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ABSTRACT

This paper is a status report of an ongoing project whose purpose is the development of simulation models to be used in the estimation of health manpower requirements. The research plan is outlined and progress to date is discussed. The models that are summarily described simulate (a) population generation and projection through time, (b) hospital episodes for the simulated population, and (c) the health manpower required in a hospital setting to satisfy the simulated demand. A review of various techniques for estimating manpower requirements in a hospital setting is presented.

INTRODUCTION

The increasing demand for medical care and the associated increase in cost has added emphasis to the need for better health planning. One important aspect of such planning arises in satisfying the demand for health manpower; as Irene Butter states,

> "The problem of providing an adequate and continually growing volume of health manpower, properly distributed both regionally and among health occupations, has become a central concern of many policy makers, health professionals, and manpower researchers" [Ref. 1].

To provide adequate manpower requires an analytical framework that aids in understanding the relationships between supply and demand. Butter provides one conceptual framework (see Fig. 1). However, in addition to such a framework, a technique for examining the dynamic interplay of these demands upon the health care system with the resulting allocation and utilization of health manpower is needed. Such a technique would allow investigation of particular relationships within the health system, for example, the effects of substituting less trained health professionals in different roles.

The research project, whose status is summarized in this paper, has as its goal the design and development of a dynamic computer simulation model of the U. S. health manpower system. The completed model, hopefully, will provide useful forecasts of health care demand, resulting manpower requirements, the interacting effects upon manpower supply and the market place phenomena which provides system equilibrium. Using the final model, the various factors influencing health manpower demand can be evaluated and the impact of both structural and technological changes can be assessed. As in any model development, one benefit will be the identification of data deficiencies and the possible coordination of other related research projects [Ref. 2]. The significant worth of the complete model will be realized if it provides a method for evaluating the benefits of alternative allocation and utilization patterns of health manpower resources.

OVERVIEW OF THE PROJECT

This research, for the Bureau of Health Professions Education and Manpower Training, National Institutes of Health, is being performed by both the Research Triangle Institute (RTI) and the Human Resources Research Center (HRRC) located at the University of Southern California. The emphasis of the research at HRRC is on the development of a total conceptual model relating the health care services, the health manpower, and the medical education markets. This is a relatively long term effort as compared to the current RTI effort which is concentrating on the development of three models to simulate (a) a sample population and the vital events which it experiences, (b) the hospital episodes for this population, and (c) the hospital services required for this simulated demand.

The HRRC conceptual model is schematically portrayed in Fig. 2, "Conceptual Model of the Total Health Manpower System." Details concerning this aspect of the research can be obtained from Dr. Donald Yett at HRRC [Ref. 3].

The RTI efforts have been directed towards the development of the model required for simulating the Population of Individuals component in the total conceptual model and also the development of one segment of the Demand for Service component. These two components have been expanded in Fig. 3, "Health Care Demand System Model." The hospital segment of the Health Service Submodel represents one of the better documented service areas making it more amenable to initial model development. The following sections will describe these models in more detail; however, emphasis will be placed upon the hospital services model since the population projection model and the hospital episodes model has been documented elsewhere [Ref. 4,5].

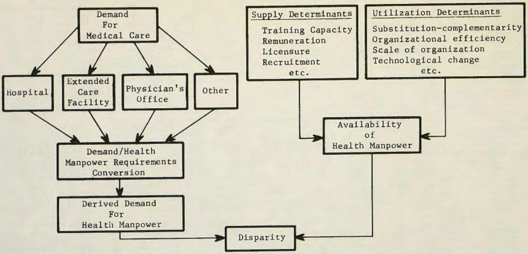

Fig. 1. Schematic of Health Manpower Demand and Supply System

THE POPULATION PROJECTION MODEL

The population projection model is a dynamic demographic computer simulation model of the vital events occurring in a human population. This model, known as POPSIM, generates a life pattern including vital event history for each individual that it is simulating. These vital events include birth, marriage, divorce, widowhood, remarriage, and finally death. POPSIM is a stochastic model and uses a random sampling of probability distributions to determine what events occur to which individuals and when. The model is made dynamic by the inclusion of time dependent characteristics.

