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QUANTITATIVE EVALUATION OF INPATIENT NURSING UNIT DESIGNS

A THESIS

Presented to

The Faculty of the Graduate Division

by

Richard Neel Sendler

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

The objective of this study was to evaluate a number of inpatient nursing unit designs, varying the shape, the number of patient rooms, the number of patients per room, and the arrangement of all functional points, in order to ascertain the relative efficiencies of alternative designs. The purpose of this study was to aid the hospital planner by illustrating how one might evaluate inpatient nursing unit designs on a quantitative basis.

The study was limited to the evaluation of medical units, surgical units, or combination units which contain both medical and surgical patients of short-term, general, voluntary hospitals.

In essence, the evaluation procedure used combines the cost of nursing traffic between functional points on the nursing unit and the cost of amortization of construction for the unit. The combined costs for the unit were used as a measure of efficiency. In this way, the fourteen nursing units used in the study were ranked on the basis of relative efficiency.

It was concluded from the study results that:

1. Unit design is more important than unit size in determining the efficiency of inpatient nursing unit designs.

2. The double corridor design is the most efficient inpatient nursing unit design followed in order by the circular design, single corridor design, and angular design.

3. Nursing unit designs with compound circulation tend to be more

efficient than those with simple circulation.

4. Multi-patient rooms of a particular design category are more efficient than private rooms of the same design category.

This study illustrates that it is possible to evaluate inpatient nursing unit designs on a quantitative basis in order to ascertain the relative efficiency of alternative designs. Since the evaluation procedure is based on monetary costs, the results are intended to be used only as a supplement to good judgment on the part of the hospital planner.

CHAPTER I

INTRODUCTION

The general purpose of this study is to illustrate to the hospital planner how one might evaluate inpatient nursing unit designs on a quantitative basis in order to ascertain the relative efficiencies of alternative designs.

The general approach used in this study is to evaluate a number of inpatient nursing unit designs using an evaluation procedure developed by Freeman (1). Essentially, this procedure "combines the cost of nursing traffic between functional points on the unit and the cost of amortization of construction, consideration being given constraints imposed by limiting factors" (2).

Nature of the Problem

Smalley and Freeman state that "the primary and overriding purpose of any physical facility is to promote the attainment of objectives of the enterprise in which the facility is to be used" (3). Applying this facilities planning principle to the hospital, the primary purpose of the hospital structure is to promote the attainment of the objectives of the hospital. In order to promote the attainment of hospital objectives the hospital structure must be designed to house the activities and processes required in carrying out the functions of the hospital. Accordingly, the design of the hospital structure must begin with the identification of the functions to be performed. Space requirements and the relative locations of these functions must then be determined based upon the relationships among the functions.

It would seem to be a reasonable goal to locate the functions in areas that would minimize the total costs of traffic between these areas or functional points. However, the minimization of the cost of traffic is often in conflict with the minimization of the cost of construction. For example, "more abundant and more expensive transportation facilities may tend to increase construction costs while decreasing traffic costs; and certain building shapes may result in lower construction costs but higher traffic costs" (4). For this reason many design decisions involve the trade-off between the cost of traffic and the cost of construction.

The problem with which this study is concerned is that of evaluating alternative inpatient nursing unit designs in order to ascertain their relative efficiencies based on the trade-off between the cost of traffic and the cost of construction. Freeman defined the general problem as follows:

> The total relevant costs for a particular inpatient nursing unit design consists of three terms:
>
> (Constant Costs) + (Traffic Costs) + (Construction Costs)
>
> The first term, "constant costs," includes all of those costs that do not vary with spatial arrangement. In respect to the labor component, all nursing time spent in work at any of the various functional points (work centers) on the unit may be considered to be constant with respect to design. However, the costs of travel to and from the functional points at which these tasks are accomplished can be expected to be influenced by the relative locations of these points; the second term, "traffic costs," accounts for this influence. This term is the sum, for all types of trips, of the product of four factors: (1) the frequency of travel, (2) the distance travelled, (3) the time required to travel a unit distance, and (4) the rate of pay per unit of time for the employee who makes the trips. Since the arrangement of facilities on the nursing unit has implications for the total amount of space required and the assignment of this space to rooms, corridors, etc., the third term in the cost function also varies with design.
>
> If this function is to be optimized, the constant term may be

ignored. Thus, it is seen that the quantitative aspects of design decisions may be reduced to a consideration of a cost function which combines only traffic costs and amortized construction costs. (5)

The present study was undertaken as part of a research project entitled "Quantitative Methods for Evaluating Hospital Designs" which is supported by a United States Public Health Service (USPHS) grant. Phase I of this project was concerned with the development of a procedure for evaluating hospital designs, with emphasis on the nature and cost of traffic flow on the nursing unit and between the nursing unit and other departments of the hospital. This phase of the project was concluded with the completion of Freeman's dissertation and Ortega's thesis (6).

The present study is part of Phase II of the USPHS project and is concerned with the application of the evaluation procedure developed in Phase I to various alternative hospital designs. The study was conducted in order to illustrate the practical value of the results of Phase I to the hospital planner.

Importance of the Problem

The importance of the problem of this study can be documented by the United States Public Health Service (USPHS), the largest single financial supporter of hospital and health research, which has specifically stated the need for the development of practical tools for the evaluation of hospital designs. In a publication outlining areas of needed research interest, the USPHS listed the following needs (7):

> "Evaluation and development of planning guides for the construction of physical facilities . . . "
>
> "The need for improved functional design of structure for maximum efficiency . . . "

"Space requirements, including floor plans and traffic flow . . ."

The evaluation of inpatient nursing unit designs is of further importance because it may provide monetary savings in the construction of hospital facilities and it may promote more effective utilization of a limited supply of qualified nursing personnel. Potential economic benefits of better hospital design may be seen by examining the trend in the investment in hospital facilities, expenses and patient-day costs (8). The value of hospital assets increased from about five billion dollars in 1946 to more than 26 billion dollars in 1966, an increase of more than 400 percent. During this same twenty-year period annual hospital expenses rose from about two billion dollars to more than 14 billion dollars. This represents an increase of more than 600 percent in annual hospital expenses, whereas the cost of living increased only 60 percent during this period. Approximately two-thirds of these annual expenses are for wages and salaries paid hospital employees. Also during this same period costs per patient-day in voluntary hospitals increased from $10.04 to $48.82, not including private medical care and certain drugs. It is not suggested that a large proportion of these costs can be saved by the application of the results of this study. However, since nursing service does account for almost two-fifths of all labor costs and it has been estimated that nursing departments in short-term general hospitals account for almost one-half of the construction costs, even a small percentage savings would yield a significant absolute economic return (9).

The current shortage of health manpower also demonstrates the importance of this problem. Some way must be found to increase the productivity of the available personnel such as relieving them of nonproductive activities, for example, traveling between functional points on a nursing unit. If more efficient nursing unit designs can be developed and evaluated it may be possible to realize a savings in time expended by nurses in nonproductive traffic on a nursing unit. The Director of the American Hospital Association has stated that the health manpower problem is an extensive one and that no other problem is more in need of definition and action (10). A number of legislative programs have been aimed at meeting the problem of health manpower shortages through extensive training projects, including the Health Professions Educational Assistance Act of 1963, the Nurse Training Act of 1964, the Comprehensive Health Planning and Public Health Services Amendments of 1966, and the Allied Health Professions Personnel Act of 1966. Even though these programs have been undertaken to alleviate the health manpower problem, the shortages are expected to be increased by the increased demands associated with the implementation of Medicare.

McNulty (11) may have identified the basis of the health manpower problem when he stated that the productivity gains of hospitals have not matched the productivity gains in other areas or industries. The results of this study should promote sound hospital design decisions, and hence, better personnel utilization and productivity.

Objective

The objective of this study is to evaluate a number of inpatient nursing unit designs, varying the shape, the number of patient rooms, the number of patients per room, and the arrangement of all functional points in order to ascertain the relative efficiencies of alternative designs.

Scope and Limitations

There exists a large number of inpatient nursing unit designs and design variations and it is neither practical nor possible to evaluate each one. Therefore, it was necessary to limit the designs to be evaluated in this study to a number of inpatient nursing units which formed a representative collection.

This study is limited to the evaluation of selected versions of medical units, surgical units, and combination units which contain both medical and surgical patients of short-term, general, voluntary hospitals. The study is restricted to these types of units because the method developed by Freeman provides a model for predicting travel frequencies on only these three types.

Since the purpose of this study is to illustrate to the hospital planner how one might evaluate inpatient nursing unit designs on a quantitative basis, no attempt was made to validate Freeman's model or to change any of the model parameters.

Since existing nursing unit designs were selected for evaluation, this study is not intended to be a structured or controlled experiment. The size of rooms, location of elevators, and other architectural considerations were not controlled. Therefore, the effect of these considerations upon the relative efficiency of the selected units was not measured.

It should also be noted that since the evaluation procedure is based on monetary costs, the effects of non-monetary decision determinants were not considered. Hence, results are intended to be used only as a supplement to good judgment on the part of the hospital planner.

CHAPTER II

LITERATURE SURVEY

The work of Frederick W. Taylor during the early part of this century created interest in the effects of facilities location upon traffic patterns and costs in hospitals. Professor W. Gilman Thompson of Cornell University published an article (12) in 1913, which is probably one of the earliest published studies dealing with this problem. In this article he acknowledged the work of Taylor in the manufacturing industries and suggested that similar methods be applied to work in the hospital. As an illustration of how these methods might be applied to the work within the hospital he described the results of several of his studies dealing with traffic patterns and walking distances. In these studies he recorded the distance traveled by nurses performing their duties and attempted to relate these distances to the functional arrangement of facilities on the nursing unit.

Between the time of Thompson's studies and the end of World War II there was a definite lack of interest in planning hospital facilities to accommodate specific traffic patterns. This is evidenced by the general lack of relevant literature during this period.

More emphasis was placed on the need for improvement in the design of hospitals and the need for planning hospital facilities to accommodate specific traffic patterns following the establishment of the National Hospital Program of the United States Public Health Service in 1946. As early as 1946, the results of research sponsored by the Division of Hospital Facilities of the USPHS were being published in the hospital literature. The results of these research projects developed guidelines and suggestions for the planning of floor space requirements and facilities for the various hospital departments and suggested layouts were presented. These guidelines and suggestions were based on experience and judgment instead of justifiable quantitative criteria.

The Hospital Survey and Construction Act of 1946 was also instrumental in affecting the direction of hospital design. In order to qualify for federal support under the provisions of this act, it was necessary for construction projects to satisfy certain minimal design standards pertaining to floor space per bed, per room, and per department; number of beds per room; nursing unit size; and various other design decisions (13).

