	3	3	1	1	2	2	7	7	7	7	9	9	0
0	3	3	3	3	1	1	1	1	7	7	10	10	9	8	0
0	3	3	3	3	1	1	1	1	10	10	10	10	8	8	0
0	3	3	3	3	1	1	1	1	10	10	8	8	8	8	0
0	3	3	1	1	1	1	1	1	8	8	8	8	8	8	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0	0
0	0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET NECESSARY RELATIONSHIP.

102	108
102	110
104	106
104	107
104	108
106	104
107	104
108	102
108	104
110	102

Figure 34. Problem 4 - ALDEP final output with SW=4 US=64 sq ft RN=0931 DC=01.

TRIAL LAYOUT 1 SCORE = 536

0 0
0 0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	1	1	4	4	4	4	4	4	8	8	10	10	10	0
0	1	1	1	4	4	4	4	4	4	8	8	8	10	10	0
0	1	1	1	4	4	4	5	5	5	8	8	8	10	10	0
0	1	1	1	4	4	4	5	5	5	8	8	8	9	10	0
0	1	1	1	3	3	3	5	5	5	8	8	7	9	9	0
0	1	1	1	3	3	3	5	5	5	7	7	7	9	9	0
0	1	1	2	3	3	3	5	5	5	7	7	7	9	9	0
0	2	2	2	3	3	3	6	6	6	7	7	7	9	9	0
0	2	2	2	3	3	3	6	6	6	6	6	6	9	9	0
0	2	3	3	3	3	3	6	6	6	6	6	6	9	9	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0 0
0 0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET NECESSARY RELATIONSHIP.

102	105
102	106
102	108
102	110
104	106
104	107
105	102
106	102
106	104
107	104
108	102
110	102

Figure 35. Problem 4 - ALDEP final output with SW=3 US=64 sq ft RN=0931 DC=064.

TRIAL LAYOUT 13 SCORE = 528

0	0
0	0

TOP FLOOR

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	2	2	2	4	4	4	4	4	4	8	8	10	10	10	0
0	2	2	2	4	4	4	4	4	4	8	8	8	10	10	0
0	2	2	1	4	4	4	5	5	5	8	8	8	10	10	0
0	1	1	1	4	4	4	5	5	5	8	8	8	9	10	0
0	1	1	1	3	3	3	5	5	5	8	8	7	9	9	0
0	1	1	1	3	3	3	5	5	5	7	7	7	9	9	0
0	1	1	1	3	3	3	5	5	5	7	7	7	9	9	0
0	1	1	1	3	3	3	6	6	6	7	7	7	9	9	0
0	1	1	1	3	3	3	6	6	6	6	6	6	9	9	0
0	1	3	3	3	3	3	6	6	6	6	6	6	9	9	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

GROUND FLOOR

0	0
0	0

TERRACE LEVEL

UNDER THE RULES OF FOR EVALUATION, THIS LAYOUT DOES NOT MEET NECESSARY RELATIONSHIP.

102	103
102	105
102	106
102	108
102	110
103	102
104	106
104	107
105	102
106	102
106	104
107	104
108	102
110	102

Figure 36. Problem 4 - ALDEP final output with, SW=3 US=64 sq ft RN=0397 DC=01.

CRAFT

CRAFT outputs indicate that there are variations when the initial layout is changed. CRAFT improved the final layouts of all three layout programs viz. CORELAP, PLANET and ALDEP. CRAFT prints out the amount of dollars saved in material handling cost. The average percentage of cost reduced for the problems 2, 3 and 4 are:

Initial layout	Ave % reduction (2,3,& 4)
CORELAP final layout	18%
PLANET final layout	3.5%
ALDEP final layout	18.5%

The complete CRAFT solution for problem 2 is given in Figure 39A through Figure 39F.

CRAFT could not improve the final layouts of problem 1 obtained by other methods (Figure 37).

The results of the CRAFT solutions for the three problmes have been tabulated (Table 5).