POPSIM consists of two main parts; the first is used for creating an initial population which can be thought of as a random sample of individuals selected from a population register. A series of subroutines assign characteristics to each individual including age, race, sex, marital status, number of marriages, date of current marriage, and date of birth of spouse. If the record is for a female over 15 years of age, the characteristic of her parity and the date of birth and sex of each of her children is also included. Routines for adding family income, health insurance status, and urban-rural residence are now being incorporated.

The second element of POPSIM is used for generating the change in these vital events over time. Each individual is processed in a computer population, generating marriages, births, divorces, and death using transitional probabilities for the appropriate time periods. The time of each event and other pertinent information as determined by the simulation are added to the individual's record. Each birth that is generated creates a new record. The flow diagram for this model is presented in Fig. 4, "POPSIM Flow Chart."

There are two types of output available from the program. First, tabulations of the population by various characteristics can be generated. In addition, a magnetic tape containing the records of each individual and his vital event data can be prepared. This history tape contains the information on the projected population in a time-event format.

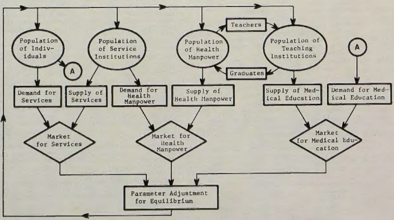

Fig. 2. Conceptual Model of the Total Health Manpower System

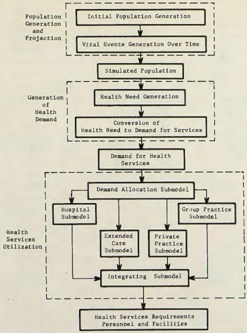

Fig. 3. Health Care Demand System Model

HOSPITAL EPISODES MODEL

The Hospital Episodes Model generates hospital admission and discharge history for each individual in the computer population generated by POPSIM. This model uses weekly transitional probabilities to generate admission and discharge dates based upon the age and sex of the individual in a manner similar to the generation of the vital events in POPSIM.

The Hospital Episodes Program has been modified to generate hospital admissions according to demographic characteristics including race, income, residence, and health insurance. In addition, the diagnosis of each admission, the size of the hospital where treatment is sought, and whether surgery is required will be assigned. The diagnostic category will depend on the various demographic characteristics noted above. The length of stay will be determined by sampling a distribution of length of stay appropriate to the diagnostic category. The flow chart for this model is presented in Fig. 5, "Hospital Episode Flow Chart."

Data sources used in estimating the parameters and distributions for this model include the Hospital Discharge Surveys, the National Mortality Surveys, and the Health Interview Surveys of the National Center for Health Statistics.

HOSPITAL SERVICES MODEL

Various models have been developed of the hospital. Some of these have simulated hospital activities [Refs. 6-17]. Models for estimating hospital manpower requirements generally have not used a simulation technique. Certain of these

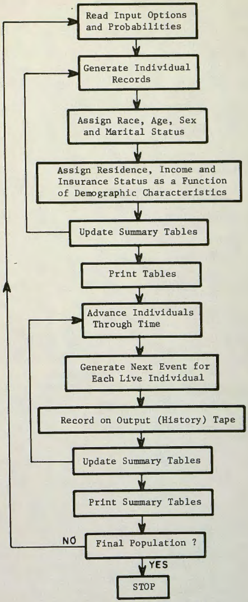

Fig. 4. POPSIM Flow Chart

hospital models are reviewed in the following paragraphs; the current model being developed at RTI is then described.

Baligh and Laughhunn [Ref. 18] model the hospital as an economic entity with inputs, constraints, and intermediate outputs from which they devise a linear model for scheduling admissions. Basic to this model is the concept of patient equivalence classes defined by requirements for goods and services. The hospital's terminal output is defined as the weighted sum of patients treated in all equivalence classes where the weights, specified by hospital administration, reflect the relative importance of the equivalence classes. This output definition avoids certain of the objections raised to other measures, e.g., patient days as being homogeneous and all not of the same value to the hospital; weighted average of the number of patient

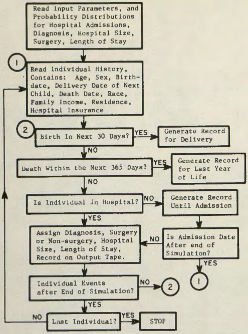

Fig. 5. Hospital Episode Flow Chart

services with the weights being determined by average costs as being an intermediate output and not a measure of the terminal output of treated patients [Ref. 19]. An optimal solution of the objective function defines the hospital's capacity. The general model form is contained in Table 1, "A Linear Economic Model of the Hospital."