In 1955 the Nuffield Provincial Hospitals Trust (14) conducted one of the earliest studies of a quantitative nature examining the effects of designs and facilities upon the patterns of work. The actual point-to-point sequence of nurses' movements on the nursing units of three hospitals were studied from the point of view of the use of space and provision of ancillary rooms and services. For purposes of analyzing the trips, the nursing units were considered to consist of two elements: the beds, and the ancillary rooms and services, the three most important rooms being the kitchen, the dirty-utility room, and the clean-utility room. The observed trips were categorized as either trips into the bed area, trips between the bed area and an ancillary room, and trips between two ancillary rooms. The results of these studies indicated that the distribution of frequencies for the three categories of trips were similar despite the differences in the layouts of the nursing units. This finding has implications for the study being reported here in terms of the degree to which a traffic frequency model developed in one institution may be applied to another institution with similar services but different layouts, which is exactly what the present study entails.

Freeman (15) cited a study reported in 1960 which attempted to determine if increases in the amount of quality of nursing care resulted in corresponding improvements in patient welfare. As Freeman states:

> The major finding was that, when the size of a unit's nursing staff was increased without increasing the patient load, the members of the staff did not redistribute their time in such a way that more time would be allocated to those nursing activities which were thought to be of most benefit to the patients. Even though this study did not consider the effects of alternative physical designs, it suggested that potential benefits of design changes which tend to reduce nursing labor may not be fully realized, since nurses do not automatically adjust their activity patterns in the most beneficial manner. (16)

In 1960 Pelletier and Thompson reported the results of one of the earliest attempts to evaluate inpatient nursing units on a quantitative basis (17)(18). They identified sixteen separate areas on a typical nursing unit and observed the number of trips between them. Each pair of areas was referred to as a "link" with the number of possible links in a system of sixteen areas being 120. "It was found that more than 91 percent of the traffic on the unit could be accounted for by only 14 links involving seven of the 16 areas" (19). These links were considered the prime determinants of the functional efficiency of a particular inpatient nursing design. The "Yale Traffic Index" which was used to make comparative evaluations of inpatient nursing units with similar facilities but different layouts was calculated by multiplying the actual length of each link by the weight (relative trip frequencies) of each link and totaling the products.

This study is significant because it is one of the first attempts to develop a procedure to evaluate the functional efficiency of an inpatient nursing unit design on a quantitative basis. The usefulness of this procedure is limited by the failure to incorporate labor costs and construction costs in the evaluation procedure and because no attempt was made to relate trip frequencies to patient census, nursing unit size, and number of patients per room.

In 1963 and 1964 two publications of the American Hospital Association reported the preliminary results of a research project conducted by Souder. One of these studies (20) developed methods for estimating space requirements and costs for the construction of general hospitals and the other (21) was concerned with the development of criteria for hospital planning and design. The second study resulted in the development of a computerized method for evaluating alternative designs utilizing a digital computer equipped with an oscilloscope to scan background data and measure the effectiveness of designs against scales of performance values.

In an article (22) published in 1964, McLaughlin noted:

> Surprisingly few studies have been made on the efficiency of nursing unit design, and even the studies in existence have not been carried forward and applied to the analysis of nursing unit plans which are similar in the number and type of bedrooms, support facilities, and other features, but different in shape.

McLaughlin then proceeded to evaluate eight alternative nursing unit designs using an adaptation of the "Yale Traffic Index." He did carry the analysis one step further than the Yale researchers by calculating a construction cost factor per bed. However, he did not attempt to convert the Yale Index to a cost index nor did he try to combine this index with the construction cost.

The interest in quantitative criteria for the design of hospital facilities is demonstrated by a case study presented by Dudek (23) in a recently published book concerning industrial engineering in the hospital environment. In this study a quantitative approach to the proximity chart is used to determine the relative location of facilities in a hospital. This study demonstrates the potential of quantitative techniques for the design of hospital facilities and the need for the cooperation of the engineer and architect.

In summary, it has been shown that there exists a need for quantitative criteria for the evaluation of hospital designs. In addition, there exists a need for a procedure for evaluating alternative designs on the basis of these quantitative criteria. The present study will illustrate the use of just such an evaluation procedure in hopes of expanding the limits of present knowledge concerning the evaluation of inpatient nursing unit designs.

CHAPTER III

METHOD OF PROCEDURE

The method of procedure used in conducting this study consisted of the following steps:

1. Collect a large number of inpatient nursing unit designs.

2. Select a representative collection of inpatient nursing unit designs to be evaluated.

3. Categorize the inpatient nursing unit designs in the representative collection.

4. Apply the evaluation procedure to the selected inpatient nursing unit designs.

The collection of a large number of inpatient nursing unit designs, from which a representative group would be selected, was obtained from numerous sources. Among these sources were hospital and architectural literature, textbooks, Atlanta, Georgia area hospitals, and United States Public Health Service publications.

A representative group of inpatient nursing unit designs was selected from the above collection. This selection process was based on the shape of the nursing unit, the number of patient rooms, the number of patients per room, and the arrangement of functional points on the nursing unit. During this selection process emphasis was placed on nursing unit designs of recent years.

It was decided that a representative group of inpatient nursing unit designs had been obtained when it was no longer possible to find a design (from those available) which was neither included in the group nor was a variation of a design already included.

The fourteen inpatient nursing unit designs selected as a representative group were categorized as follows:

Single Corridor Nursing Unit -- A nursing unit with simple circulation (only one path from A to B) which has all its functional points located along a single straight corridor.

Double Corridor Nursing Unit -- A nursing unit with compound circulation (alternate paths from A to B) which has all its functional points located along a corridor which forms a closed loop. This closed loop is equivalent to two parallel corridors which are joined at the ends and possibly at some point or points between the ends.

Circular Nursing Unit -- A nursing unit with compound circulation which has all its functional points located along a corridor which forms a closed loop in the shape of a circle.

Angular Nursing Unit -- A nursing unit which did not qualify for one of the above categories was placed in this category. There were several units which were placed in this category in the study reported here; namely, a T-shaped unit, a cross-shaped unit, and a triangular-shaped unit.

The evaluation procedure was used to evaluate the inpatient nursing unit designs in the representative group after they had been categorized. A description of the methods used in applying the evaluation procedure will be postponed until the next chapter since a discussion of the procedure will be presented along with the results.

CHAPTER IV

EVALUATION PROCEDURE

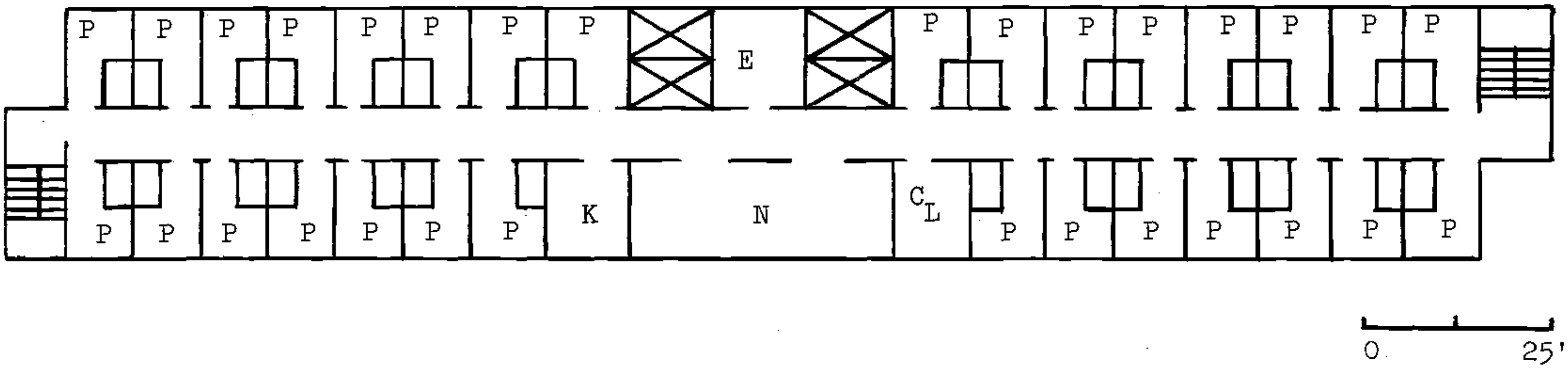
In order to make comparisons of inpatient nursing unit designs with similar services but different layouts on the basis of results of the evaluation procedure presented in this chapter, two basic assumptions must be made:

1. Nursing activities are uniformly performed throughout the United States.

2. A traffic frequency model developed in one institution may be applied to other institutions with similar services but different layouts.

Previous studies cited in the literature survey of this study indicate that both of the above are reasonable assumptions.

It was also necessary to make some assumption about the distribution of patient types in order to use the models developed by Freeman (24) in estimating the travel frequencies for the fourteen nursing units presented in Figures 1 through 14. (Table 1 is a listing of these fourteen units and Table 2 is a legend for Figures 1 through 14.) So that comparisons could be made on the same basis and to keep the calculations as simple as possible, it was assumed that all of the units contain medical and surgical patients in the same proportions and that a patient on any of the unit is equally likely to be in any of the six patient classifications used in the original model development. (These patient classifications were: medical total care, medical partial care, medical self care, surgical total



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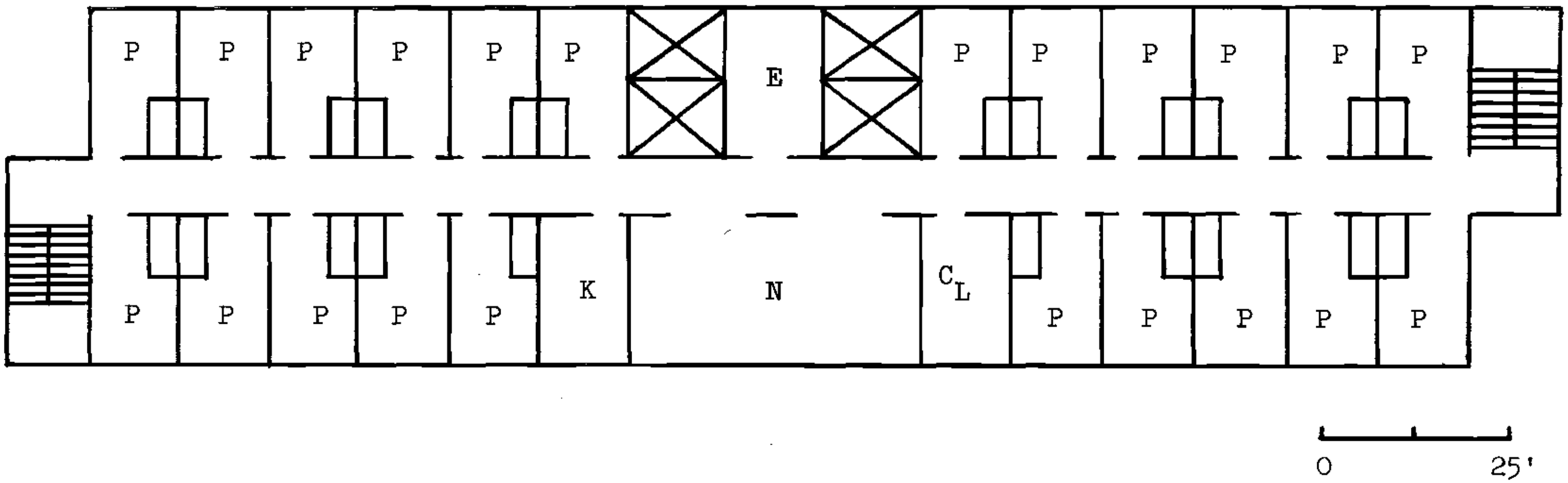

