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SYSTEMS APPROACH TO HEALTH PLANNING

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INTRODUCTION

The term system has very many meanings. There are systems of numbers and of equations, systems of valuesand of thought, systems of law, solar systems, management systems, electronic systems, even the New York Central System. All of these terms have the common meaning of having "a group of interacting elements under the influence of related forces."[1]

The state of a health services system is defined by the value of the variables that describe its elements (e.g., prevalence of a particular disease, or available hospital beds, etc.) as well as by the transformation process in the system whereby inputs are translated into outputs.

The elements of the health services system are grouped in sub-systems the composition of which depends on the criterion for the grouping. If that criterion is type of care (e.g., primary care, hospital care, etc.) then the terms sub-systems is interchangeable with the term state of care. In this sense, states are functional levels of care within the health services system. The elements that are grouped at each state of care are called units, e.g., several hospitals(units) constitute the hospital care state.

INSERT FIGURE I

The input into each state is measured by the number of "entries," i.e., persons or conditions as determined by the actual "demand" for services, e.g., a patient who twice visits a consultant specialist because of otitis media constitutes an entry to the consultant care state with two visits for that entry into that state. If need is preferred to actual demand, the input in the model can be changed to a desired potential demand. Such a shift assumes that need, i.e., the submerged part of the iceberg, can be translated into demand.[2] The conceptual distinction between these two approaches has been discussed somewhere else.[3] The parameters that define this input will depend on the criterion chosen to define disease, disability, dissatisfaction, and discomfort.[4]

The output of the different states is measured by the number of discharges from each. Possible outcomes are dead/alive, diseased/healthy, disabled/fit, dissatisfied/satisfied, uncomfortable/comfortable.

The throughput represents the movement of patients through successive states of the system. Movements within the system can take place between two units belonging to the same state of care, i.e., a transfer, or to two different states, i.e., a referral.

Transfers and referrals document the movement or flow of people within the health services system and illustrate the dynamic relationships among its different states and units. The series of referrals and transfers experienced by each patient defines his utilization experience and reflects the utilization strategy employed.[5] Thus, the throughput of the whole system can be defined as the totality of utilization strategies for all patients.

INSERT FIGURE II

SYSTEMS APPROACH TO PLANNING

Planning of personal health services can be based upon analysis of the performance or the structure of the system. The difference between the two is that, while the latter deals with the internal relations among the system's parts, the former refers to the acquisition of inputs and their transformation into outputs.[6] In the performance methods the required resources are determined by the amount and type needed to achieve a defined output, measured in terms of performance such as reduction or control of death, disease, disability, discomfort, etc., whereas the methods based on the system structure the output is given in terms of number of services provided. Effectiveness is the relationship between input and output in the system performance method; efficiency is this relationship in the system structure method. ?

Unfortunately, little is known about the effectiveness of different health services systems. Most analytical studies of health services have been concerned with productivity, expressed in terms of efficiency, but not with effectiveness.

The paucity of effectiveness studies is due to present limitations in knowledge of methods to measure the different variables involved in the output as well as in the input of the system and their interrelationships. Except in a few instances, relationships between the system and its performance are not known; even less is known about methods of quantifying them. There is no evidence, for example, that by providing X units of prenatal care one will save Y children's lives.

The absence of objective measurement of the relationship between systems and performance explains the use of subjective measurements, such as the opinions of experts or the experiences of other areas or countries.[7,8] CENDES

Most productivity studies of health services in the system structure methods have been limited to considering utilization of units at different states of the system as measured by counting the number of services provided by each unit or state. Only a few studies have extended their analysis of utilization to include an analysis of the functional relationships among the units or states.[9,10] They have been concerned with both the number of entries into or departures from each unit or state and with the preceding and subsequent states.

Planning for personal health services frequently has been based on the first type of productivity studies. They have dealt separately with different states of care, i.e., planning for hospital services, nursing homes, etc., without considering the mutual dependency among the several states of care. The planning model described below has a holistic approach. It plans for the different parts or sub-systems of the total, taking into consideration their interdependency. This model is based upon the second type of productivity studies and requires information describing internal relationships among the states of the system and therefore requires data not only on the number of services provided at each state but also on the functional relationship among the states of the system defined by the referral and transfer movement within the whole system.

A MARKOVIAN PLANNING MODEL

This model is based upon the Markovian process,[11,12] in which the health services states are postulated and the probabilities of going from one state to another, called the transitional probabilities, determine the number of people in the various states throughout time.[13] The postulated health services states can be chosen to meet any desired criteria. The ones shown in Figure III have been chosen arbitrarily.