TABLE 5

CRAFT Summary of Results

Problem	Initial layout	No. of iterations	Initial cost $	Final cost$	Reduction in cost	Percent reduction	Figure
2	CORELAP	2	0.86	0.75	0.11	12.8%	38
2	PLANET	2	2.54	2.45	0.09	3.5%	39F
2	ALDEP	0	2.50	2.50	0	0	40
3	CORELAP	4	15.45	12.57	2.88	18.6%	41
3	PLANET	4	17.24	16.21	1.03	6%	42
3	ALDEP	4	27.19	21.51	5.68	20.9%	43
4	CORELAP	6	0.53	0.41	0.12	22.6%	44
4	PLANET	1	1.71	1.71	0	0	45
4	ALDEP	4	0.66	0.43	0.23	34.8%	46

Legend

Problem 1

A - Shipping

B - Warehouse

C - Receiving

Problem 2

A - Receiving

B - Milling

C - Press

D - Screw machine

E - Assembly

F - Plating

G - Shipping

H,I,J - Dummies

Problem 3

A - Restaurant

B - Club restaurant

C - Bar lounge

D - Kitchen

E - General storage

F - Waiting preparation

G - Rest rooms

H - Cashier office

I - Lobby

J - Stage

K - Dance floor

L - Private dinning

M - Workers storage

N,O,P - Dummies

Problem 4

A - Woodcutting

B - Receiving

C - Framing

D - Upholstery

E - Fabric storage

F - Fabric cutting

G - Sewing

H - Shipping

I - Offices

J - General storage

K,L, M- Dummies

LOCATION PATTERN

	1	2	3	4	5	6	7	8	9	10
1	B	B	B	B	B	C	C	C	C	C
2	B				B	C				C
3	B				B	C				C
4	B	B	B	B	B	C	C	C	C	C
5	D	D	D	D	D	A	A	A	A	A
6	D				D	A				A
7	D				D	A				A
8	D	D	D	D	D	A	A	A	A	A

TOTAL COST 0.07 EST. COST REDUCTION 0.00 MOVEA A

Figure 37. Problem 1 - CRAFT's evaluation of PLANET output.

```
                         LOCATION PATTERN


     1  2  3  4

  1  D  A  A  C

  2  D  B  G  G

  3  H  E  F  F
TOTAL COST      0.75  EST. COST REDUCTION       0.02  MOVEA  F
```

Figure 38. Problem 2 - CRAFT's evaluation of CORELAP output.

INTERDEPARTMENT PRODUCT FLOW

	A	B	C	D	E	F	G
A	0.0	45.000	15.000	25.000	10.000	5.000	0.0
B	0.0	0.0	0.0	30.000	25.000	15.000	0.0
C	0.0	0.0	0.0	0.0	5.000	10.000	0.0
D	0.0	20.000	0.0	0.0	35.000	0.0	0.0
E	0.0	0.0	0.0	0.0	0.0	65.000	35.0
F	0.0	5.000	0.0	0.0	25.000	0.0	65.0
G	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I	0.0	0.0	0.0	0.0	0.0	0.0	0.0
J	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 39A. Problem 2 - CRAFT's evaluation of PLANET output, page 1.

INTERDEPARTMENT MOVE COST
PER UNIT LOAD PER UNIT DISTANCE

	A	B	C	D	E	F	G
A	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C	0.001	0.001	0.001	0.001	0.001	0.001	0.001
D	0.001	0.001	0.001	0.001	0.001	0.001	0.001
E	0.001	0.001	0.001	0.001	0.001	0.001	0.001
F	0.001	0.001	0.001	0.001	0.001	0.001	0.001
G	0.001	0.001	0.001	0.001	0.001	0.001	0.001
H	0.001	0.001	0.001	0.001	0.001	0.001	0.001
I	0.001	0.001	0.001	0.001	0.001	0.001	0.001
J	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Figure 39B. Problem 2 - CRAFT's evaluation of PLANET output, page 2.