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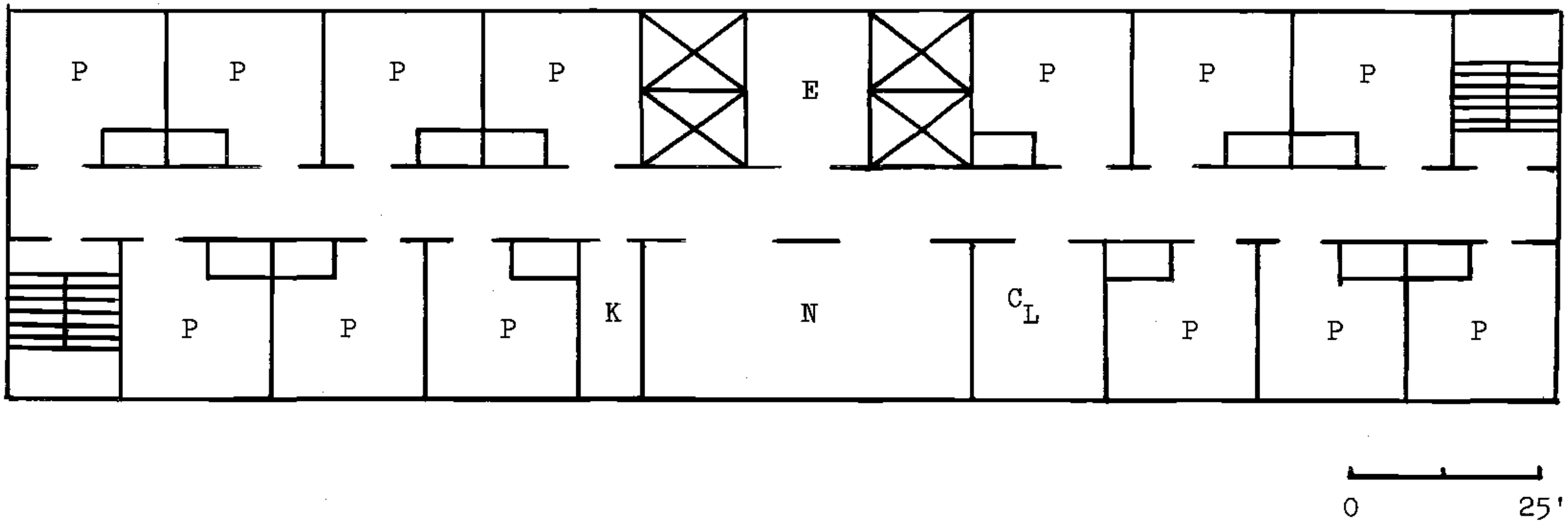

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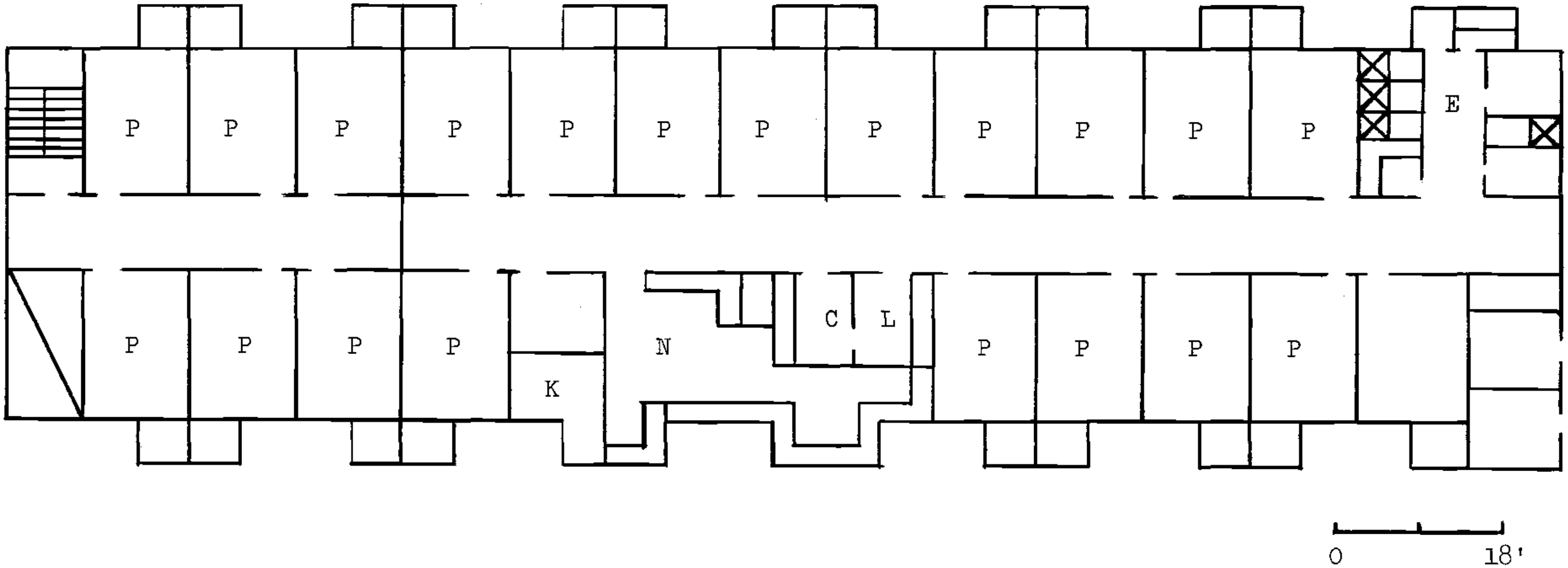

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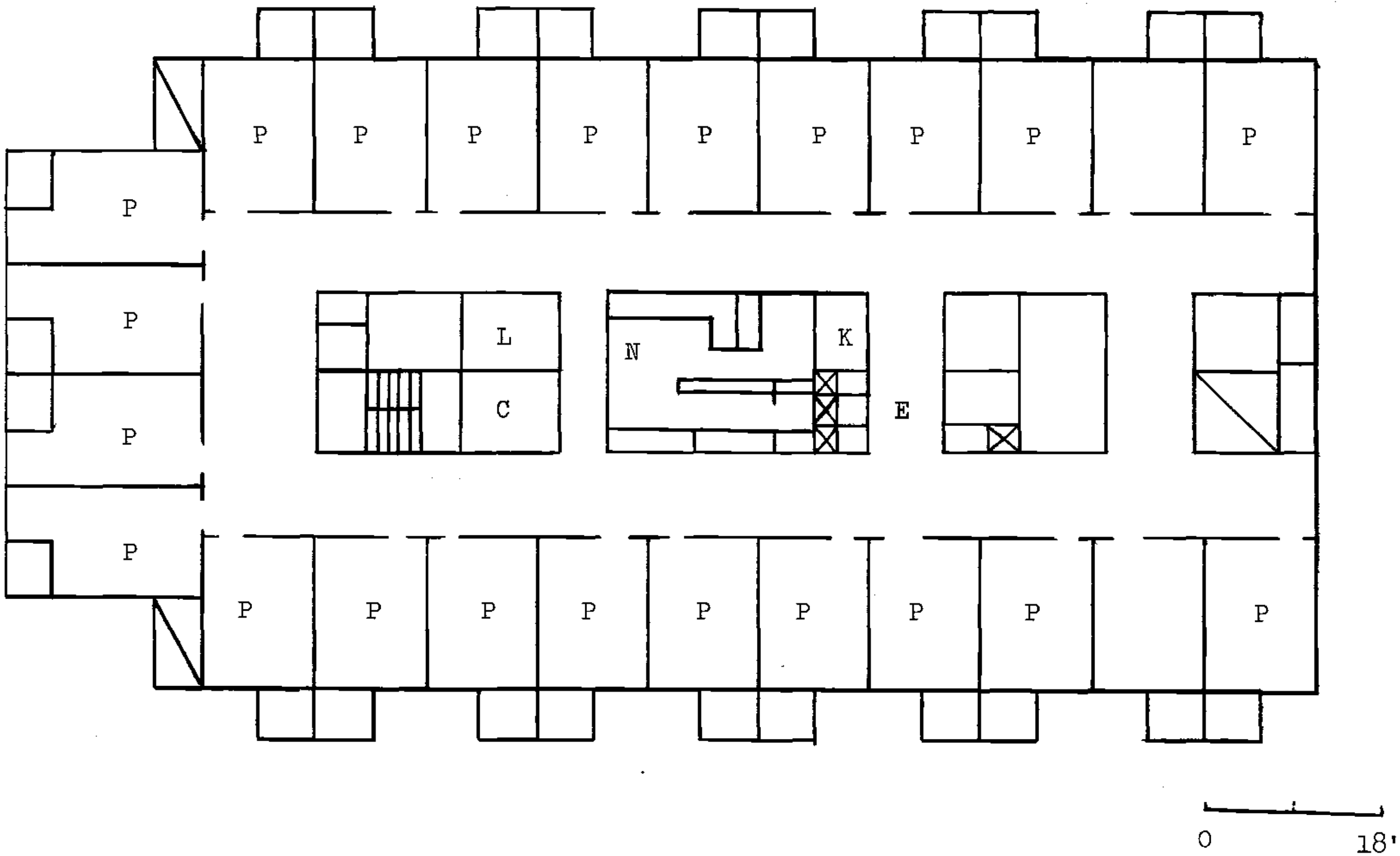