INSERT FIGURE III

The number of health services states can be extended depending on the complexity and comprehensiveness desired and the availabilities of usable information. Primary medical care, consultant medical care, hospital care, nursing home care and domiciliary care states contain people receiving these levels of care respectively. The state Population Not Under Care includes all persons not in any of the other states. It includes sick persons who are not under care in any of the other states as well as healthy persons. The population of the region chosen can be defined according to any desired demographic and epidemiological parameters. In the present application the assumption is made that every person in the population of a defined geographical region at any point in time is characterized as belong to one, and only one, of several mutually exclusive states of a health services system.

If n_i is the number of persons at a given moment t, in state i, and k is the number of states, the total population of the defined region at that moment equals N(t).

$$[1] \qquad N(t) = \sum_{i=1}^{k} n_i(t)$$

In other words $n_i(t)$ is the number of persons in state i at a given moment. It is denoted by the census in that state at moment t.

The fraction $\frac{n_i(t)}{N(t)}$ denotes the proportion of the population in state i at time t, and is expressed by $P_i(t)$.

$$[2] \qquad P_i(t) = \frac{n_i(t)}{N(t)}$$

Therefore, by definition

$$[3] \qquad \sum_{i=0}^{k} P_i(t) = 1$$

In the Markovian process the fractions of the population in different health services states at different time periods, $P_i(t)$, are determined by the transitional probabilities of going from one state to another during the chosen period. These transitional probabilities indicate the probability that a person who is in one state at the beginning of the defined period will go to another state during that period. If n_{ij} is the number of people who during a fundamental time period go from state i to state j, and n_i is the number of people in state i at the beginning of that period, then the transitional probability for that period of time equals P_{ij}.

$$[4] \qquad P_{ij} = \frac{n_{ij}}{n_i}$$

This transitional probability denotes the probability that a person in state i at the beginning of the time period chosen will go to state j during that period.

P_{ij} defines the movement of people within the system and reflects the functional relationships among its state; in other words, it translates the organizational structure of the system. P_{ij} determines the utilization patterns of the different states in the system in different time periods $P_i(t)$ and thus, the type and number of resources required.

It is worth noting in this context that the Markovian assumption implies that a patient's future utilization history depends only on his present position; that is, the transitional probability of going from state i to state j is taken to be the same for all people in state i regardless of how they happen to have arrived in state i. Hence, the number of people considered should be large enough so that the average is minimally influenced by extreme values. In formula [4] an increase of the denominator will increase the precision and reliability of P_{ij}.

P_{ij} is considered as known in this model. Its value is calculated as follows:

Let

q_{ij} be the probability of going from state i to state j during a time interval of one day,

q_{ii} be the probability of remaining in state i during a time interval of one day,

$a_{ij}(T_{ij})$ be the probabilities of going from state i to state j during the time interval T_{ij}, i.e., the empirical estimates which are the input to the Markovian models,

then

[5] $$q_{ij} = \frac{a_{ij}(T_{ij})}{T_{ij}} \quad \text{for } i \neq j$$

[6] $$q_{ii} = 1 - \sum_{j \neq i} q_{ij}$$

Let matrix Q be defined by

$$Q = \begin{pmatrix} q_{11} & q_{12} & \cdots & q_{1I} \\ q_{21} & q_{22} & \cdots & q_{2I} \\ \cdots & \cdots & \cdots & \cdots \\ q_{I1} & q_{I2} & \cdots & q_{II} \end{pmatrix} \qquad (T_{ij} = 1 \text{ day})$$

Matrix T is then given by,

[7] $$T = Q^{365}$$

where

$$T = \begin{pmatrix} P_{11} & P_{12} & \cdots\cdot & P_{1I} \\ P_{21} & P_{22} & \cdots\cdot & P_{2I} \\ \cdots & \cdots & \cdots\cdot & \cdots \\ P_{I1} & P_{I2} & \cdots\cdot & P_{II} \end{pmatrix}$$

and P_{ij} is the probability of going from state i at the beginning to state j at the end regardless of the intermediate states.

The transitional probabilities, P_{ij}, have been estimated from empirical sources such as published data on referrals, or data from which data on referrals could be estimated. It would be possible, however, for those populations were such data are available, to relate P_{ij} as the dependent variable in a multiple regression analysis, considering as determinant variables those variables which condition utilization from the standpoint of the persons, of the system, and of enabling factors.

CALCULATING RESOURCES REQUIREMENTS

The number of resources, manpower and facilities required at each health services state would depend on the fractions of population in the different health services states and the productivity of these resources defined by given parameters.