CCVOL = (MOVE COST/LCAD)X(NC. CF LOADS)

	A	B	C	D	E	F	G
A	0.0	0.045	0.015	0.025	C.010	C.005	0.0
B	0.0	0.0	0.0	0.030	C.025	0.015	0.0
C	0.0	0.0	0.0	0.0	C.005	0.010	0.0
D	0.0	0.020	0.0	0.0	C.035	C.0	0.035
E	0.0	0.0	0.0	0.0	0.0	0.065	0.065
F	0.0	0.005	0.0	0.0	C.025	0.0	0.0
G	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H	0.0	0.0	0.0	0.0	C.0	0.0	0.0
I	0.0	0.0	0.0	0.0	0.0	C.0	0.0
J	0.0	0.0	0.0	0.0	C.0	C.0	0.0

Figure 39C. Problem 2 - CRAFT's evaluation of PLANET output, page 3.

LOCATION PATTERN

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

TOTAL COST 2.59 EST. COST REDUCTION 0.0 MOVEA

Figure 39D. Problem 2 - CRAFT'w evaluation of PLANET output, Iteration #1, page 4.

LOCATION PATTERN

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

TOTAL COST 2.54 EST. COST REDUCTION 0.08 MOVEA C

Figure 39E. Problem 2 - CRAFT's evaluation of PLANET output. Iteration #2, page 5.

LOCATION PATTERN

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

TOTAL COST 2.45 EST. COST REDUCTION 0.06 MOVES C

Figure 39F. Problem 2 - CRAFT's evaluation of PLANET output. Iteration #3, page 6.

LOCATION PATTERN

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

TOTAL COST 2.50 EST. COST REDUCTION 0.0 MOVEA

Figure 40. Problem 2 - CRAFT's evaluation of ALDEP output.

LOCATION PATTERN

	1	2	3	4	5	6	7	8	9	10
1	R	R	R	R	O	N	N	N	N	N
2	R	R	C	C	O	O	N	H	N	N
3	R	R	C	C	O	O	N	H	L	L
4	R	R	C	C	C	C	I	I	I	L
5	R	R	C			C	G	G	L	L
6	K	K	C	C	C	C	G	G	L	L
7	K	K	B	B	B	B	G	A	A	A
8	J	J	B	B	F	B	M	A		A
9	Q	Q	B	B	F	B	B	A	A	A
10	Q	Q	B	B	D	D	D	A	P	P
11	Q	Q	B	B	D		D	P	P	P
12	Q	Q	E	E	D	D	D	P	P	P

TOTAL COST 12.57 EST. COST REDUCTION 0.26 MOVEA C

Figure 41. Problem 3 -CRAFT's evaluation of CORELAP output.

LOCATION PATTERN

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

TOTAL COST 16.21 EST. COST REDUCTION 0.36 MOVEA K

Figure 42. Problem 3 -CRAFT's evaluation of PLANET output.

LOCATION PATTERN

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	C	C	C	B	B	B	B	B	B	D	D	M	M	M	E	E	E	K	K
2	C		C	B					B	D	D	D	F	F	F	E	K	K	K
3	C		C	B		B	B	B	B	D		D	F	G	L	J	J	J	K
4	C		C	B		B	A	A	B	D		D	G	G	L	J	J	J	K
5	C		C	B		B	A	A	A	D		D	G	G	L	L	L	L	K
6	C		C	B		B	A		A	D		D	G	G	L		L	L	K
7	C		C	B		B	A		A	D		D	G	G	L	L	L	H	N
8	C		C	B	B	B	A		A	D	D	D	G	G	L	L	H	H	N
9	C		C	B	C	C	A		A	D	A	A	G	I	I	L	L	L	N
10	C	C	C	C	C	C	A	A	A	A	A	A	I	I	I	I	I	I	N

TOTAL COST 21.51 EST. COST REDUCTION 0.15 MOVEA G

Figure 43. Problem 3 - CRAFT's evaluation of ALDEP output.

LOCATION PATTERN

	1	2	3	4	5	6
1	K	H	M	L	L	L
2	C	H	I	I	J	A
3	C	D	E	E	B	A
4	C	D	F	F	G	A

TOTAL COST 0.41 EST. COST REDUCTION 0.02 MOVEA M

Figure 44. Problem 4 - CRAFT's evaluation of CORELAP output.

