A Methodology for Total Hospital Design

by Gerald L. Delon

A procedure is described that integrates three techniques into a unified approach: a computerized method for estimating departmental areas and construction costs, a computerized layout routine that produces a space-relationship diagram based on qualitative factors, and a second layout program that establishes a final layout by a series of iterations. The methodology described utilizes as input the results of earlier phases of the research, with the output of each step in turn becoming the input for the succeeding step. The method is illustrated by application to a hypothetical pediatric hospital of 100 beds.

One of the objectives sought in hospital design is to locate the departments of the hospital in such a way as to minimize the total cost of traffic among all departments. Since this cost will be affected by the type and shape of the building, construction costs must also be considered. Earlier studies in this research project provided quantitative procedures by which to balance or optimize these two types of costs.

But less tangible factors must also be allowed to play a role if a model is to approach reality. Factors such as acceptability of different traffic densities and noise levels, asepsis, patient privacy, and ease of supervision are critical in the design process but are seldom integrated into a quantitative solution. Too often the consequence is that hospital representatives on the planning team examine the results of the model, point out that the intangible variables far outweigh the measurable quantities, and end up doing what they intended to do from the start. Such a procedure can result in an unbalanced design for which the consumer of the hospital's product, the patient, ultimately pays. Systems analysis, unfortunately, has so far offered few practical alternatives to this procedure.

In an attempt to resolve this dilemma, the climax of this research project, utilizing and combining the results of its earlier phases, was the development of a methodology for the incorporation of qualitative as well as quantitative factors into the design and evaluation of alternative hospital plans. In this methodolgy for total hospital design, the output of each step becomes the input for the succeeding step, thus ultimately yielding a single unified approach.

First, a method for estimating departmental area requirements and construction costs was computerized to be used in a conversational mode at a remote terminal. The planner can alter and adjust the parameters at this stage of the planning process until he is satisfied that the areas and costs meet design requirements. In the next step a computerized layout program, CORELAP (for COmputerized RElationship LAyout Planning), generates an initial hospital layout based on these departmental areas and on qualitative, functional relationships among departments and activities. This initial layout, together with the quantitative data on interdepartmental traffic frequencies derived from the stochastic traffic model described in the preceding article, becomes the input for the final stage, a second computerized layout program, CRAFT (for Computerized Relative Allocation of Facilities Technique). Figure 1 depicts the methodology in the form of a flow chart.