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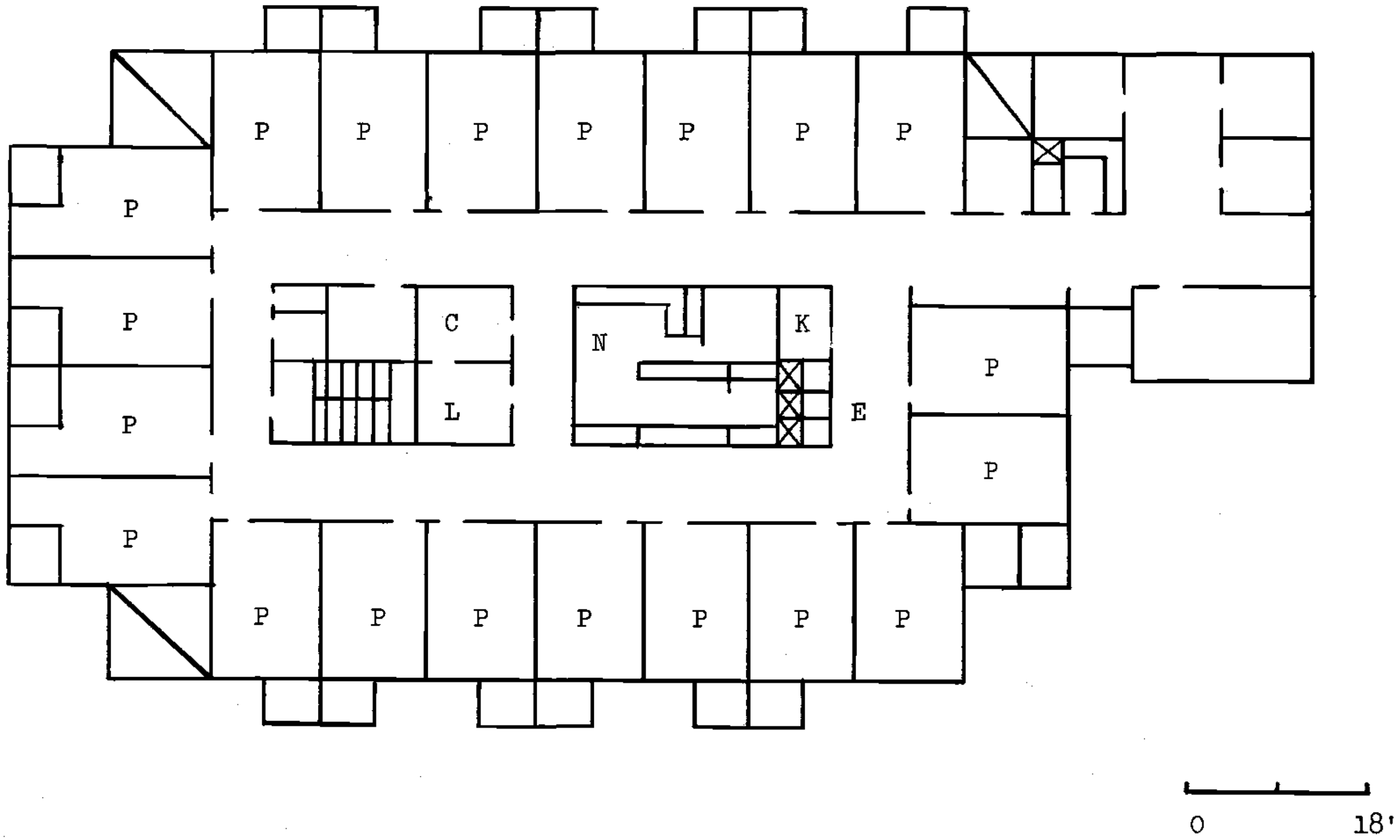

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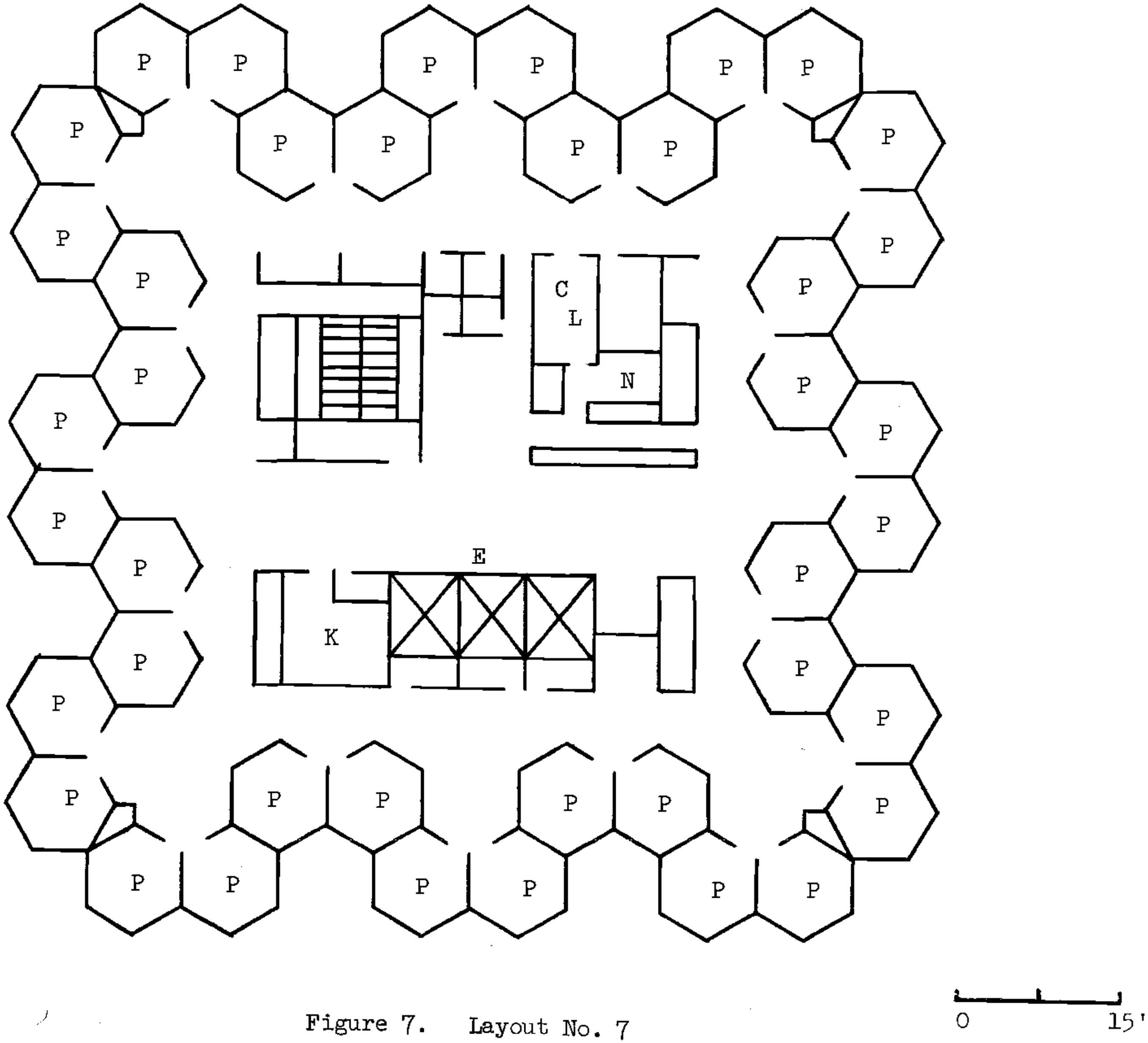

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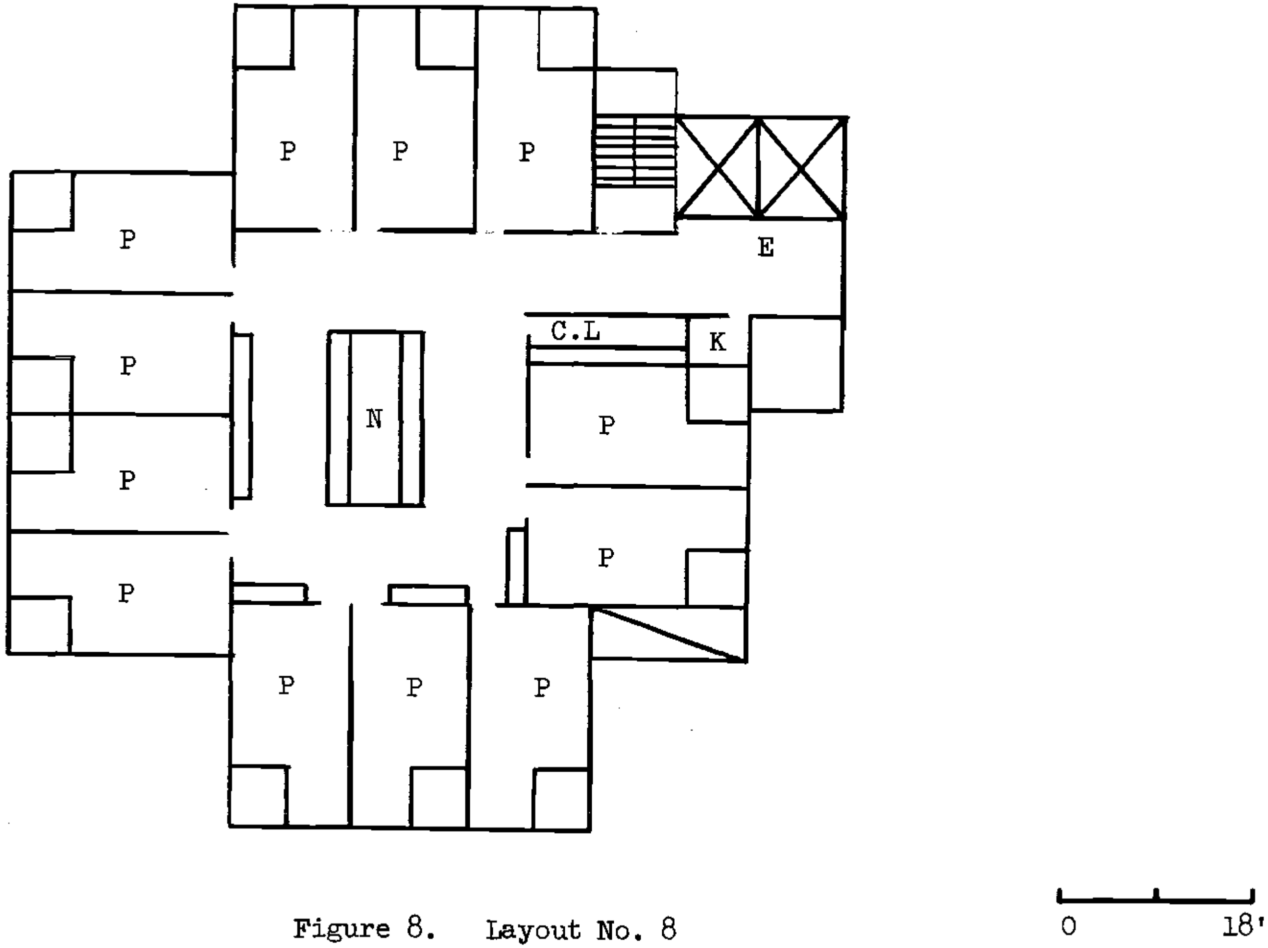