Knowing the health services state fractions $P_i(t)$, the manpower (MD = physicians) and facilities (BEDS) requirements are calculated from formula [8] and [9].

$$[8] \qquad R_{MD_i}(t) = \frac{\dfrac{P_i(t).N(t)}{L_i} \times \gamma_i \times 365}{\theta_i}$$

where,

$R_{MD_i}(t)$ is the required number of physicians for state i (as a function of time t),

$P_i(t)$ is the fraction in state i at time t,

$N(t)$ is the size of population base, at time t, and determined by the rate of population growth,

L_i is the average length of stay in health services state i and is equal to the fraction $q_{ii}/(1 - q_{ii})$, (q_{ii}, daily probability of remaining in state i), and

γ_i is the number of visits per entry at state i.

$\frac{P_i(t).N(t)}{L_i}$ is the number of entries to state i per day.

It may help to clarify this formula if $P_i(t).N(t)$ is considered to be prevalence. Prevalence is the, equal to number of entries, i.e., incidence, per day multiplied by the average length of stay.

Altogether the numerator $\frac{P_i(t).N(t)}{L_i} \times \gamma_i \times 365$ is the number of visits required for state i per year. θ_i, the denominator, is the average physician load factor or the number of visits at state i per physician per year.

Similarly, the requirements for beds is calculated with formula [9].

$$R_{BEDS_i}(t) = \frac{P_i(t).N(t)}{F_i} \qquad [9]$$

where,

F_i is the occupancy desired at state i.

APPLICATIONS OF THE MODEL:

PREDICTION

Prediction is the ordinary statistical problem of forecasting, which at the simplest level involves extrapolation of past experiences into the future. Mathematically, if $P_i(0)$ represents the fraction of the population in state i at the present time (t=0), $P_i(-t)$ is the fraction in state i, t years ago, and $P_i(t)$ is the fraction expected t years hence, then the prediction problem is to determine $P_i(t)$, when t = 0, 1, 2, ..., given some of the values for $P_i(-t)$, when t = 0, 1, 2, ... If only prediction is required then mere extrapolation is sufficient.

In the Markovian model if the transitional probabilities for P_{ij} are known, then the prediction problem is solved by knowing only $P_i(0)$.

If t equals one year (t=1), for instance, the fraction of the population in state i at the end of the year will be equal to the number of people staying in that state during the year plus the new entries from the other states.

For

$$[10] \qquad P_i(1) = P_{1i}P_1(0) + P_{2i}P_2(0) + \ldots\ldots + P_{Ii}P_I(0)$$

where i = 1, I, denoting the total number of health service states as I, i.e., the probability of being in state i at time 1 is equal to the probability of going from state 1 to state i during the time interval multiplied by the probability of being in the first state at time 0, plus the probability of going from state 2 to state i during the time interval multiplied by the probability of being in the second state at time 0, etc.

In matrix notation, expression (10) is given by

$$[11] \qquad \overrightarrow{P(1)} = \overrightarrow{P(0)}T$$

where

$$\overrightarrow{P(1)} = [P_1(1), P_2(1), \ldots\ldots, P_I(1)]$$

$$\overrightarrow{P(0)} = [P_1(0), P_2(0), \ldots\ldots, P_I(0)]$$

$$T = \begin{pmatrix} P_{11} & P_{12} & \cdots\cdots & P_{1I} \\ P_{21} & P_{22} & \cdots\cdots & P_{2I} \\ \cdots & \cdots & \cdots\cdots & \cdots \\ P_{I1} & P_{I2} & & P_{II} \end{pmatrix}$$

Similarly

$$[12] \qquad \overrightarrow{P(t)} = \overrightarrow{P(0)T}^t$$

where

$$\overrightarrow{P(t)} = [P_1(t), P_2(t), \ldots\ldots, P_I(t)]$$

Thus, given $P_i(0)$ and P_{ij}, one may calculate $P_i(t)$ using the Markovian assumption.

In summary then, prediction involves calculating the fractions of population $P_i(t)$ expected to be in the various health services states i at different future time periods t, and the resources $R_{MD_i}(t)$ and $R_{BEDS_i}(t)$ that will be required in the states i in those time periods. The inputs of the model in prediction are the known current fractions $P_i(0)$ in state i and the transitional probability matrix $\{P_{ij}\}$ reflecting the dynamics of the system. The outputs of the model are the estimated future fractions of the population at each state i, at different time periods t. When the productivity of current resources (given by γ_i, θ_i, L_i, and F_i) is known the estimated manpower and facility requirements in different time period can be calculated.