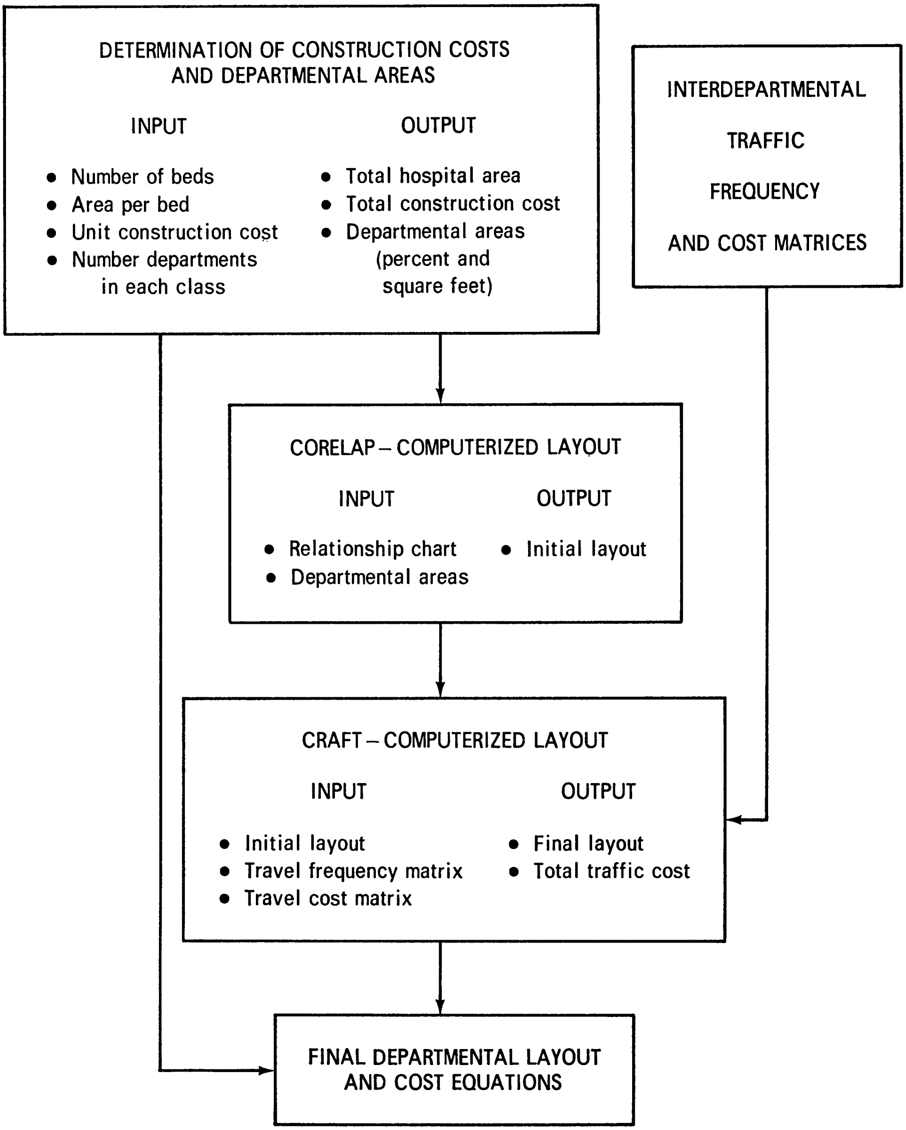

Fig. 1. Flow diagram of methodology for total hospital design.

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$   1500000   Initial Estimate of Construction Cost
      50000   Initial Estimate of Total-Area-in-Square Feet
        100   Total Number of Beds
        500   Area-Per-Bed-in-Square-Feet
      50000   Calculated Total Area in Square Feet
         department      area(per cent of total)      area(square feet)
Administration            10       7.62                    3810
Laboratory                21       4.79                    2395
Radiology                 22       5.15                    2575
Physical Medicine         23       1.95                     975
Pharmacy                  24        .62                     310
Inpatient Nursing Unit    31      28.13                   14065
Surgical Suite            32       8.17                    4085
Obstetrics                33       0.                         0
Emergency                 34       0.                         0
Dietary                   41       4.90                    2450
Housekeeping              42        .22                     110
Employee                  43       1.50                     750
Central Stores            44       2.59                    1295
Central Sterile Supply    45       1.93                     965
Laundry                   46       1.98                     990
Outpatient                50       2.86                    1430
General Circulation       61       8.48                    4240
Education                 62       7.57                    3785
Mechanical                63       4.44                    2220
Unassigned                64       3.30                    1650
Exterior Walls            65       3.80                    1900
Do you want to change the percent distribution?
        if yes, insert 1.  if no, insert 0.
ans1
0
Do you want to change the basic parameters?
        if yes, insert 1.  if no, insert 0.
ans2
0
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Fig. 2. Sample output, departmental-area determination for hypothetical hospital.

Departmental Areas and Construction Costs

Souder's method of establishing departmental areas and corresponding construction costs [1] in three categories—basic enclosed space or structural cost, partitions and finishes cost, and mechanical services and fixed equipment cost—to yield construction-cost coefficients for each department was programmed for use on an IBM 1050 remote terminal in CPS (Conversational Programming System [2]). The large number of sequential, interrelated decisions and computations involved in the initial planning stages, many of them subject to repeated alteration and adjustment as the planning is further refined, presents a formidable barrier that can inhibit creative suggestions for design changes. The computerized approach not only obviates this difficulty but gives the planner the opportunity, starting from Souder's sound and tried base, to vary the area distributions and cost coefficients to accommodate the special characteristics of the hospital being designed.

The program requires the user to specify values for three basic parameters of the hospital: number of beds, square feet per bed, and local or regional

Output -- Detailed Construction Costs.