Jellinek has proposed a structural model based on elemental patient care units [Ref. 20]. Each patient care operation has the following elements:

1) Input factors: personnel and facility resources
2) Organizational factors: defined by the organization form used in the operation; includes the rules and policies used, degree of work specialization, supervision patterns.
3) Workload factors: determines the workload imposed on the resources by a group of patients characterized by number and patient condition.
4) Environmental factors: those elements effecting or affected by, patient care but not a part of the operation.
5) Output factors: categorized into quantity and quality of patient care, patient satisfaction and personnel satisfaction.

The generalized formulation of this model is presented in Table 2, "Jellinek's Structural Model." Development of such a model requires selection of the variables to be included in the model, constructing the actual structure (i.e., hypothesizing the existence and form of the relationships) and estimating the parameters. Such a model is descriptive in nature and does not lead to an optimal system.

Jellinek uses this methodology in developing a nursing unit model. The variables endogeneous to the nursing unit were defined to be the hours of (a) direct patient care, (b) indirect care, and (c) nonproductive and miscellaneous activity given to each patient by four nursing categories (professional nurses, practical nurses, nursing aids, and student nurses). Using maximum likelihood estimates for the parameters, a set of structural equations are derived. Such a model can be used (a) in analysis of current operations, (b) for estimating effects of substitution of different categories of staff, and (c) for control or planning by using various results as measures of desired work characteristics.

Maki has developed a recursive programming model that seeks to minimize the difference between demand and employment for each manpower category [Ref. 22]. The general form of his model is presented in Table 3, "Maki's Recursive Programming Model."

These three models have been included to provide examples of the more appropriate models for estimating health manpower requirements. Each has its defiencies when considered in terms the total conceptual model. Maki's approach is an attempt to relate the demand and supply phenomena yet assumes within limits a free entry and exit into the market place. Extensions of his concepts will be incorporated in the market place models. Jellinek's model is descriptive (i.e., non-optimizing) and has been estimated only for nursing units in one hospital. Baligh and Laughhunn's efforts provide an indication of possible future activities since they have not estimated any of the parameters. Yet this model deals with the micro-model of the hospital not the total complex of manpower demand and supply. Other historic efforts have been critically received elsewhere [Ref. 23].

Following an extensive literature search and review of available data sources, it was decided that initial RTI modeling efforts should center on four hospital functions, namely

1. clinical laboratory
2. radiology
3. pharmacy
4. physical therapy

Each of these areas have an easily identifiable unit of work which can be used as a model basis. The two categories of nurses and physicians have been omitted because the complexity of their operations require a more comprehensive analysis than that which has been realizable to date. The Jellinek effort is a sound first step in providing the necessary nursing model; his methodology needs to be extended to other hospitals of different sizes with different patient characteristics to determine the appropriate parameter distributions. An analysis of equivalent depth should be performed for physicians in the hospital setting.

Four general factors enter into the estimate of manpower requirements, namely

1) Demand for services,
2) Care requirements,
3) Performance, and
4) Personnel utilization.