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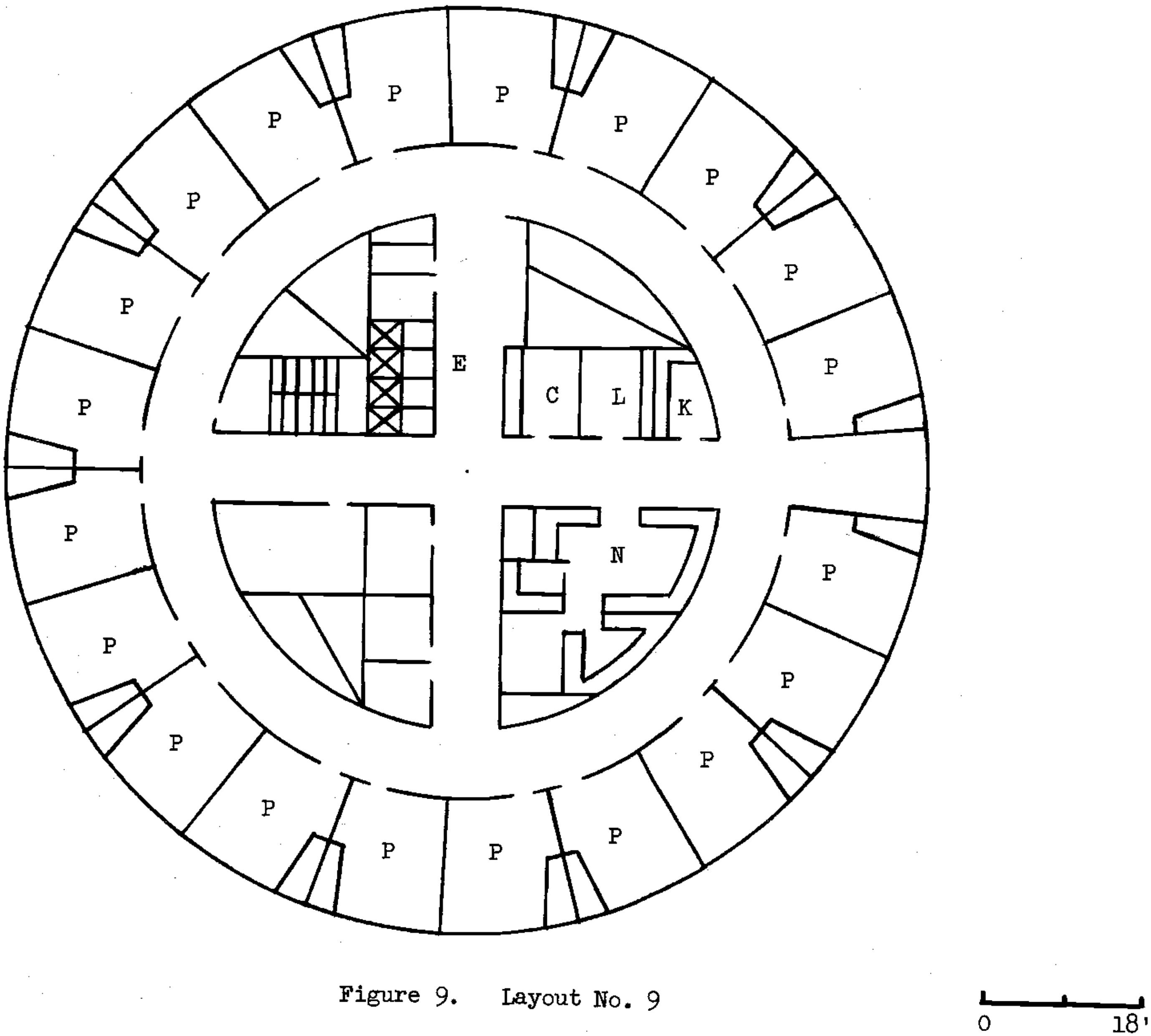

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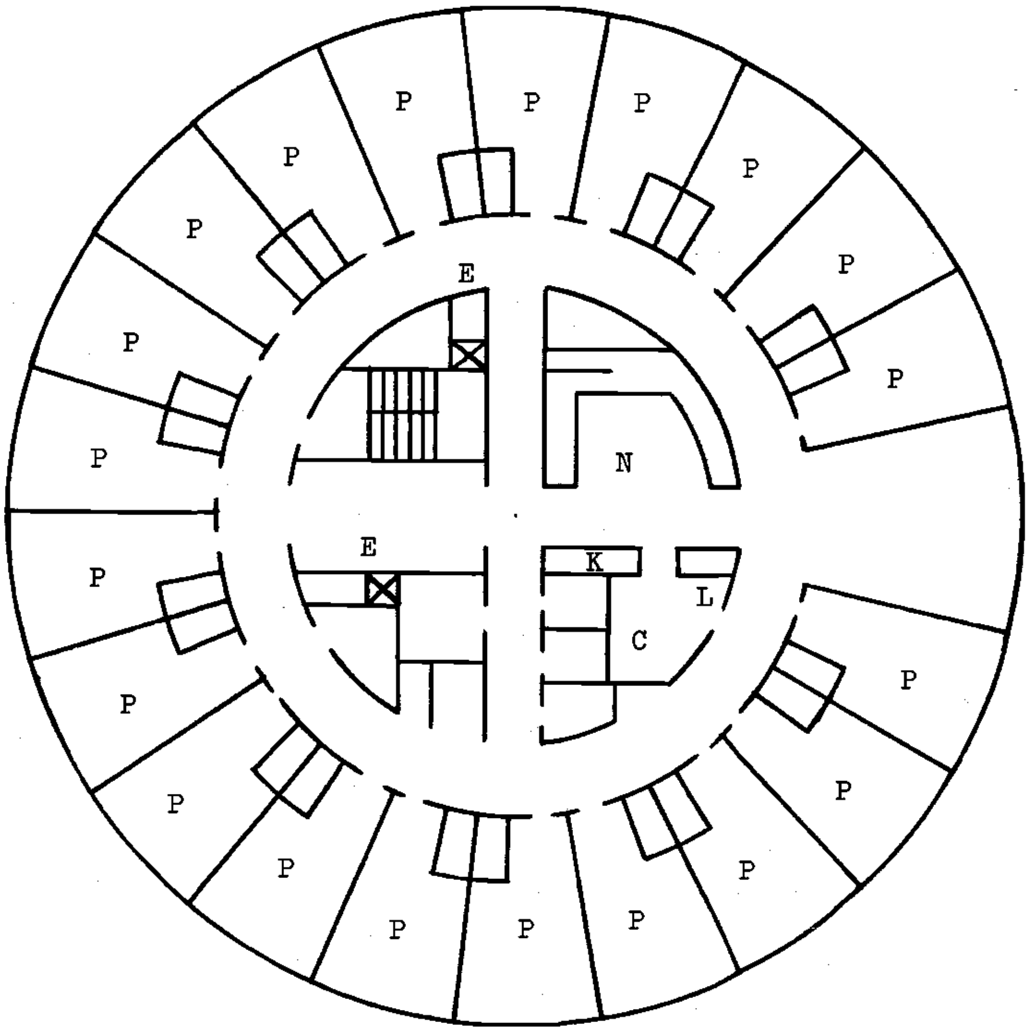

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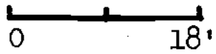