Total Cost = $ 1580283

Dept	Total Cost	Coeff	Basic Cost	Coeff	Part Fin Cost	Coeff	Equip Cost	Coeff
10	109728	.96	51435	.45	43434	.38	14859	.13
21	82628	1.15	32332	.45	32332	.45	17962	.25
22	94245	1.22	34762	.45	40170	.52	19312	.25
23	31882	1.09	13162	.45	13455	.46	5265	.18
24	12369	1.33	4185	.45	5859	.63	2325	.25
31	447267	1.06	189878	.45	156122	.37	101268	.24
32	205884	1.68	55148	.45	72305	.59	78432	.64
33	0	1.42	0	.45	0	.44	0	.53
34	0	1.18	0	.45	0	.58	0	.15
41	111720	1.52	33075	.45	29400	.40	49245	.67
42	4323	1.31	1485	.45	1386	.42	1452	.44
43	22050	.98	10125	.45	6975	.31	4950	.22
44	26418	.68	17482	.45	6993	.18	1943	.05
45	44583	1.54	13027	.45	14475	.50	17081	.59
46	49896	1.68	13365	.45	5940	.20	30591	1.03
50	42471	.99	19305	.45	15015	.35	8151	.19
61	81408	.64	57240	.45	20352	.16	3816	.03
62	115821	1.02	51098	.45	54504	.48	10219	.09
63	46620	.70	29970	.45	11322	.17	5328	.08
64	24750	.50	22275	.45	1980	.04	495	.01
65	26220	.46	25650	.45	399	.01	171	.00

Do you want to change the cost coefficients?
If yes, insert 1. If no, insert 0.
ans3
0

Output -- Final Summary Report.

class	total area (square feet)	total construction cost
administration	3810	109728
adjunct facilities	6255	221124
nursing dept.	18150	653151
service dept.	6560	258990
outpatient dept.	1430	42471
all other space	13795	294819
TOTAL	50000	1580283

Fig. 3. Sample output, construction-cost determination for hypothetical hospital.

construction cost per square foot. On the basis of Souder's space allocations, contained internally in the computer, the computer then calculates and prints out the departmental areas in square feet as percentages of the total hospital area. At this point the designer has the opportunity to adjust the percentage distributions of the departments in accordance with the requirements of the particular hospital, and the computer recycles and recomputes the new departmental areas in square feet. A sample of the output from this stage of the conversational program, based on data for a hypothetical 100-bed pediatric hospital in a nonurban area, is shown in Fig. 2.

Once the designer is satisfied with the area distribution and the basic design parameters, the construction costs for each department are calculated and printed out, along with the total cost for the entire hospital (Fig. 3). After making the first complete pass through the routine, the designer can make further passes revising the basic parameters, area distribution, and cost coefficients for the departments until a desirable combination is found.

Initial Layout by CORELAP Program

The departmental areas established in the first step, described above, form part of the input for the CORELAP program. The remaining primary input to that program, as indicated in Fig. 1, is a "relationship chart." The relationship chart, pioneered by Muther [3], establishes defined activities or departments and assigns a "closeness priority rating" for each pair. As the name implies, a closeness priority rating indicates the desirability or undesirability of locating two departments close to each other. The chart is in the form of a matrix, with the rating for each pair of departments entered at the point where their columns intersect. Alphabetic ratings can be used (transformed into numerical ratings in the CORELAP program by a linear weighting scheme), combined with code numbers indicating the reasons for the ratings, as exemplified in Fig. 4 for the hypothetical pediatric hospital used to illustrate the computer output in the preceding section. (The chart shown is not intended as a "universal" relationship chart; it merely illustrates some hypothetical interdepartmental proximity relationships.)

The closeness priority rating of the relationship chart permits the designer to include in his analysis the cumulative result of the many qualitative considerations important to hospital design and requires him to think in terms of the functional relationships between activities and departments. Moreover, it facilitates reduction of the complex problem of hospital design to a step-by-step procedure by analyzing the functional relationships between departments a pair at a time until the entire hospital has been analyzed. This approach is particularly useful in the early stages of the planning process, since the designer will be in a much better position to begin thinking about the arrangement of facilities into a layout after the chart has been prepared.