B. SIMULATION

Simulation implies studying changes in the health services system and the repercussions that these changes have upon present and future utilization and resources. The inputs of the model in simulation are the present fractions of population $P_i(0)$ and a new set of transitional probabilities P^0_{ij} reflecting simulated changes in the system. The multiplication of the vector $\overrightarrow{P^0(t-1)}$ by the new matrix $\{P^0_{ij}\}$ yields the outputs: the new patterns of utilization $\overrightarrow{P^0(t)}$ being determined by the changes. If the productivity of the resources is known, the $\{P^0_i(t)\}$ can be translated into a new set of resources, $R^0_{MD}(i)$ and $R^0_{BEDS}(i)$. The variables which define the productivity of the system can be the same as in prediction or can be different (γ^o_i, θ^o_i, F^o_i, and L^o_i), indicating a simulated change in its efficiency.

C. GOAL SEEKING

Goal seeking involves calculating the alternative referral pattern $\{P^1_{ij}\}$ which will minimize such an objective function as "cost" or "change in current resources" in such a manner as to reach in a given time period t, specified utilization patterns, $P_i(t)$, or require a desired amount of resources, $R_{MD_i}(t)$ or $R_{BEDS_i}(t)$

The inputs of the Markovian model in goal seeking are: the present fractions of population, $P_i(0)$, the desired future steady state fraction in state i, $P_i(t)$, (or the desired number of resources in that state i), and the chosen objective function (cost limitation, change limitation, etc.) that the chosen alternative $\{P^1_{ij}\}$ must meet. The problem is to choose the alternative defined by a transitional probability matrix, which will minimize that objective function. Actually there will be an infinite number of alternatives of dynamic change to reach the desired goal, but only one alternative will minimize the chosen objective function. For instance, if the objective function were "cost", then the alternative chosen would be the one which would minimize costs. Another objective function might be "limit in change" and, in that case, the chosen alternative would be the one which would require fewest additional resources for each state i at different time periods. The problem solved in goal seeking is to minimize "change" subject to reach the desired goal. This minimizing change is embodied in the selection of the objective function in a mathematical quadratic program. The problem solved is:

$$[13] \quad \text{minimize} \quad \sum_{i=1}^{I} \sum_{j=1}^{I} W_{ij}(P^1_{ij}-P_{ij})^2$$

$$\text{subject to} \quad \overrightarrow{P(\infty)} = \overrightarrow{P(\infty)} \{P^1_{ij}\}$$

The constraint $\overrightarrow{P(\infty)} = \overrightarrow{P(\infty)} \{P^1_{ij}\}$, assumes that the solution, referring pattern $\{P^1_{ij}\}$, has the desired steady state of health services utilization. The minimization involves finding that referral pattern $\{P^1_{ij}\}$ which comes closest (in the sense of weighted distance) to a given actual referral pattern $\{P_{ij}\}$.

The size of weight W_{ij} represents the ease or costliness with which the given referral pattern may be changed. If $W_{ij} = \infty$, no change is allowed, and $P^1_{ij} = P_{ij}$, reflecting an infinite costliness in altering a current referral rate P_{ij}. In the case all $W_{ij} = 1$, the incremental cost of changing any referral pattern equals the incremental cost of chaning any other one.

Figure IV represents graphically the three applications of the Markovian model.

INSERT FIGURE IV

PRACTICAL EXAMPLES

The present example illustrates the applications of the described Markovian model in the planning of personal health services at the levels of primary medical care, consultant medical care, hospital care, nursing home care and domiciliary care for a hypothetical region of two million people with an annual population increase rate of 1.2 percent. In a previous study this model was applied to the planning of personal health services for patients with cardiovascular diseases at different regional levels.[14]

INSERT TABLE 1

Table 1 shows the transitional probability matrix representing all possible movements of people among the health services states in this example. The transitional probabilities are given in different fundamental time periods, due to the difficulty of obtaining data for the different states for the same period of time.

INSERT TABLE 2

Table 2 presents the empirical estimates of the initial fractions of the total population in each of the health services states.

The empirical estimates have been adapted from different sources.[15,16,17,18] The data is merely illustrative and no significance should be attached to the particular numbers used.

INSERT FIGURES V AND VI

The broken lines in Figures V and VI show the predicted manpower and facility requirements at different states calculated from the fractions of the population in these states; it is the output of the prediction model.

SIMULATION

As an example of simulation, suppose that a health services administrator responsible for the health of the population in this region is interested in discovering the impact that a new policy of promoting more comprehensive care in nursing homes would have upon the whole system. It is estimated that this new policy will produce a change in the daily transitional probability of going from hospital care to primary care services from .051 to .049 and in the daily probability of going from hospital care to nursing home care from .001 to .003. The health services administrator may ask for an estimate of the repercussions this change will have on the requirements for resources at the several health services states at different time periods.

The unbroken lines in Figures V and VI reflect the new manpower and facility requirements as a result of the simulated situation.