LOCATION PATTERN

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	M	M	M	C	C	C	C	C	C	C	K	K	K	K	K	K	K	K	K	K
2	M		M	C						C	H	H	H	H	H	I	I	I	I	I
3	M		M	C						C	H				H	I				I
4	M		M	C	C					C	H				H	I				I
5	M		M	M	C					C	H				H	I				I
6	M	M	M	M	C	C	C	C	C	C	H	H	H	H	H	I	I	I	I	I
7	J	J	J	D	D	D	D	D	D	D	F	F	F	F	F	F	G	G	G	G
8	J		J	D						D	F					F	G			G
9	J		J	D						D	F					F	G			G
10	J		J	D						D	F					F	G			G
11	J	J	J	D	D	D	D	D	D	D	F	F	F	F	F	F	G	G	G	G
12	N	N	A	A	A	A	A	B	B	B	B	E	E	E	E	E	L	L	L	L
13	N	N	A				A	B			B	E				E	L			L
14	N	N	A				A	B			B	E				E	L			L
15	N	N	A	A			A	B	B		B	E				E	L			L
16	N	N	N	A			A	A	B	B	B	E				E	L			L
17	N		N	A				A	A	L	L	E	E	E	E	E	L			L
18	N	N	N	A	A	A	A	A	A	L	L	L	L	L	L	L	L	L	L	L

TOTAL COST 1.71 EST. COST REDUCTION 0.00 MOVEA H

Figure 45. Problem 4 - CRAFT's evaluation of PLANET output.

LOCATION PATTERN

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

TOTAL COST 0.43 EST. COST REDUCTION C.01 MOVEA J

Figure 46. Problem 4 -CRAFT's evaluation of ALDEP output.

COFAD

COFAD produced the same layout as CRAFT, for problem 2. The data inputed and program is similar to CRAFT (Figure 47), and it can be considered an extension of CRAFT.

Among the two alternate material handling equipments, fork lift truck and electric platform truck, the results indicate that the fork lift truck is cheaper to operate. $2732 per year for fork lift truck compared to $3821 per year for electric platform truck. Sensitivity analysis indicated that at 110% of flow volume, three fork lift trucks may be needed or else only two are sufficient. At 100% of flow volume, the percentage of utilization of fork lift truck was 97%.

LOCATION PATTERN

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

TCTAL COST 36.38 EST. COST REDUCTION C.C MCVEA
********* END ITERATION NUMBER 6**********

EQUIPMENT TYPE 1
****
NUMBER OF MOVES INCLUDED 1
SUM OF ALCOTK 3452.52
NUMBER OF PIECES OF EQUIPMENT REQUIRED 1.000

EQUIPMENT TYPE 2
****
NUMBER OF MOVES INCLUDED 16
SUM OF ALCOTK 46571.51
NUMBER OF PIECES OF EQUIPMENT REQUIRED 3.000

Figure 47. Problem 2 - COFAD's evaluation of ALDEP output.

DISCUSSION

Each problem has been evaluated as to whether or not the layout programs honor the input relationships, when other input quantities are changed.

Two departments having either "A" (absolutely necessary) or "E" (especially important) relationship inputted ,are next to each other, then it is termed "The layout program honors the relationship ".

The results of the specific relationships that were honored or not honored by the layout programs, are given in Table 6, 7 and 8 for problems 2, 3 and 4 respectively. A detailed analysis of each problem is given in the next section.

In problem 1 both CORELAP and PLANET produced almost identical layouts. The layouts generated by ALDEP were not different, except that the departments were split. CRAFT could not improve the final layouts of CORELAP, PLANET and ALDEP. This problem is, of course, trivial.