Developing a relationship chart for a complex system is not a simple task. It requires detailed knowledge of how each entity reacts and interacts with all

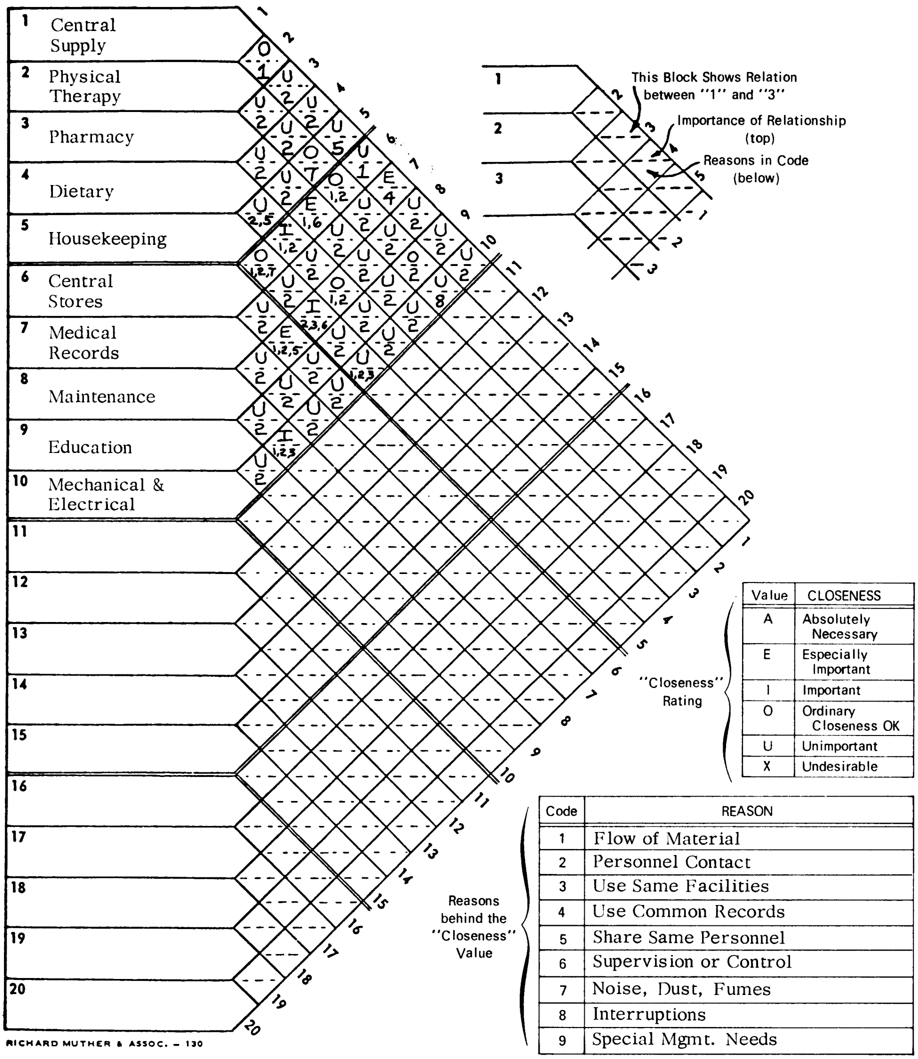


Fig. 4. Sample relationship chart, ground floor of hypothetical hospital.

others; and even though all hospitals basically entail the same facilities and operating procedures, each hospital has its own facets of uniqueness. It will often be difficult to get the architect, the hospital consultant, and the hospital officials to agree on the closeness rating for certain departments. Compromises will be necessary, but these very compromises should give the designer more insight into the problem.

The CORELAP program [4] utilizes a unique nomenclature. Among its most important terms are the following:

Candidate: A department that is eligible for placement or rearrangement in the layout.

Victor: A candidate that has been victorious over other candidates and has earned the right to be the next to be placed in the layout.

Winner: A victor that has been placed earlier in the layout.

Total Closeness Rating (TCR): The summation for each department of its closeness relationships with all other departments.

Figure 5 shows the overall logic of CORELAP. Basically, two questions are asked in the main portions of the program: (1) Which department is to be placed next in the layout? (2) How is this Victor entered into the layout? The main algorithm asks and answers these questions in a heuristic fashion. By the logical decision rules of the program, a layout is established step by step, with a new department being added to the layout at each step until all departments are in the final layout. The contiguity relationships of the final CORELAP output correspond to the qualitative considerations expressed in the relationship chart.