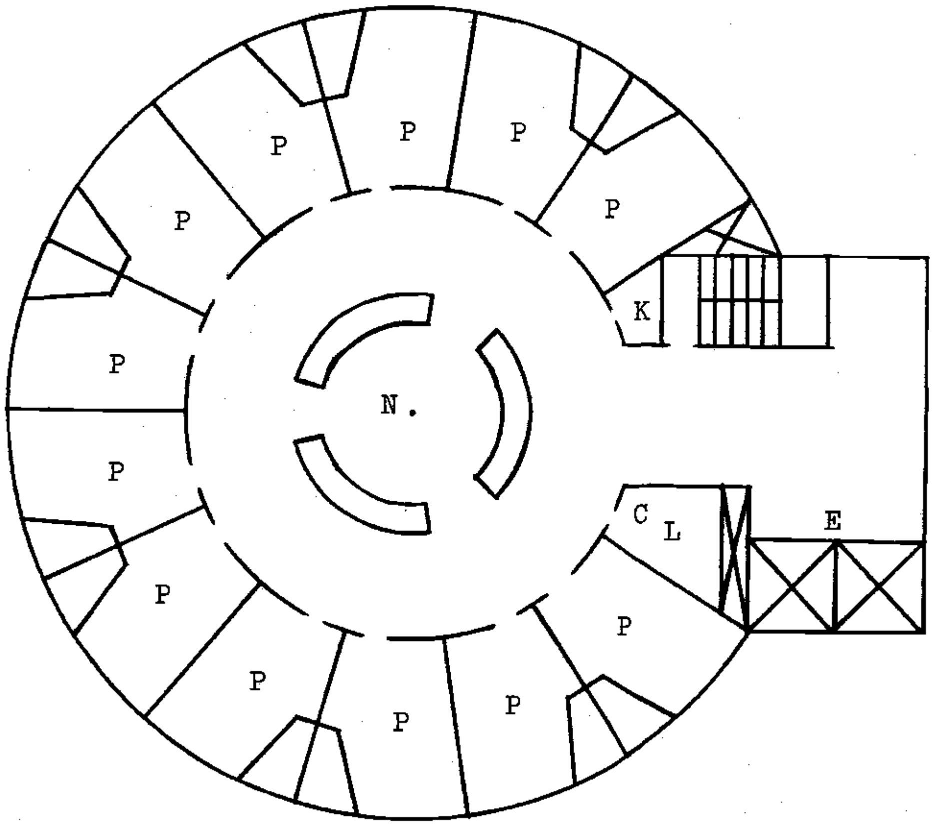

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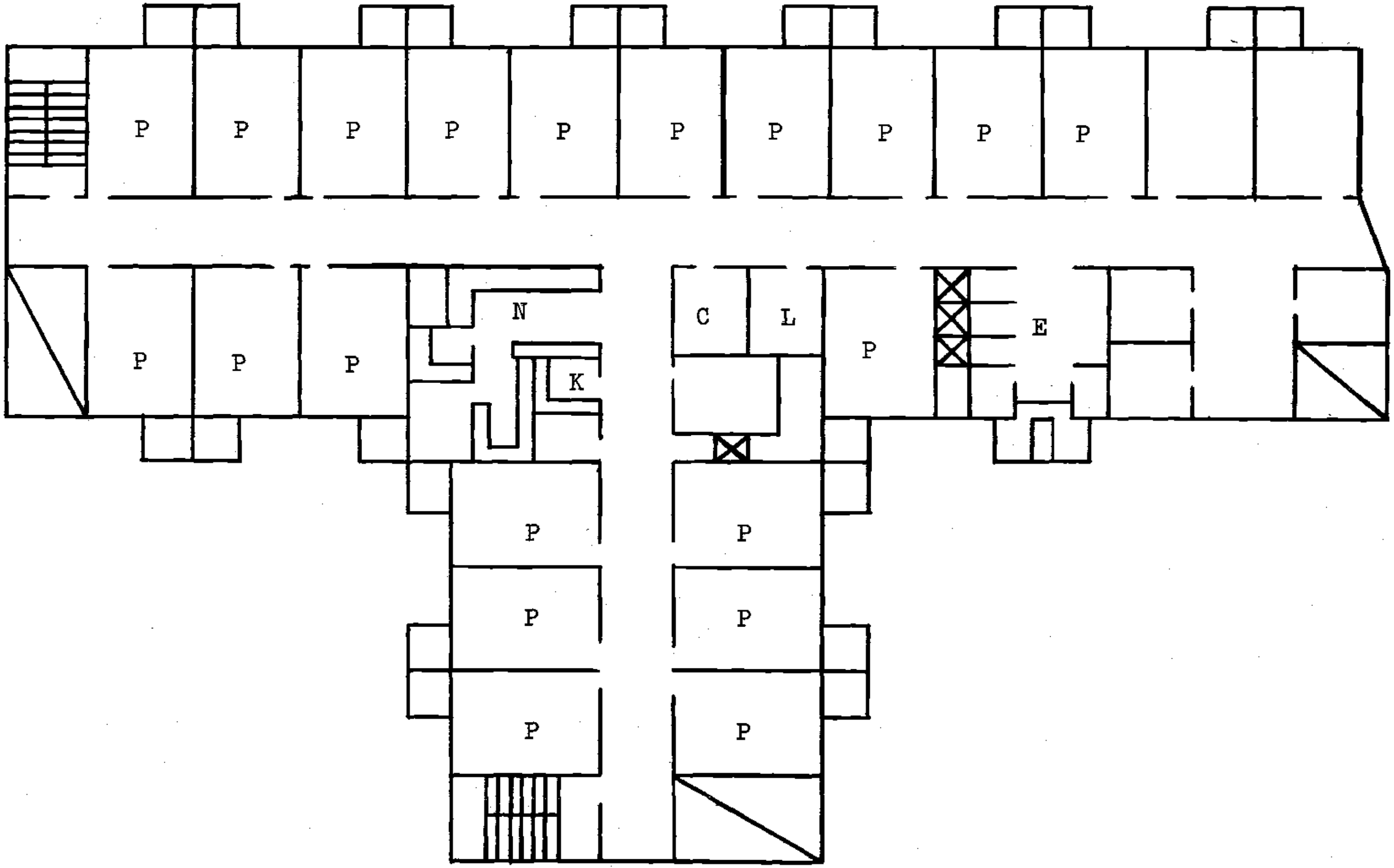

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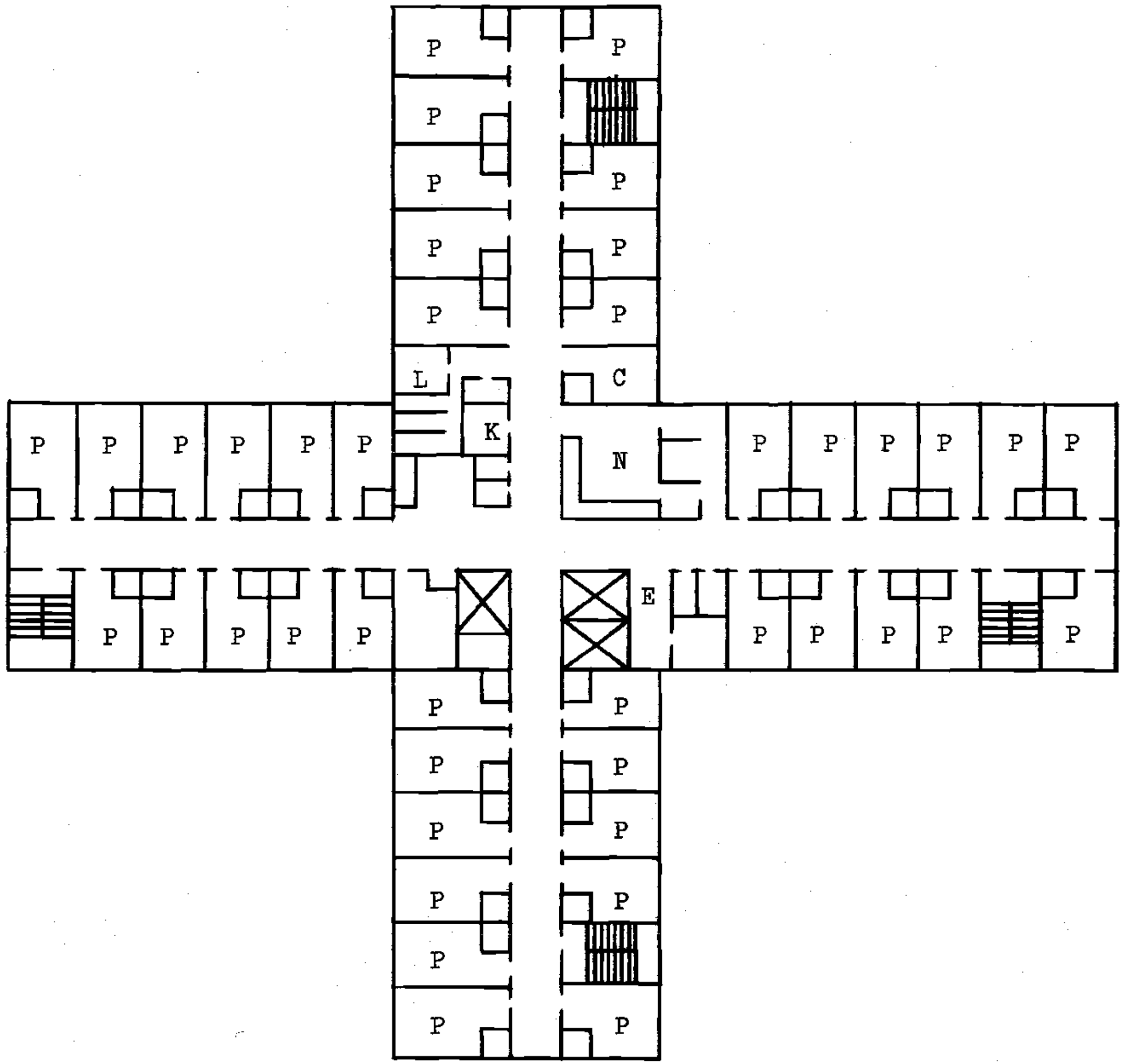

Figure 13. Layout No. 13

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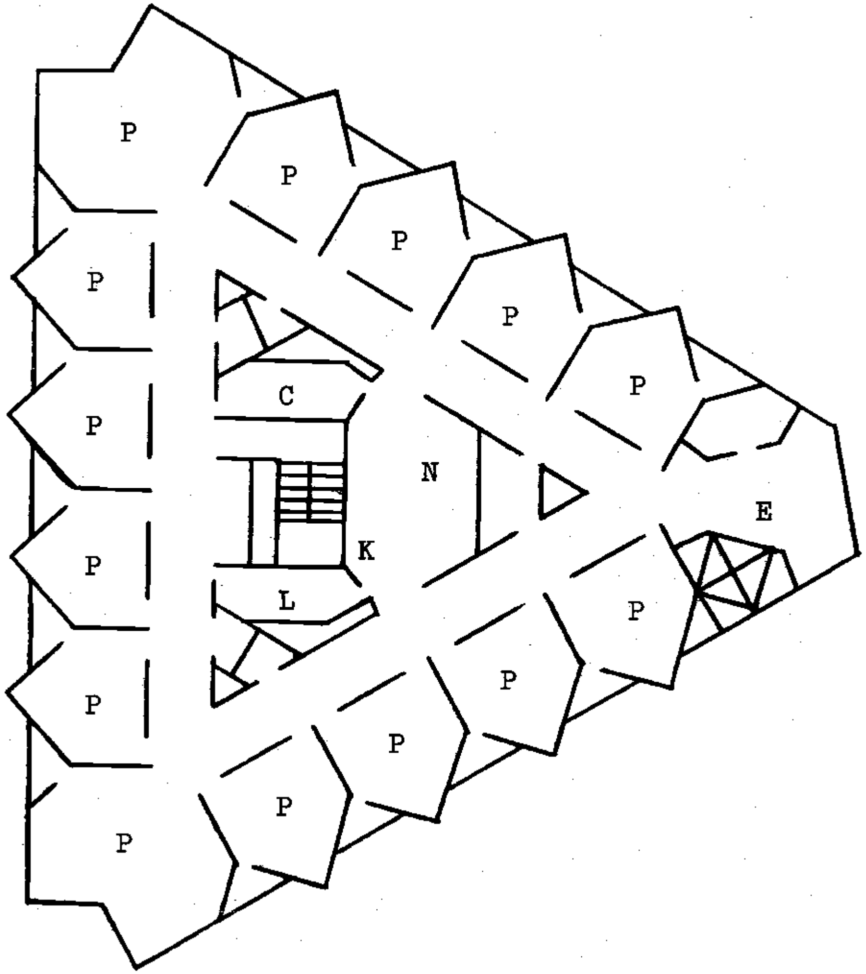

Figure 14. Layout No. 14

Table 1. Listing of Study Nursing Units

Nursing Unit	Category	Number of Beds
1	Single Corridor	30
2	Single Corridor	44
3*	Single Corridor	52
4	Single Corridor	40
5	Double Corridor	44
6	Double Corridor	40
7*	Double Corridor	40
8	Double Corridor	24
9	Circular	40
10	Circular	40
11	Circular	24
12	Angular, T-shaped	40
13*	Angular, Crossed-shaped	63
14	Angular, Triangular	32

* These atypical units were included because they were available in the literature and it was of interest to see how they compared with the other units.

Table 2. Legend for Study Nursing Units

Nurses' Station (N) -- Area which includes the chart room and the ward clerk's work area as well as the nurse call system.

Clean Supplies (C) -- Area or room which contains supplies such as toilet tissue, prep kits, etc.

Laundry Chute (L) -- Means by which dirty linen items are returned to the laundry to be cleaned.

Kitchen (K) -- Area in which ice for drinking water and certain special-order foods are kept.

Elevator (E) - Means by which personnel leave or enter the nursing unit.

Patient Rooms (P) - Rooms in which the patients are housed, listed by number.

care, surgical partial care, and surgical self care.)

With these assumptions it was possible to calculate the expected travel frequencies between functional points of a nursing unit by using the expressions in Table 3 and the constants of proportionality in Table 4, as developed by Freeman.

The constants of proportionality in Table 4 are needed for predicting the number of trips between pairs of patient rooms. It was found in the original model development that as the distance between two rooms containing given patient populations increased, the number of trips between these rooms decreased. It was also found that if the distance between two rooms is greater than twelve the frequency of trips between these two rooms goes to zero. The measure of distance used consisted of ranking the patient rooms with respect to distance down the corridor from the nurses' station in either direction and taking the absolute value of the difference between the ranks for any pair of patient rooms as the measure of distance between them.

Travel Frequencies

In order to understand the expressions in Table 3 the reader should be familiar with the following abbreviations and definitions of the functional points of the nursing unit as used in this study:

Nurses' Station (N) -- Area which includes the chart room and the ward clerk's work area as well as the nurse call system.

Clean Supplies (C) -- Area or room which contains supplies such as toilet tissue, prep kits, etc.