In problem 2, all three layout programs gave different outputs. But both CORELAP and PLANET generated layouts that honored all the departmental input relationships (Table 6). All but one ALDEP layouts honored most of the relationships (Table 6). ALDEP produced a suboptimal layout, when the input value for degree of closeness was "64". CRAFT improved the final layouts of CORELAP and PLANET. The percentage reduction in material handling costs was CORELAP (18.6%) and PLANET (6%). It could not improve the final layout of

TABLE 6

Problem 2 - Evaluation of Departmental Relationships

Departments	Relationship	CORELAP	PLANET			ALDEP				CRAFT		
		NO ES	BS= 200 PP A02 G02	BS=500 PP 01	PP A02 G02	SW 2	SW 3	R.NO 0937	DC 064	Initial layout CO	PL	AL
		Figure	Fig. 13	Fig. 15	Fig. 14	Fig. 26E	Fig. 27	Fig. 26E	Fig. 28	Fig. 38	Fig. 39	Fig. 40
5(E) 6(F)	A	/	/	/	/	/	/	/	/	/	/	/
1(A) 2(B)	E	/	/	/	/	/	/	/	/	/	/	/
2(B) 4(D)	↓	/	/	/	/	/	/	/	X	/	/	/
6(F) 7(G)	↓	/	/	/	/	/	/	/	/	/	/	/

Legend

/ - Honors the relationship
X - Does not honor the relationship
BS - Block size
ES - Element square
RNO - Random Number
DC - Degree of closeness
1(A) 2(B) - The relationship between dept. 1 and dept. 2
H02 I02 - Dept. H has placement priority 02 and dept. I has placement priority 02.
01 - All depts. have assigned placement priority of 1.
CO - CORELAP, PL - PLANET, AL - ALDEP

ALDEP. The minimum material handling cost layout was obtained using the final layout of CORELAP as the initial layout in CRAFT.

In problem 3, the layouts generated by CORELAP indicates that when a value for element square was inputted, it produced a better layout. CORELAP does not honor all the relationships, when it assumed an element square. In Table 7 both CORELAP solutions show that they do not honor three relationships. But when the element square is not specified, it does not honor a more important "A" relationship. It can be infered that CORELAP produces better layouts when the element square value is used. The PLANET solutions show that the best layout is one with block size 30 square feet and a placement priority of "01" for all departments (Table 7). When the block size and placement priority are altered the program does not honor all the relationships, resulting in sub-optimal layouts. ALDEP results indicate that with an input sweep width value of "4" and a degree of closeness of "01", ALDEP produced a better layout (Table 7). When a smaller sweep width "3" and a higher degree of closeness "64" was inputed, the program does not honor all the relationships. Changing the random number had no effect on the solution.

CRAFT improved the final layouts of CORELAP, PLANET and ALDEP. The percentage reduction in material handling costs was CORELAP (18.6%), PLANET (6%) and ALDEP (20.9%). The layout with minimum material handling cost layout was

TABLE 7

Problem 3 - Evaluation of Departmental Relationships

Departments		Relationship	CORELAP NO ES	CORELAP ES = 5	PLANET BS = 30 PP G02 H02 M02	PLANET BS = 30 PP 01	BS = 25 PP G02 H02 M02	ALDEP SW 3	ALDEP SW 4	ALDEP R.NO. 0397	ALDEP D.C. 064	CRAFT Initial layout CO	CRAFT Initial layout PL	CRAFT Initial layout AL
			Fig. 8	Fig. 9	Fig. 17	Fig. 18	Fig. 16	Fig. 29	Fig. 30	Fig. 32	Fig. 31	Fig. 41	Fig. 42	Fig. 43
4(D)	5(E)	A	/	/	/	/	/	/	/	/	/	/	/	/
4(D)	6(F)	↓	/	/	/	/	/	/	X	/	/	/	/	X
9(I)	8(H)	↓	/	/	/	/	/	/	/	/	/	/	X	X
11(K)	10(J)	↓	/	/	/	/	/	/	/	/	/	/	/	/
13(M)	6(F)	↓	X	/	/	/	/	X	/	X	X	X	/	/
2(B)	3(C)	E	/	/	X	X	X	/	/	/	X	/	X	/
4(D)	1(A)	↓	/	/	/	/	/	/	/	/	/	/	/	/
4(D)	2(B)	↓	/	/	/	X	/	/	/	/	/	/	/	/
7(G)	1(A)	↓	/	X	X	/	X	/	/	/	/	/	/	/
7(G)	2(B)	↓	/	X	X	/	X	X	X	X	X	/	X	X
7(G)	3(C)	↓	/	/	X	X	X	X	X	X	X	/	/	X
9(I)	7(G)	↓	/	/	X	X	/	/	/	/	/	/	X	/
10(J)	2(B)	↓	/	/	/	/	X	X	X	X	X	/	/	X
11(K)	2(B)	↓	/	/	/	/	/	X	X	X	/	/	/	X
11(K)	3(C)	↓	/	/	/	/	/	X	X	X	X	/	/	X
12(L)	4(D)	↓	X	X	/	/	/	/	/	/	/	X	/	X
12(L)	7(G)	↓	X	/	/	/	/	/	/	/	X	/	/	/
12(L)	9(I)	↓	/	/	/	/	/	/	/	/	/	/	/	/