An example of the preliminary block layout produced as final output from the CORELAP program is shown in Fig. 6*A*, again for the hypothetical pediatric hospital. It was assumed, in applying the methodology to this hospital, that the design of the nursing units on the upper floors had been completed by use of the methodology developed in the first phase of the research project. Relationship charts were prepared for the lower floors; the ground-floor layout shown here was developed from the relationship chart in Fig. 4.

The importance of CORELAP is that it produces a space-relationship diagram that locates departments in a manner consonant with the qualitative factors on which the closeness ratings were based. But the CORELAP output is not necessarily a finished layout; further modification and analysis of the output may be required in order to work out a completely satisfactory arrangement. The overall building shape may need modification to conform to the topography of the site and to esthetic considerations, as in Fig. 6*B*, in which the nonsymmetrical shape has been changed to a symmetrical layout by adding one "block" to Department I and one to Department F; and the process of making final adjustments on the CORELAP output may lead to alternative layouts needing further evaluation. The layout is then systematically evaluated on a more quantitative basis with the aid of a second computerized layout routine known as CRAFT, which utilizes the CORELAP layout as input and incorporates traffic-frequency and cost data derived from the model described in the preceding article and other portions of the research study.

In the design of new hospitals, for which interdepartmental traffic may be difficult to predict if staffing patterns and certain operating policies are not concurrently established, the designer may choose to terminate the analysis at this stage, without using CRAFT, and instead proceed with final construction plans on the basis of the layouts produced by CORELAP. But when a more quantitative basis for final layout is required, and when interdepartmental traffic frequencies and costs can be estimated and predicted with some confidence, CRAFT provides a powerful adjunct and complement to CORELAP.