Table 1

BALIGH AND LAUGHHUNN'S LINEAR ECONOMIC MODEL

Maximize $$Z = \sum_{i=1}^{m} w_i (X_i + Y_i)$$

X_i - number of paying patients in equivalence class i

Y_i - number of indigent patients in equivalence class i

w_i - weight assigned to equivalence class i by the policy-making group

Subject to

Resource Constraint

$$\sum_{i=1}^{m} \sum_{j=1}^{n} (X_i + Y_i)\, a_{kj} R_{ij} \leq T_k$$

X_i, Y_i - as above

a_{kj} - amount of fixed resource k used in fulfilling requirement j

R_{ij} - average requirement of a patient in equivalence class i for service j

T_k - total available fixed resource k

Patient Constraint

$$X_i + Y_i \leq H(E_i)$$

X_i, Y_i - as above

$H(E_i)$ - total number of potential patients in equivalence class i

Budgetary Constraint

$$\sum_{i=1}^{m} \sum_{j=1}^{n} X_i R_{ij} P_j - \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{\ell=1}^{L} c_\ell\, b_{\ell j} (X_i + Y_i) R_{ij} \geq G + F - S$$

X_i, R_{ij}, Y_i - as above

P_j - price charged for one unit of the j service

c_ℓ - cost per unit of variable input ℓ

$b_{\ell j}$ - absorption of variable resource ℓ in producing one unit of service j

G - target profit level

F - total cost of fixed resources

S - external subsidy

Policy Constraints

$$X_i + Y_i \geq D_i$$

$$Y_i (1-V_i) - V_i X_i \geq 0$$

X_i, Y_i - as above

D_i - minimum acceptable number of patients in equivalence class i

V_i - minimum acceptable fraction of indigent patients in equivalence class i

Table 2

JELLINEK'S STRUCTURAL MODEL

$$y_i = f(y_j, x_\ell, w_k, o_m, e_n)$$

where y_i, y_j - the output factors (endogenous variables), $i \neq j$

x_ℓ - input factors (resources)

w_k - workload factors

o_m - organizational factors

e_n - environmental factors

as an example: [Ref. 21]

$$Y_1 = a_{10} + a_{11} Y_4 + a_{12} Y_7 + a_{13} Y_{10} + b_{11} X_1 + b_{12} \ln(X_1 + a_1) + b_{13} X_5 + b_{14} X_6 + b_{15} X_7 + b_{16} X_8 + c_{11} X_9 + c_{12} X_{10} + c_{13} X_{11}$$

where Y_1 - hours of direct patient care provided by professional nurses

a_{ij}, b_{ij}, c_{ij} - parameters estimated from data

Y_4 - hours of direct patient care provided by practical nurses

Y_7 - hours of direct patient care provided by nursing aides

Y_{10} - hours of direct patient care provided by student nurses

X_1 - professional nursing hours per patient day

X_5 - fraction of partial care patients

X_6 - fraction of total care patients

X_7 - patient census

X_8 - admissions within last 24 hours

X_9, X_{10}, X_{11} - Dummy variables set equal to 1 if estimate is for the appropriate nursing unit, zero otherwise. X_9 for the orthopedic unit, X_{10} for the urology and neurosurgery unit and X_{11} for the general surgery unit.

The demand for services is a function of the number of persons admitted to the hospital, their length of stay, their diagnosis, and their ability to pay. Fluctuations in the demand for services will effect the manpower estimates.

Care requirements refer to the type and amount of care provided each patient. Such care is a function of the patient's medical condition and his length of stay in addition to the hospital size, and procedures used; data on the interrelationships of all of these elements has not been found, so an expected value model, based on hospital size and number of admissions, will be used.

Performance is a measure of time required to perform a task. This time includes not only the actual time to perform the task but times required for all other support functions such as supervision, administration, personnel activities, etc. As an example from the clinical laboratory: the ratio of tests per man hour is caluculated from the total tests performed in a given time period divided by the total paid man hours for that period. Performance measures will vary from hospital to hospital depending upon size of the hospital, extent of automation, general organizational considerations, and operating procedures. In the current model, as a result of data availability, only hospital size is being considered as a determining factor.