In these tables it is seen that the new policy would require the same number of physicians for consultant and domiciliary care, but a decrease in the number of physicians required for primary care. By the second year, for instance, the number of primary care physicians needed would be ten less than were initially needed.

On the facility side, the new policy would require the same number of hospital beds every year and more nursing homes. By the second year, 15,995 more nursing home beds would be required.

GOAL SEEKING

Goal seeking consists in calculating the best alternative for the chosen constraint to reach a desired goal. The health services administrator mentioned could take as his ten year goal a reduction in hospital care utilization by 28% while at the same time increasing nursing home utilization by 100%, domiciliary care utilization by 215%and consultant utilization by 12%. He might also plan to increase the efficiency of the nursing homes, by reducing average length of stay from 474 to 430 days, and to increase the efficiency of the domiciliary service, by reducing the average length of stay in this state from 50 days to 30 and by increasing the number of home visits per person from 1.5 to 2.5. Further, the health services administrator knows that he has to reach the desired goal with minimum change in current resources. The question he might ask is how these resources should be utilized at different time periods to reach the desire objective, in a way that would minimize the number of additional resources required.

The output of the model would be the optimum utilization strategy, at different time periods, to reach the specified goal with minimum change in current resources.

Normalización

The dotted line in Figures V and VI shows the manpower and facility requirements at different time periods, in order to meet the goal defined above.

OTHER APPLICATIONS

This Markovian model can be expanded to include two new states, death and birth, and different transitional probabilities matrices per each age group and thus, consider the different utilization rates of personal health services by different age groups. With this expansion, the model takes into account: first, changes in size and age structure of the population and second, the different utilization experiences of the different age groups.[19]

SUMMARY CONCLUSION

Plannimetrics in health services is in the incipient stages. Planning is still an intuitive rather than a factual process. This paper presents a method directed towards reversing this situation. The described model is used to predict resource requirements, to calculate changes in these requirements in simulated situations and to estimate the best alternative for reaching a desired goal in the presence of a defined constraint. The method allows the maximum of flexibility to the planner to face the continuously changing health services system.

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Figure I

INPUT, THROUGHPUT, AND OUTPUT IN THE HEALTH SERVICES SYSTEM

NEEDS	SERVICES	OUTCOMES
Disease	Primary Medical Care	Dead/Alive
Disability	Consultant Medical Care	Diseased/Healthy
Dissatisfaction	Hospital Care	Disabled/Fit
Discomfort	Nursing Home Care	Dissatisfied/Satisfied
	Domiciliary Care etc.	Uncomfortable/Comfortable
INPUT	THROUGHPUT	OUTPUT

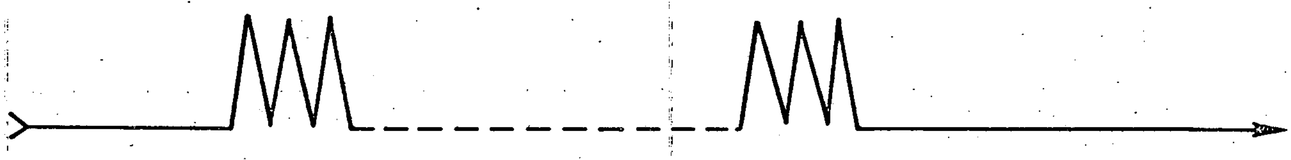
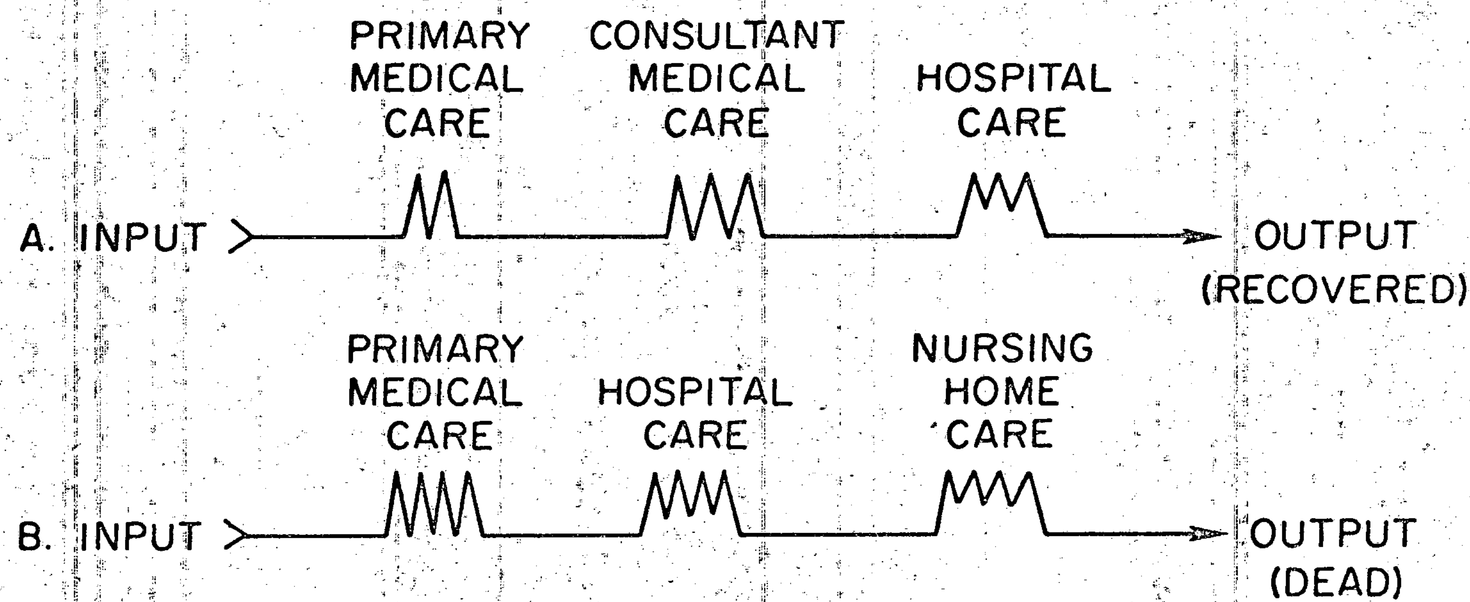