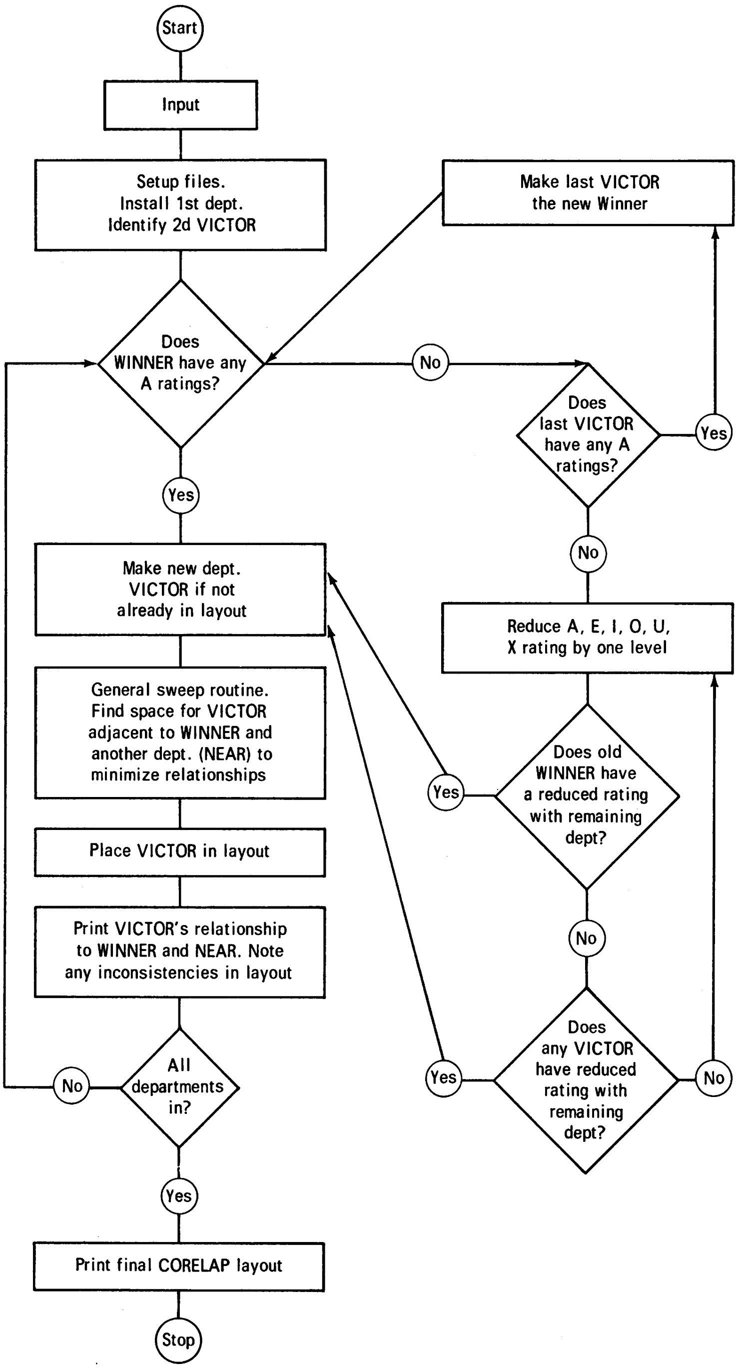
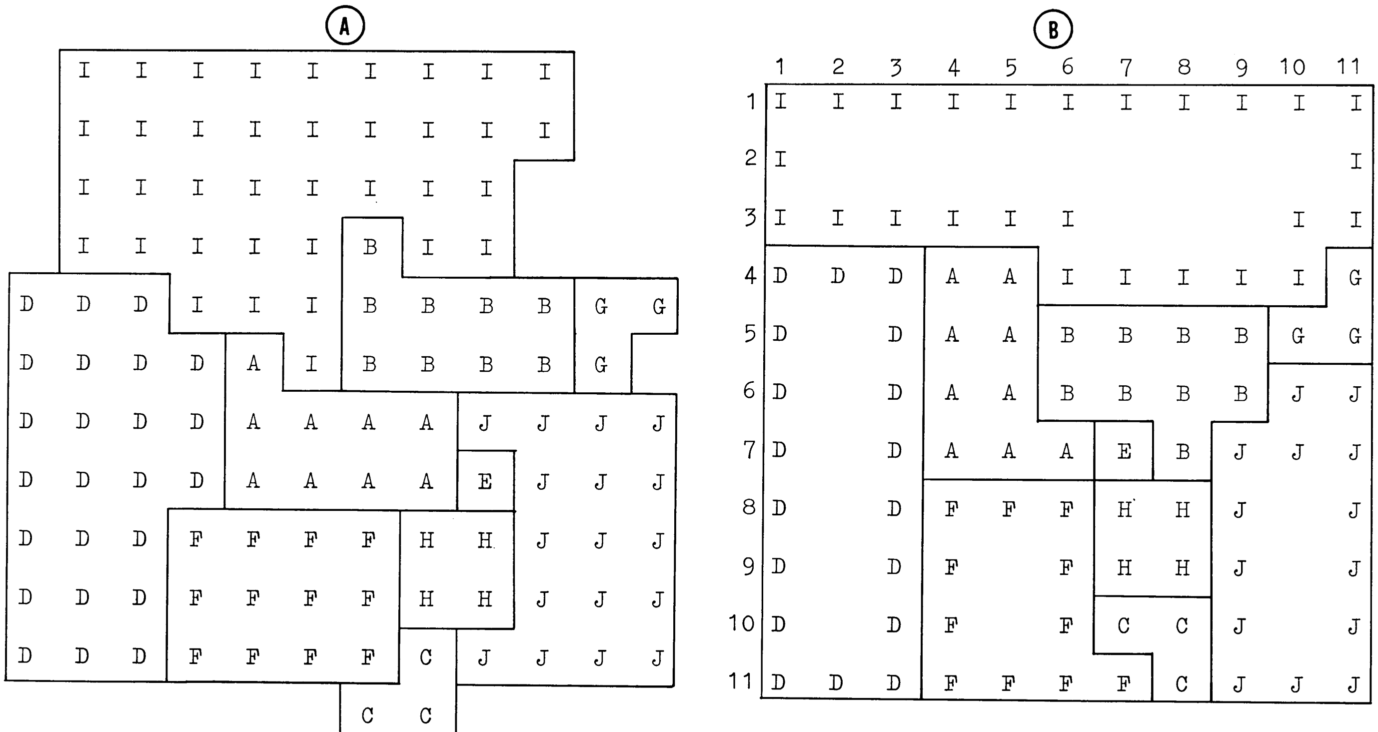


Fig. 5. CORELAP logic flow chart.