Personnel utilization converts man hours to the number of people. This factor includes considerations similar to those in the performance measure, e.g., whether paid absence was included, what is the standard work time, what is the mix of personnel

Table 3

MAKI'S RECURSIVE PROGRAMMING MODEL

Minimize $Z = (D_{jt} - X_{jt})$

where D_{jt} - demand for personnel in occupation j in time period t

X_{jt} - employment in occupation j in time period t

Subject to:

$$X_{jt} \leq (1 + B_{jt\ max})X_{j,t-1}$$

$$X_{jt} \geq (1 - B_{jt\ min})X_{j,t-1}$$

$$X_{jt} \geq 0$$

$$\Sigma E_{jt} \cdot X_{jt} \leq TR_t$$

where $B_{jt\ max}$ - maximum percentage increase in number of workers in occupation j in time period t

$B_{jt\ min}$ - maximum percentage decrease in number of workers in occupation j in time period t

E_{jt} - average annual earnings in each occupation in time t

TR_t - total resources available for payment of earnings in time period t

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types, and whether you staff for the maximum load or for an average load. One problem encountered in this conversion arises in the use of both full time and part time personnel. The output will contain the total estimated man hours, the personnel equivalents and the assumed ratio of part time to full time staff.

The general form of the hospital service model is given by:

$$M_{si} = \sum_j D_{sj} R_{sij} P_{si} U_{si}$$

where

M_{si} is the estimated number of personnel of type i required for the hospitals of size s.

D_{sj} is the demand for hospitals services measured in either number of admissions or average daily census or some other demand variable, for diagnosis j.

R_{sij} equals care requirements pertinent to type i personnel per unit of demand for hospitals of size s, measured in number of work units per admission or number of work units per average daily census, for diagnosis j.

P_{si} equals time required of type i personnel to perform a unit of work in a hospital of size s, measured in hours per unit of work.

U_{si} equals the ratio of personnel and man hours for type i personnel in hospitals of size s, measured in number of personnel per man hour.

Total hospital manpower for any given type would be obtained by summing over all hospital sizes;

$$M_i = \sum_s M_{si}$$

Input from the Hospital Episode Program to the Hospital Services Model will provide estimates of the demand by diagnosis placed upon each hospital. Requirements and performance parameters will be obtained from historic data and will be time dependent. Personnel utilization characteristics will be estimated from a single sample but will also have the provision to be time dependent. Thus the general model, with a linear time relationship (for R, P, U), is of the following form:

$$M_{si} = \sum_j (D_{sj}(t))([a_{1sij} + b_{1sij}(t)])([a_{2si} + b_{2si}(t)])([a_{3si} + b_{3si}(t)])$$

The capabilities incorporated in the current version of the model for the four manpower categories are summarized in Table 4.

Investigations are currently underway into possible models of both nursing and physician activities. One model now being considered for the initial

Table 4

SUMMARY OF THE HOSPITAL SERVICE MODEL EQUATIONS

Clinical Laboratory

$$M_{sm}(t) = \sum_{j} A_{sj}(t)\,{}_{c}R_{sj}(t)\,{}_{c}P_{s}(t)U_{sm}$$

- M - manpower requirements as a function of time
- s - hospital size (approximately five categories are being studied)
- m - personnel categories: medical technologist, laboratory assistant, laboratory helpers
- A - number of admissions
- j - diagnosis category
- ${}_{c}R$ - number of clinical tests per admission
- ${}_{c}P$ - time required to perform a test
- U - ratio of personnel category to laboratory manhour; this is the product of the ratio total lab personnel/manhour and the ratio personnel category m/total lab personnel

${}_{c}R$ and ${}_{c}P$ are of the form $a_i + b_i t$

Radiology

$$M_{sm}(t) = \sum_{j} A_{sj}(t)\,{}_{r}R_{sj}(t)\,{}_{r}P_{s}(t)U_{sm}$$

- M, s, A, j, U - as above
- m - personnel categories: x-ray technician and radiology helper
- ${}_{r}R$ - number of radiological procedures per admission
- ${}_{r}P$ - time to perform a radiological procedure

${}_{r}R$ and ${}_{r}P$ are of the form $a_i + b_i(t)$

Pharmacy

$$M_{sm}(t) = \sum_{j} C_{sj}(t)\,{}_{p}R_{sj}(t)\,{}_{p}P_{s}(t)U_{sm}$$

- M, s, j, U - as above
- m - personnel categories: pharmacist, pharmacist assistant
- C - average daily census
- ${}_{p}R$ - number of pharmacy dispersements per patient day
- ${}_{p}P$ - time required to make a dispersement