Figure II

UTILIZATION STRATEGIES



A. 2 visits per entry to Primary Medical Care
3 visits per entry to Consultant Medical Care
3 days per entry to Hospital Care

B. 4 visits per entry to Primary Medical Care
4 days per entry to Hospital Care
4 days per entry to Nursing Home Care

Figure III

STATES AND FLOWS

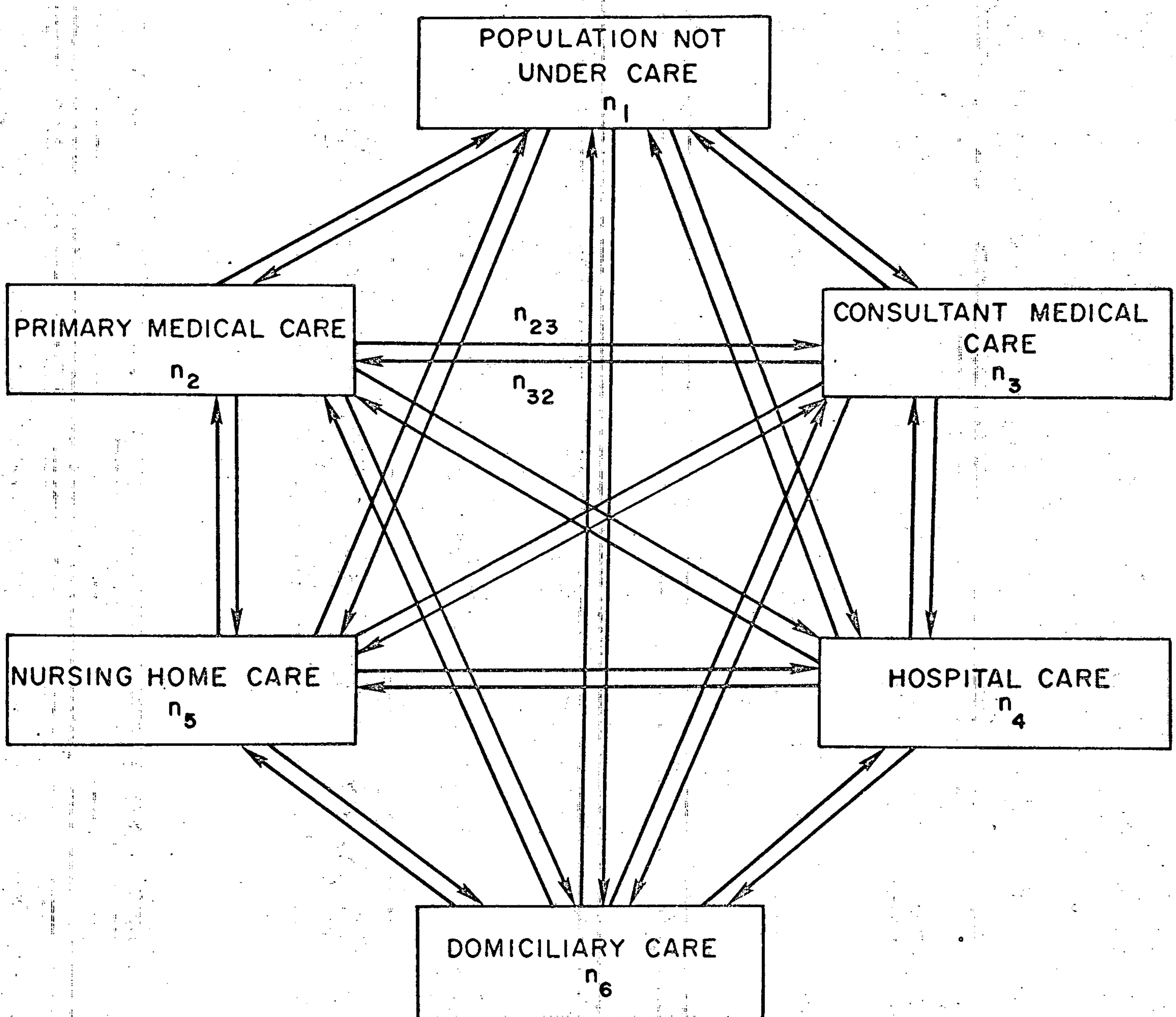


Figure IV

GRAPHICAL REPRESENTATION OF PREDICTION, SIMULATION AND GOAL SEEKING

The encircled elements are the outputs, the uncircled are the inputs.