A Central Supply
B Physical Therapy
C Pharmacy
D Dietary
E Housekeeping
F Central Stores
G Medical Records
H Maintenance
I Education
J Mech. & Elec.

Fig. 6. *A*. Block layout produced by CORELAP for ground floor of hypothetical hospital from relationship chart in Fig. 4. *B*. Modification of *A* to produce symmetrical layout, used as initial input to CRAFT. Interdepartmental travel cost per unit distance 425 891.51 mills.

Final Layout by CRAFT Program

The CRAFT program, developed by Buffa et al. [5] for computerized evaluation of alternative layouts or designs, requires as input an initial representation of an existing or proposed layout, in addition to data on interdepartmental travel frequencies and travel costs per unit distance between each pair of departments. The logical decision rules of CRAFT are summarized in Fig. 7.

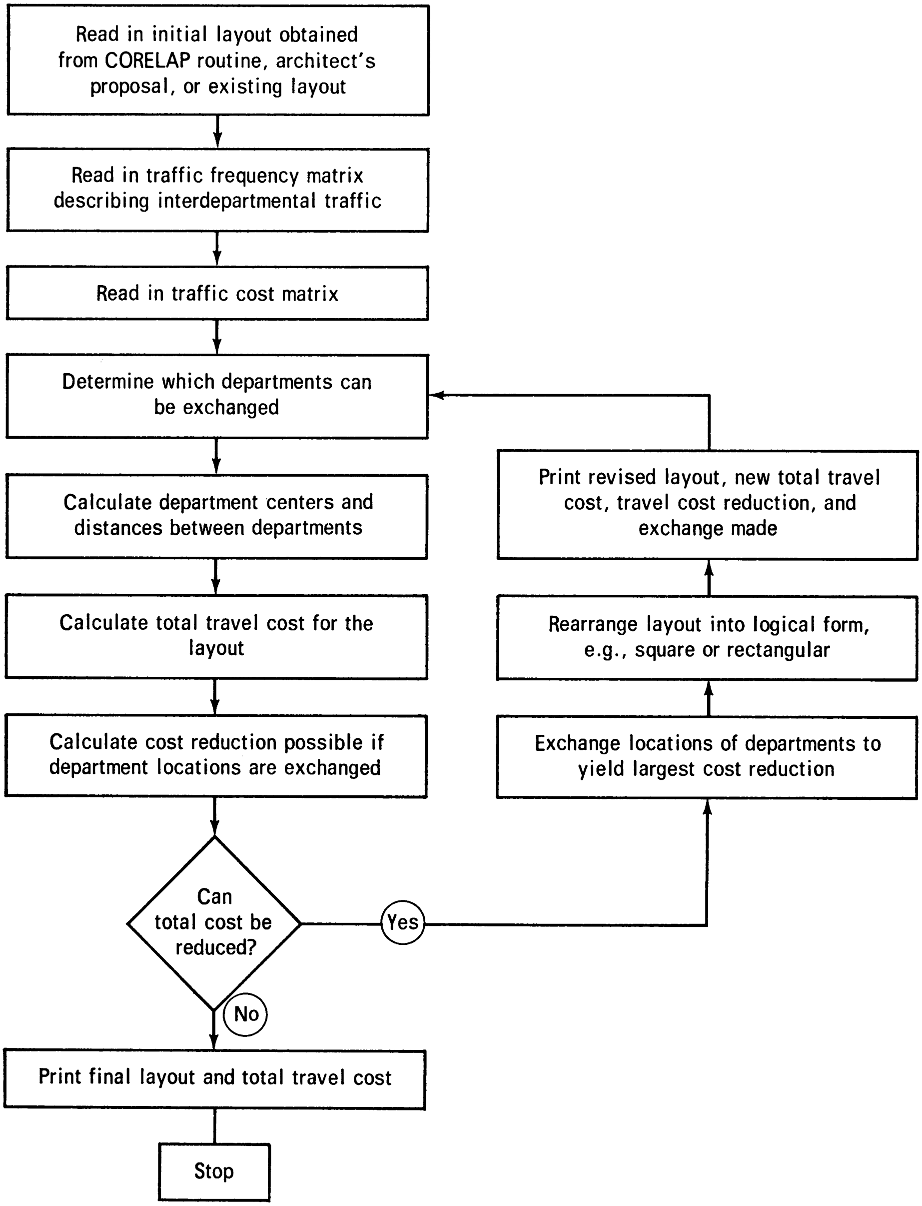


Fig. 7. CRAFT logic flow chart.