Laundry Chute (L) -- Means by which dirty linen items are returned

Table 3. Expected Travel Frequencies for Study Comparisons

Trip	Expected Travel Frequency
$P_i \cdot N + \Sigma_j P'_j$	$43.77\ \alpha_i n_i$
$P_i \cdot P_j$	$\beta_{i-j}[(P_i \cdot N + \Sigma P'_i) + (P_j \cdot N + \Sigma P'_j)]$
$N \cdot P_i$	$(P_i \cdot N + \Sigma P'_i) - \Sigma_j P_i \cdot P_j$
$P_i \cdot C$	$2.09\ n_i$
$P_i \cdot L$	$1.25\ n_i$
$P_i \cdot K$	$4.91\ n_i$
$P_i \cdot E$	$0.61\ n_i$
$N \cdot C$	$28.81 + 0.088\ \Sigma_i n_i$
$N \cdot L$	$0.400\ \Sigma_i n_i$
$N \cdot K$	$2.190\ \Sigma_i n_i$
$N \cdot E$	$16.87 + 0.591\ \Sigma_i n_i$

$P_i P_j$ refers to travel between patient rooms i and j.

α_i is equal to 1.000 if the total number of patients in room i is one, 0.889 if there are two patients, 0.849 if there are three patients, and 0.838 if there are four patients.

n_i refers to the total number of patients in room i.

β_{i-j} refers to the constants of proportionality in Table 2.

Table 4. Constants of Proportionality (β_{i-j}) for Trips Between Rooms

Distance Between Rooms	Constant of Proportionality
1	0.063
2	0.043
3	0.025
4	0.018
5	0.013
6	0.010
7	0.009
8	0.007
9	0.006
10	0.005
11	0.003
12	0.002
13 or greater	0.000

to the laundry to be cleaned.

Kitchen (K) -- Area in which ice for drinking water and certain special-order foods are kept.

Elevator (E) -- Means by which personnel leave or enter the nursing unit.

Patient Rooms (P) -- Rooms in which the patients are housed, listed by number.

The first step in evaluating the nursing unit designs was to calculate the expected travel frequencies between the functional points on each nursing unit by using the expressions in Table 3 and the constants of proportionality in Table 4. The only exception to the use of the expressions in Table 3 was that if the shortest route between two patient rooms passed by the nursing station then there was considered to be no travel between this pair of rooms. This provided a consistent method of assigning travel frequencies and did not result in any error in the total distance travelled since a trip of this nature still showed up as two separate trips between the nursing station and each patient room of such a pair.

The matrix of travel frequencies for the nursing unit of Figure 3 is shown in Table 5. The values of this matrix follow directly from the information presented in Tables 3 and 4, except for the 7 by 6 sub-matrix consisting of all zeros which illustrates the exception noted above.

The elements of the matrix in Table 5 are based on full occupancy of the nursing unit and must be adjusted for the ordinary situation in which occupancy is less than 100 percent. This was done by using the national average occupancy rate for all accredited, short-term, general, voluntary, non-profit hospitals which is 79.5 percent (25). If the elements

Table 5. Travel Frequency Matrix for Nursing Unit of Figure 3

C	L	K	E	1	2	3	4	5	6	7	9	10	11	12	13	14	
33.39	20.80	113.88	47.60	96.23	80.69	71.88	69.81	71.88	80.69	96.23	99.18	84.50	77.16	77.16	84.50	99.18	N
	0	0	0	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	C
		0	0	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	L
			0	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65	19.65	K
				2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	E
				18.49	12.62	7.34	5.28	3.82	2.94	0	0	0	0	0	0	0	1
					18.49	12.62	7.34	5.28	3.82	0	0	0	0	0	0	0	2
						18.49	12.62	7.34	5.28	0	0	0	0	0	0	0	3
							18.49	12.62	7.34	0	0	0	0	0	0	0	4
								18.49	12.62	0	0	0	0	0	0	0	5
									18.49	0	0	0	0	0	0	0	6
										0	0	0	0	0	0	0	7
												18.49	12.62	7.34	5.28	3.82	9
													18.49	12.62	7.34	5.28	10
														18.49	12.62	7.34	11
															18.49	12.62	12
																18.49	13

of the travel frequency matrix are f_{ij}, then the elements of the adjusted frequency matrix are equal to 0.795 f_{ij}.

Direct Labor Costs for Travel

The first requirement in using these adjusted frequencies to calculate the traffic costs for a particular nursing unit is a matrix of travel distances for each pair of functional points. Therefore, the second step in evaluating the nursing units was to construct travel distance matrices for each of the units using measurements taken directly from the floor-plan drawings. Table 6 is the travel distance matrix for the nursing unit of Figure 3.

The elements of these travel distance matrices were converted to standard times per trip occurrence by multiplying by a constant which represents the standard time for walking a unit distance. By using four feet per second as normal walking speed and allowing 10 percent of normal time as the personal and fatigue allowance, this constant becomes 7.64×10^{-5}. If the element of the travel distance matrix is d_{ij} then the element of the labor-hours per occurrence matrix is $7.64\ d_{ij} \times 10^{-5}$.

Labor times were converted to labor cost per occurrence by multiplying by the appropriate hourly wage rate from Table 7. These wage rates are adjusted for the types of nursing personnel contributing to the different categories of trips as well as for non-productive work and fringe benefits. If w_{ij} represents the hourly adjusted wage rate for a trip between points i and j, then the elements of a labor-cost per occurrence matrix can be computed with its elements equal to $7.64\ d_{ij}\ w_{ij} \times 10^{-5}$.

It is now possible to compute a travel cost matrix whose elements

Table 6. Travel Distance Matrix for Nursing Unit of Figure 3

C	L	K	E	1	2	3	4	5	6	7	9	10	11	12	13	14	
27	27	27	22	96	84	71	60	54	44	30	36	48	48	58	74	82	N
	0	66	43	132	120	107	96	90	80	66	16	28	28	38	52	62	C
		66	43	132	120	107	96	90	80	66	16	28	28	38	52	62	L
			44	75	63	50	39	33	23	10	70	82	82	92	106	116	K
				110	98	85	74	68	58	44	52	64	64	74	88	98	E
					20	33	44	50	60	74	138	150	150	160	174	184	1
						20	31	37	47	61	125	137	137	147	161	171	2
							20	26	36	50	114	126	126	136	150	160	3
								14	24	38	102	114	114	124	138	148	4
									18	32	96	108	108	118	132	142	5
										23	85	99	99	109	123	133	6
											73	87	87	97	111	121	7
												20	20	30	44	54	9
													8	18	32	42	10
														18	32	42	11
															22	32	12
																18	13

Table 7. Wage Rates for Trip Categories

Trip	Weighted Wage Rate	Adjusted Wage Rate
N·P	$ 2.32	$ 2.95
P·P	2.19	2.78
P·C	1.87	2.38
P·L	1.81	2.30
P·K	1.97	2.50
P·E	1.76	2.24
N·C	1.99	2.53
N·L	1.96	2.49
N·K	2.32	2.95
N·E	2.01	2.55

are equal to 0.795 f_{ij} (7.64 d_{ij} w_{ij} x 10^{-5}), which reduces to 6.07 f_{ij} d_{ij} w_{ij} x 10^{-5}. The sum of all the elements of this travel cost matrix represents the traffic cost for a full 24-hour day of the nursing unit. A simple computer routine was written to perform these computations for the fourteen nursing units of this study. Table 8 shows the daily traffic costs for each of the units as well as the number of beds, average census and traffic costs per patient-day.

Construction Costs

The third step in evaluating the nursing units was to determine the construction costs of each. Souder's method (26) for estimating costs in general hospital construction was used for this purpose. In Souder's method the cost per square foot of a particular area is equal to an index for that area times the cost per square foot for the entire hospital.

For the inpatient nursing unit Souder gives two separate construction cost indices which are 1.13 for "bed services" and 0.70 for internal circulation. The term "bed services" refers here to all area other than that provided for internal circulation. With these indices it is possible to estimate the cost per square foot of the inpatient nursing unit in terms of the cost per square foot of the entire hospital. For the purpose of comparing the study nursing units the average cost figures for the Atlanta area ($24.94 per square foot) were chosen since this is consistent with the Atlanta area wage rates used previously. Tables 9 and 10 show the areas and the estimated construction costs for the fourteen nursing units of this study.

Table 8. Traffic Costs for Study Nursing Units

Nursing Unit	Total Daily Traffic Costs	Number of Beds	Average Census*	Traffic Costs Per Patient-Day
1	$ 10.78	30	23.85	$ 0.45
2	13.76	44	34.98	0.39
3	19.10	52	41.34	0.46
4	9.44	40	31.80	0.30
5	12.64	44	34.98	0.36
6	8.65	40	31.80	0.27
7	21.95	40	31.80	0.69
8	4.33	24	19.08	0.23
9	11.28	40	31.80	0.35
10	8.60	40	31.80	0.27
11	4.85	24	19.08	0.25
12	11.53	40	31.80	0.36
13	26.10	63	50.09	0.52
14	8.28	32	25.44	0.33

* Based on an occupancy rate of 79.5 percent.

Table 9. Floor Space for Study Nursing Units

Nursing Unit	Total Area	Number of Beds	Square Feet Per Bed
1	9,370	30	312
2	10,000	44	228
3	9,850	52	189
4	8,737	40	218
5	8,876	44	202
6	8,158	40	202
7	7,092	40	177
8	5,091	24	212
9	10,330	40	258
10	8,598	40	215
11	5,466	24	228
12	9,165	40	229
13	18,063	63	287
14	8,081	32	253

Table 10. Estimated Construction Costs for Study Nursing Units*

Nursing Unit	Square Feet, Bed Services	Square Feet, Internal Circulation	Construction Cost
1	6,952	2,418	$ 238,126
2	7,840	2,160	258,645
3	7,539	2,311	252,799
4	7,299	1,438	230,793
5	6,776	2,100	227,614
6	6,095	2,063	207,777
7	4,857	2,235	175,893
8	3,847	1,244	130,129
9	7,631	2,699	262,166
10	6,275	2,323	217,389
11	4,115	1,351	139,549
12	7,164	2,001	236,819
13	15,323	2,740	479,643
14	6,396	1,685	209,659

* Based on Atlanta, Georgia construction costs.

Combining Costs

In order to combine the cost of traffic and the cost of construction, it is necessary that both be expressed in the same units of measurement. It seems logical to convert the construction costs to a per patient-day basis since this is simple and easily understood. Another advantage of this conversion is that the traffic costs have already been expressed in this manner.

The initial construction costs for the study nursing units were converted to a yearly basis by using the engineering economy concept of capital recovery. A recovery period of thirty years and an interest rate of 5 percent were assumed for this purpose. The annual costs were converted to daily costs by dividing by 365 days per year. Construction costs per patient-day were calculated by dividing the daily construction costs by the average census of each unit. The construction cost per day and construction cost per patient-day for each of the study nursing units are both shown in Table 11.

Since traffic costs and construction costs are now on a per patient-day basis they may be combined by adding. This sum is shown for each of the nursing units of this study in Table 12. The annual cost for a 100-bed hospital and a 500-bed hospital are also shown in this table so that the reader might appreciate the full impact of these nursing unit costs upon the entire hospital.