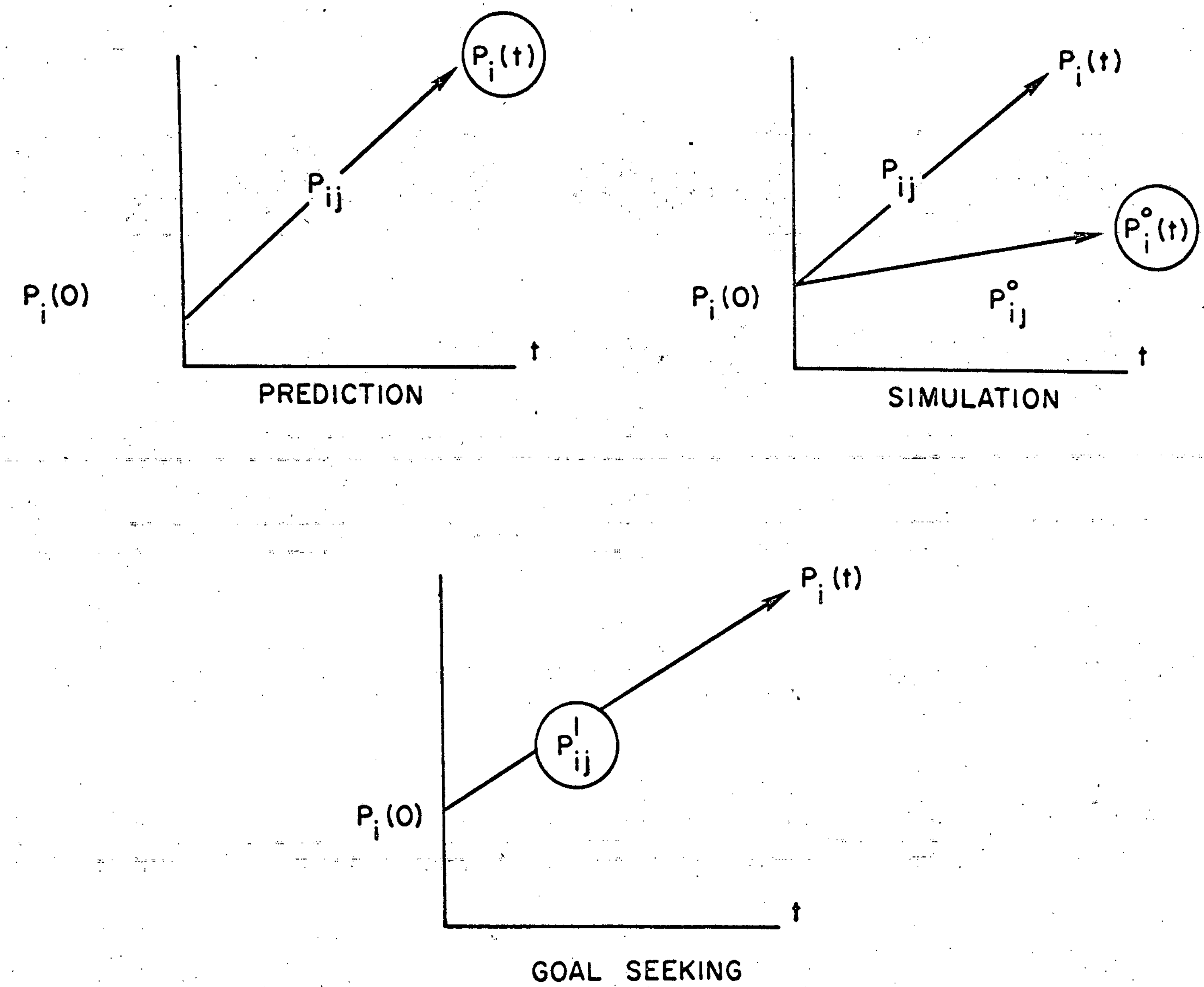


Figure V

MANPOWER REQUIREMENTS IN PRIMARY MEDICAL CARE, CONSULTANT MEDICAL CARE