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

Fig. 8. Interim CRAFT location pattern, Iteration 1, transposing C and F. Interdepartmental travel cost per unit distance, 391 938.91 mills.

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

Fig. 9. Interim CRAFT location pattern, Iteration 2, transposing C and A. Interdepartmental travel cost per unit distance, 390 364.80 mills.

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

Fig. 10. Final CRAFT location pattern, Iteration 3, transposing A and F. Interdepartmental travel cost per unit distance, 380 394.79 mills.

The program calculates department centers and total traffic cost for the input initial layout, with distances assumed to be between department centers. It then searches through a list of possible configurations, each representing a small modification of the layout made by transposing the location of two departments, which must meet one of the following criteria: they are the same size; they have a common border; or they both border on a common third department. The modification that results in the greatest reduction in traffic cost is selected and the departments are transposed. The new layout offers another list of possible modifications, and the procedure is repeated, generating new layouts at each repetition, until there is no configuration on the list of possibilities that yields a cost reduction over the current layout.

Examples of interim layouts and final layout evolved by this process are shown in Figs. 8–10. Comparing the final layout (Fig. 10) with the initial (modified CORELAP) layout in Fig. 6*B*, it is seen that departments C and F (pharmacy and central stores) have been moved from the perimeter to the interior and department A has been shifted from the interior to a perimeter location, with an associated reduction of over 10 percent in the interdepartmental travel cost per unit distance.

The alternatives investigated by CRAFT can include the effects of "fixing" a department's location. Certain factors virtually dictate the location of some functions in a hospital: central stores, for instance, must be located along an outside wall where trucks can unload. To fix the location of a department, the CRAFT user simply specifies it as not a candidate for transposition. The analysis of layouts generated first with a department fixed and then with the department not fixed will enable the designer to determine the effects of fixing it in terms of both costs and qualitative considerations.

The program can also be applied, independently of CORELAP, to the evaluation of layouts obtained from other sources or to the modification of existing layouts. The final layout obtained by the program is dependent on the initial layout and on the modifications selected at each step of the routine. Once a layout problem has been formulated and the input data for a layout prepared, additional layouts using the same departments, traffic flows, and unit travel costs but with different building configurations can readily be investigated to increase the chances of improving the balance between traffic costs and construction costs.

Implications of the Methodology

The combination of these planning and design stages provides a dynamic and comprehensive means for investigating the trade-offs between traffic costs and construction costs and simultaneously incorporating intangible or qualitative factors in the design. A significant benefit of this approach is that once the computerized models have been formulated, very little manual effort is required to determine how sensitive the layout is to changes in the input parameters. For instance, the effect of reducing traffic frequency between departments can be examined by modifying the traffic-frequency matrix. The CRAFT routine can then be rerun with the modified data to determine the extent to which the layout would change. Area requirements can also easily be changed to determine the effects of building expansion on the layout. Such investigations will help the designer arrive at a layout that will be economical in the long run, as inevitable expansions and additions occur.

On the other hand, the user of this methodology should avoid the indiscriminate use of the initial percentage distribution of departmental areas available from the computer program. These percentages, in effect, reflect current hospital usage and at least tacit agreement that needs are being met by this particular area allocation. To the extent that historical percentage distributions incorporate inadequacies and inefficiencies, past errors will tend to be perpetuated by their use. In addition, many changes have occurred, and are occurring today, to invalidate area distributions that may have been correct in their time: for example, technological advances in materials handling, automated laboratories, and convenience food services.

A more appropriate approach to determining departmental areas would be to perform a functional analysis of the needs of each department—a task outside the scope of this research. This "building block" approach would incorporate factors such as the number of personnel in each department, the volume and variation in patient flows and supplies, the mobility of equipment, and the relative degree of expansion needed to accommodate anticipated increased activity. Many contributions in this area are yet to be made. Departmental areas determined in this manner would be custom-suited to the needs of a particular hospital and would be a more valuable input to the methodology developed in this research project.

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