${}_{p}R$ and ${}_{p}P$ are of the form $a_i + b_i t$

Physical Therapy

$$M_{sm}(t) = \sum_{j} C_{sj}(t)\,{}_{pt}R_{sj}(t)\,{}_{pt}P_{s}(t)U_{sm}$$

- M, s, C, j, U - as above
- m - personnel categories: physical therapist, physical therapist assistant
- ${}_{pt}R$ - number of treatments per patient day
- ${}_{pt}P$ - time per treatment

${}_{pt}R$ and ${}_{pt}P$ are of the form $a_i + b_i t$

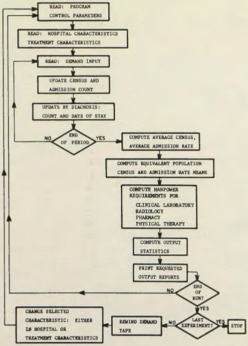

Fig. 6. Basic Flow Diagram of the Hospital Manpower Services Model

simulation program relates nurses and physicians required only to hospital admissions and census. These initial models will be supplemented as future research indicates more appropriate models.

COMPUTER PROGRAM FOR THE HOSPITAL SERVICES MODEL

The computer program incorporating the current Hospital Services Model has been designed to allow a maximum of flexibility since it is anticipated that (a) the nursing and physician estimating models will be added later, and (b) the current estimating procedures for the remaining manpower categories will be expanded. The basic flow chart of the program is illustrated in Fig. 6, "Basic Flow Diagram of the Hospital Manpower Services Model." The program components may be described as follows.

The control parameters which are read-in first, allow selection of program options including the ability to change certain characteristic both of the hospital (for example, staff composition) and of treatment (for example, hours required of a given personnel category for a given diagnosis). The hospital characteristics required include the appropriate parameters (P,U) for each size hospital; treatment characteristics are contained in the requirements parameter (R) for each diagnostic category as a function of hospital size.

The demand for services generated by the hospital episodes submodel is read-in from a tape. This input, presented as a time stream of events, contains the diagnosis, whether surgery was performed, date of admission, date of discharge, and size of hospital in which treatment was received. This data is used to derive hospital census and admissions data and to determine a case count and total days of treatment count by diagnosis.

This data input covers a specified time period. The computation of census and admission rates for the equivalent populations are then required since the demand input supplied by the demand model is for a representative sample population. Following computation of these equivalent values, the program computes the equivalent manpower required.

Various statistics are derived based upon these computations. The results are printed in the form of reports such as a report of manpower equivalents by diagnosis by category by hospital size. The report generated is determined by the report option selected.

MODEL USES

The estimates of manpower requirements are considered to be functions of diagnosis, hospital size, personnel mix, and time. Using the population generation and projection model, variations in population structure can be transformed into variations in hospital demand and resulting changes in manpower requirements. Similarly, using the Hospital Episodes Submodel, variations in length of stay, hospital insurance coverage, etc. can be reflected in variations of demand and again in manpower requirements. Finally, using the Hospital Services Model itself, changes in organization can be reflected in demand, i.e., manpower substitution schemes can be incorporated and the effects upon manpower requirements experienced. Included in the time dependent characteristics of the model is consideration for normal technological improvement. Significant changes in technology and resulting efficiencies cannot be anticipated and must be introduced into the model as exogenous changes. This is realized by varying input data. Other experiments can be envisioned including the effects of changing size of hospital, the shift in prevalence of various types of diagnosis and combinations of these factors.

This early version of the model is but a beginning attempt to provide the tool for studying dynamic interactions among the various factors affecting demand. Several assumptions have been made to date, e.g., the resources of personnel and facilities are limitless and therefore all demands can be answered. The next phase of development would consider the constrained condition in which the market place phenomena for establishing an equilibrium between demand and supply would be modeled.

Referring back to the initial outline of the total project, it is evident that continued work needs to be done both in modeling all three market places where demand and supply for services interact. It is hoped that these modeling efforts and the associated efforts for other components of the total system will be undertaken in the forthcoming years.

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(23) Hiestand, D.L., "Research into Manpower for Health Service," MILBANK MEMORIAL FUND QUARTERLY, Vol. XLIV, No. 4 Part 2, October 1966.