obtained using the final layout of CORELAP as initial layout in CRAFT.

In problem 4, the layouts generated by CORELAP satisfied all the relationships that has been inputed. The solution obtained using an input value of "4" for element square produced a better layout (Table 8). The results are similar to the one's obtained in problem 3. PLANET results indicate that when the input values for placement priority are "01" for all departments, superior layouts are obtained (Table 8). Changing block size has also resulted in a better layout , contrary to the results obtained in Problem 3. However when placement priority values were changed, a sub-optimal layout was produced, similar to the results of problem 3. The ALDEP solution obtained by using "4" as input value for sweep width and "01" for degree of closeness, was the best layout (Table 8). When the input values for sweep width, random number and degree of closeness are changed, the program does not honor all the relationships resulting in sub-optimal layouts.

CRAFT improved the final layouts of CORELAP and ALDEP. The percentage reduction in materials handling cost was CORELAP (22%) and ALDEP (34.8%). CRAFT could not improve the final layout of PLANET. The minimum material handling cost layout was obtained using the final layout of CORELAP as initial layout in CRAFT

It can be concluded from this study that the scores generated by layout programs are of no consequence when

TABLE 8

Problem 4 - Evaluation of Departmental Relationships

Departments	Relationship	CORELAP		PLANET			ALDEP				CRAFT		
				BS=32		BS=64					Initial layout		
		NO ES	ES* 4	PP 01	PP H02 I02	PP H02 I02	SW 3	SW 4	R.NO. 0397	D.C. 064	CO	PL	AL
		Fig. 10	Fig. 11	Fig. 19	Fig. 20	Fig. 21	Fig. 33	Fig. 34	Fig. 36	Fig. 35	Fig. 44	Fig. 45	Fig. 46
1(A) 2(B)	A	/	/	/	/	/	/	/	/	/	/	/	/
5(E) 6(F)	↓	/	/	/	/	/	/	/	/	/	/	/	X
6(F) 7(G)	↓	/	/	/	/	/	/	/	/	/	/	/	X
1(A) 3(C)	E	/	/	/	X	/	/	/	/	/	X	X	/
2(B) 5(E)	↓	/	/	X	/	/	/	/	X	X	/	/	X
2(B) 6(F)	↓	/	/	/	/	/	/	X	X	X	/	/	X
4(D) 5(E)	↓	/	/	/	/	/	X	X	/	/	/	/	/
5(E) 7(G)	↓	/	/	/	/	/	/	/	/	/	/	/	/
8(H) 10(J)	↓	/	/	/	X	X	/	/	/	/	X	X	/

Legend
/ - Honors the relationship
X - Does not honor the relationship
BS - Block size
ES - Element square
RNO- Random number
DC - Degree of closeness
1(A) 2(B) - The relationship between dept. 1 and dept. 2
H02 I02 - Dept. H has placement priority ⌀2 and dept. I has placement priority ⌀2.
01 - All depts. have assigned placement priority of 1.

comparing layouts obtained by varying input quantities for the same problem. Of all the construction programs PLANET seem to produce better quality layouts and three alternate solutions. In case of improvement layouts, where the objective is to minimize material handling cost, CRAFT produces the best layouts. If a new layout has to be created from scratch, with an objective of minimizing material handling costs, then the combination of CORELAP and CRAFT produce the best results.