Table 11. Construction Costs Per Patient-Day for Study Nursing Units

Nursing Unit	Construction Cost Per Day	Construction Cost Per Patient-Day
1	$ 42.44	$ 1.78
2	46.10	1.32
3	45.05	1.09
4	41.13	1.29
5	40.57	1.16
6	37.03	1.16
7	31.35	0.99
8	23.19	1.22
9	46.72	1.47
10	38.74	1.22
11	24.87	1.30
12	42.21	1.33
13	85.48	1.71
14	37.37	1.47

Table 12. Combined Costs for Study Nursing Units

Nursing Unit	Costs Per Patient-Day			Annual Traffic and Construction Costs	
	Traffic	Const.	Total	100-Bed Hospital	500-Bed Hospital
1	$ 0.45	$ 1.78	$ 2.23	$ 64,709	$ 323,545
2	0.39	1.32	1.71	49,620	248,100
3	0.46	1.09	1.55	44,977	224,886
4	0.30	1.29	1.59	46,138	230,689
5	0.36	1.16	1.52	44,107	220,533
6	0.27	1.16	1.43	41,495	207,475
7	0.69	0.99	1.68	48,749	243,747
8	0.23	1.22	1.45	42,075	210,377
9	0.35	1.47	1.82	52,811	264,059
10	0.27	1.22	1.49	43,236	216,180
11	0.25	1.30	1.55	44,977	224,886
12	0.36	1.33	1.69	49,040	245,198
13	0.52	1.71	2.23	64,709	323,545
14	0.33	1.47	1.80	52,232	261,158

CHAPTER V

DISCUSSION

From the results presented in Table 12 it can be seen that the difference in the efficiency of the fourteen nursing unit designs of this study is considerable. Table 13 is a ranking of these nursing unit designs on the basis of relative efficiency. Traffic and construction cost per patient-day vary from $1.43 for the most efficient design to $2.23 for the least efficient design.

This difference in costs per patient-day of $0.80 seems quite insignificant. However, there were more than 9,000 new beds provided under the Hill-Burton program in 1966 (27). This number of beds will accomodate more than 2.5 million patient-days per year at an occupancy rate of 79.5 percent. In this case, the saving of $0.80 per patient-day would result in the potential savings of more than two million dollars annually. From this it can be seen that a savings of $0.80 per patient-day would result in monetary returns of substantial sizes.

Examination of the ranking in Table 13 indicates that the double corridor design is the most efficient, followed in order by the circular design, single corridor design, and the angular design. The dispersion of the design categories in this ranking can be accounted for by the difference in the number of square feet per bed for the individual designs within each category. As the number of square feet per bed increases, the construction costs rise, resulting in a lower overall efficiency.

Table 13. Ranking of Study Nursing Units

Rank	Traffic and Construction Costs Per Patient-Day	Nursing Unit	Category
1	$ 1.43	6	Double Corridor
2	1.45	8	Double Corridor
3	1.49	10	Circular
4	1.52	5	Double Corridor
5	1.55	11	Circular
5	1.55	3	Single Corridor
7	1.59	4	Single Corridor
8	1.68	7	Double Corridor
9	1.69	12	Angular, T-shaped
10	1.71	2	Single Corridor
11	1.80	14	Angular, Triangular
12	1.82	9	Circular
13	2.23	1	Single Corridor
13	2.23	13	Angular, Cross-shaped

Two exceptions to the above explanation can be noted in the double corridor design category. The costs for the design of Figure 7 are higher than the other double corridor units even though it has the smallest number of square feet per bed due to its unique design. This unique design greatly increases the distance between many of the pairs of patient rooms, thereby greatly increasing traffic costs. The costs are also higher for this design because it consists of all private rooms which will be shown to increase traffic costs. For these reasons, the reduction in construction costs was unable to offset the much higher traffic costs.

The other exception is that the design of Figure 8 ranks ahead of the design of Figure 5 although the latter has less square feet per bed than the former. This exception is apparently due to the fact that the design of Figure 8 is only about half as large as the design of Figure 5. This difference in size results in shorter distances between the functional points on the smaller unit, thereby reducing the traffic costs. This reduction in costs was large enough to offset the higher construction costs due to the relatively small difference in the number of square feet per bed.

At this point it seems appropriate to discuss some of the advantages and disadvantages of the different design categories. The chief advantage of the double corridor design is that it is the most efficient. Other advantages are that patients are not as likely to see in one another's rooms, the nurses' station is centrally located and the unit is easily divided for different staffing patterns.

The advantages of the single corridor unit are simple circulation patterns, good control from the nurses' station, and less corridor than the double corridor design. The disadvantages are increased distances between functional points on the unit and the likelihood of patients being able to see into one another's rooms.

The advantages of the circular unit are a centrally located nurses' station and shorter distances between functional points on the unit. The disadvantages of this type of unit are higher costs of construction, complicated circulation patterns, limited size due to the required perimeter which forces a large core area upon the design, and lack of control from the nurses' station.

The main advantage of the angular unit is the central location of the nurses' station. In most cases the distances between functional points on the unit are less than those for a single corridor unit. The main disadvantage is that the angular unit is the least efficient design. Other disadvantages are complicated circulation patterns and poor control of the unit from the nurses' station.

It appears that nursing unit designs with compound circulation tend to be more efficient than those with simple circulation. This result is suggested by the fact that the double corridor and the circular designs, which both include compound circulation, were more efficient than the other two categories which had simple circulation. The ability to choose alternate paths between functional points on a nursing unit design with compound circulation results in shorter distances between these functional points. The shorter distances result in lower traffic costs, and hence increased efficiency.

The results also indicate that multi-patient rooms of a particular design category are generally more efficient than private rooms of the same design category. An examination of Table 13 and Figures 1 through 14 indicate that within a design category a unit with all private rooms has a lower efficiency than others within the same category but with multi-patient rooms. This result is to be expected since a look at the expressions in Table 3 indicates that the more patients per room the greater the efficiency in traffic costs. It should be noted that this advantage of multi-patient rooms diminishes at an increasing rate as the number of patients per room increases. It should also be pointed out that multi-patient rooms generally have fewer square feet per bed which reduces the construction costs, and hence increases efficiency.

Another apparent result of this study is that unit design is more important than unit size (number of beds per unit) in determining the efficiency of an inpatient nursing unit design. This result follows from the fact that many of the designs have the same unit size but differ considerably in respect to efficiency due to design considerations. For the same reason, many of the larger units are more efficient than the smaller units and vice versa.

Table 14 shows the breakdown of costs for the nursing units studied. It should be noted that the construction costs are generally much larger than the traffic costs. Due to the relative magnitude of construction costs even a moderate percentage error in construction costs for a particular unit could result in a change in the relative rank of this unit on the basis of efficiency. The accuracy of the construction cost estimates is unknown and the reader is cautioned to direct his attention to this.

It is reasonable to assume that it will cost more to build a circular unit than a single corridor unit of the same number of square feet due to construction difficulties associated with building a circular unit.

Table 14. Costs for Study Nursing Units*

Nursing Unit	Traffic Cost Per Patient-Day	Construction Cost Per Patient-Day	Traffic & Construction Costs Per Patient-Day
1	$ 0.45 (11)	$ 1.78 (14)	$ 2.23 (13)
2	0.39 (10)	1.32 (9)	1.71 (10)
3	0.46 (12)	1.09 (2)	1.55 (5)
4	0.30 (5)	1.29 (7)	1.59 (7)
5	0.36 (8)	1.16 (3)	1.52 (4)
6	0.27 (3)	1.16 (3)	1.43 (1)
7	0.69 (14)	0.99 (1)	1.68 (8)
8	0.23 (1)	1.22 (5)	1.45 (2)
9	0.35 (7)	1.47 (11)	1.82 (12)
10	0.27 (3)	1.22 (5)	1.49 (3)
11	0.25 (2)	1.30 (8)	1.55 (5)
12	0.36 (8)	1.33 (10)	1.69 (9)
13	0.52 (13)	1.71 (13)	2.23 (13)
14	0.33 (6)	1.47 (11)	1.80 (11)

* The numbers in parentheses indicate the relative rank of that particular element within the column.

However, at the present time there are no indices available which indicate how much more it would cost to build one type unit as opposed to another. Research in this area of construction costs indices would promote the use of the evaluation procedure used in this study by improving the accuracy of the procedure. Such research would also prove invaluable to architects and the construction industry.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The objective of this study was to evaluate a number of inpatient nursing unit designs, varying the shape, the number of patient rooms, the number of patients per room, and the arrangement of all functional points in order to ascertain the relative efficiencies of alternative designs. This objective was satisfied in Chapter IV.

From the results presented in Chapter IV it was possible to rank the fourteen study nursing units on the basis of relative efficiencies as was done in Table 13.

In addition to the ranking of the study nursing units, the following conclusions can be drawn from the results presented in this thesis:

1. Unit design is more important than unit size (number of beds per unit) in determining the efficiency of an inpatient nursing unit design.

2. The double corridor design is the most efficient inpatient nursing unit design followed in order by the circular design, single corridor design, and the angular design.

3. Nursing unit designs with compound circulation tend to be more efficient than those with simple circulation.

4. Multi-patient rooms of a particular design category are more efficient than private rooms of the same design category.

The results of this study show that it is possible to evaluate inpatient nursing unit designs on a quantitative basis in order to ascertain the relative efficiency of alternative designs. Since the evaluation procedure is based primarily on monetary costs, the results are intended to be used only as a supplement to good judgment on the part of the hospital planner.

Recommendations

Based on the experience gained while carrying out the present study, the following areas of future research are suggested:

1. Determine the accuracy of the evaluation procedure used by comparing actual traffic and construction costs of hospitals with predicted and estimated costs.

2. Use computer techniques such as: CRAFT, CORELAP, or ALDEP to generate and compare a number of "optimal" inpatient nursing unit designs. Evaluate these "optimal" designs and compare with the nursing units of this study.

3. Determine if the difference in labor and construction costs in different areas of the country will affect the ranking of the relative efficiency of the study nursing units.

4. Determine if there is a significant difference in cost for medical versus surgical patients on similar units and, if so, whether this difference is enough to justify separate designs for medical and surgical nursing units.

5. Determine cost indices for the construction of the various design categories in order to improve the accuracy of the estimated construction costs. A cost index in this context refers to an index which would

show how much more it would cost to build one type of unit as opposed to building another type unit with the same number of square feet.

6. Investigate the effect of availability of money for construction on the design of an inpatient nursing unit.

7. Determine factors in hospital construction whose costs vary with changes in the design of the nursing unit. Determine and examine significant relationships between these factors.

8. Investigate the effect of inflation on wages and their effect on traffic costs versus the constant construction costs which are "paid off" in future dollars.

9. Conduct a controlled experiment in which the size of rooms, location of elevators, and other architectural considerations are controlled and determine the effect of these considerations upon the relative efficiency of nursing units.

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