AND DOMICILIARY CARE

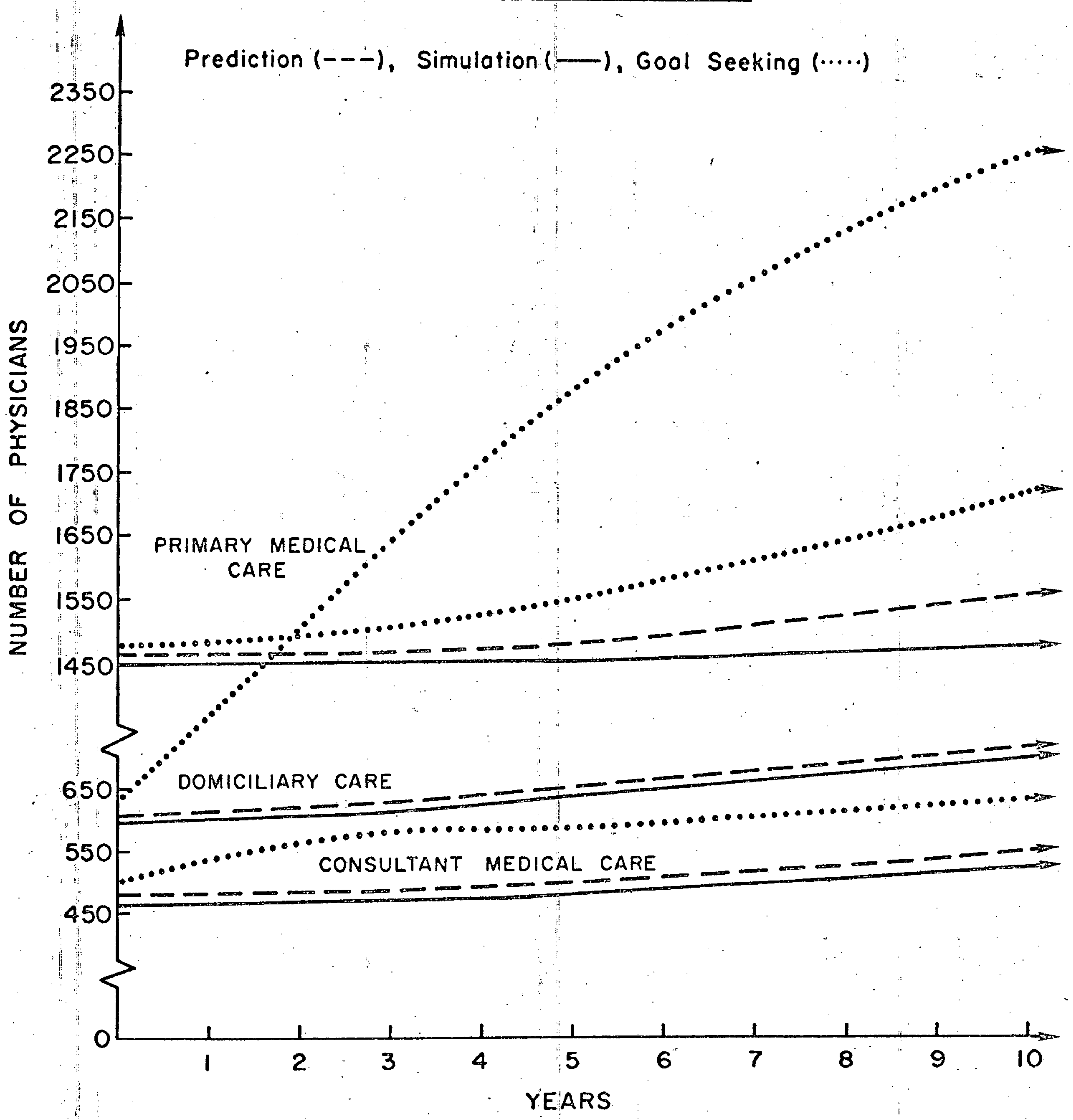


Figure VI

BED REQUIREMENTS IN HOSPITAL AND NURSING HOME CARE