CRAFT is suitable for evaluating the layouts obtained by other layout programs. And if alternate solutions are to be generated, PLANET produces up to three layouts.

A few general rules that would aid a layout planner utilizing the layout programs can be stated.

In CORELAP the input value chosen for element square should be the highest common denominator of all the departmental areas. It does not produce an under or oversized layouts, when the element square is inputted. In general, better layouts are obtained if the element square is specified as above.

If the objective is minimizing material handling costs, then the final layout of CORELAP can be inputted as initial layout in CRAFT to obtain an optimum layout. The CORELAP and CRAFT combination usually produces the best layouts.

In PLANET, the input values for placement priority should be "01" for all departments. The block size should be the highest common denominator of all the departmental areas. If more than one exists then the program should be rerun using different block sizes. The program is useful for generating alternate layouts. Among the construction programs, PLANET is a better program than either CORELAP or ALDEP. And if the objective is minimizing material handling cost than the final layout of PLANET can be used as initial layout in CRAFT to obtain an optimum layout.

In ALDEP, the degree of choseness should be "01". Sweep width and random number should be varied and the program should be rerun until no higher scores can be obtained. A major drawback of ALDEP solutions is that it splits the departments. If the objective is to obtain a large number of alternate layouts, then ALDEP produces upto 20 layouts.If material handling costs have to be minimized the final layout of ALDEP should be inputed as initial layout in CRAFT to obtain an optimum layout.

CRAFT should be utilized to evaluate the construction programs. And its the best layout program, if the objective of the layout planner is to minimize the material handling cost.

COFAD should be used only if the layout planner intends to compare alternate material handling equipment and perform sensitivity analysis.

This report has been an experimental study and there is scope for a more detailed study. The following factors should be considered in future studies, involving the comparison of the layout programs.

1. A greater variety and a larger number of problems including much more complex problems.
2. Evaluation of the layouts based on having someone with through knowledge and experience of the particular problem.
3. The effects of changing the input values for departmental relationships on the layout solutions in an iterative fashion after initial solutions.

Involvement of the layout planner and actual layout problems in industry would provide a more meaningful basis for a future study. As the complexity of the problem increases (i.e. more departments), computer aided layout should be easy to work with, to obtain crude layouts that could be massaged by the layout planner before implementation.

With interactive computer aided layout, it should be much easier to change layouts (or input quantities) to get the desired final layouts. Due to the inherent advantages of interactive computer aided layout there will be an increasing use of these programs in future. A study aimed at the easier selection of a program for a specific problem would help reduce the layout planner's time in arriving at the optimum solution. This could be a big step in enhancing the productivity in industry.

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COMPUTERIZED FACILITIES LAYOUT AND DESIGN - A COMPARISON

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ABSTRACT

This study was an attempt to test and compare the five plant layout programs viz. CORELAP, PLANET, ALDEP, CRAFT and COFAD. The factors considered for comparison were: generation of alternate layouts, minimum material handling cost and variable input characteristics in the programs.

Four layout problems were solved using these programs. Each program was run on the computer several times by changing the input quantities for every problem. The layouts obtained were evaluated, based on whether or not the layout programs honored the departmental relationships.

The results indicate that PLANET generates better layouts among the construction type layouts (CORELAP, PLANET and ALDEP) both in terms of honored relationships and alternate layouts. Also a combination of CORELAP and CRAFT (existing type) generates a minimum material handling cost layout. Among the existing type layouts (CRAFT and COFAD), COFAD has additional features like alternate material handling equipment and sensitivity analysis, but both produce the same kind of layouts.

A few suggestion have been made regarding the input characteristics of the programs, which would aid the layout planner to utilize the programs more effectively. In most cases the layouts produced by these programs are not final layouts, they have to be "massaged" before implementing them.