A DYNAMIC MODEL FOR PLANNING PATIENT CARE IN HOSPITALS

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This paper presents a simulation model for investigating the requirements of patient care in planning new hospitals on the basis of statistical data of health needs in a community and different administrative policies for providing services. The envisioned future service demands for planning patient care in a hospital are generated by synthetic random observations according to certain probabilistic distributions. The model permits the investigation of the effects of service demands on the utilization of patient care facilities over a period of time and on possible solutions for meeting such demands through experimenting with various administrative policy decisions in planning and management.

Introduction

The objectives of developing a comprehensive and systematic procedure for planning patient care in hospitals are two fold. First, such a procedure will yield a more accurate prediction on the personnel and facility capacities required to provide the envisioned health services in planning a new hospital. Second, the procedure can also be used to make more efficient use of fixed health care personnel and facility capacities by experimenting with various administrative policies in levelling off peak service demands when such rescheduling does not affect the quality of health care. An initial attempt has been made by Grooms and Au[1] to simulate a limited number of factors concerning the scheduling of medical treatments after the patients are admitted to a hospital. This paper presents a comprehensive model for planning health services in a proposed hospital by actually simulating the envisioned service demands on the basis of the health care needs of the community and the hospital administrative policies for providing services. The simulation model is dynamic in the sense that new information may be input into the model at various time periods and that admissions and service rates can be adjusted through feedbacks from preliminary plans. Thus, in the planning of a new hospital, a preliminary plan is first developed according to the envisioned service demands generated by random synthetic observations on the basis of health care statistics, and this plan is further improved by experimenting with various policies for personnel and facility levelling. This simulation process permits a thorough investigation of the most significant factors affecting the efficiency of health care in a hospital prior to its construction. Hence, the simulation procedure will be most useful to hospital planners and administrators.

Conception of a Preliminary Plan

The process of conceiving a preliminary plan for patient care in a new hospital is shown schematically in the functional flow chart in Figure 1. The input to the system includes the population of the community to be served and the expected types and rates of diseases. Since the characteristics of the population such as age distributions and socioeconomic factors greatly affect the health care needs, the changing patterns as well as the current status of such characteristics should be considered. The expected types of rates of diseases are represented by the significant parameters of case distributions for various diseases according to statistical records. For the purpose of planning, such medical information may be based on data compiled for Group Health Insurance.[2] The types of diseases, included singly or in groups in the case distribution array are: (1) infective and parasitic diseases, (2) allergic diseases, (3) diseases of the respiratory system, (4) diseases of cardiovascular system, (5) diseases of blood and spleen, (6) diseases of digestive system, (7) endocrine, metabolic and nutritional diseases, (8) diseases of nervous system and emotional disturbance, (9) urogenital and venereal diseases, (10) diseases of eye, ear, nose and throat, (11) diseases of locomotion system, (12) injuries and adverse affects of external causes, (13) obstetrics, and (14) special diagnostic cases. The daily distribution of the total number of hospital cases is generated randomly by synthetic observations from pseudo random numbers which represent normal distributions of the frequencies of occurrence of various types of diseases, or other probability distributions such as Poisson distributions when they appear to be more appropriate. Among the hospital cases thus generated, some are referral cases for elective admission while others are admitted as emergency cases either through direct referral by private physicians or occasionally through the emergency and outpatient department. The selection of cases through emergency and outpatient department is also made randomly by using synthetic observations. Of all the cases admitted to the hospital daily, they are classified automatically into medical, surgical and obstetric cases. Consequently, the envisioned services to be provided by the proposed hospital can be examined by generating the daily distributions of hospital cases over a period of time.

At this stage of planning, the types of facilities and personnel needed for operating the proposed hospital should be specified. However, only the types whose operational efficiency is to be investigated need be included in the model. For the sake of illustration, the present simulation model includes the following items in the facility file: (1) nursing units - both general and obstetric beds; (2) operating rooms; (3) delivery rooms; (4) three types of laboratories - general medical, chemistry and histology laboratories; (5) three adjunct diagnostic and treatment units - EKG, radiology and physical therapy. It also contains the following categories in the health care personnel file: (1) three types of nursing services - special duty nurse, regular registered nurse, and practical nurse; (2) two types of technicians - laboratory and radiology technicians. The specific information about health care personnel and facility needed to complete the treatment of each type of disease is stored in a combined personnel and facility demand file with the 15 items resulting from all personnel and facility types listed above. This information includes the required number of units of demand (man-hours of personnel or

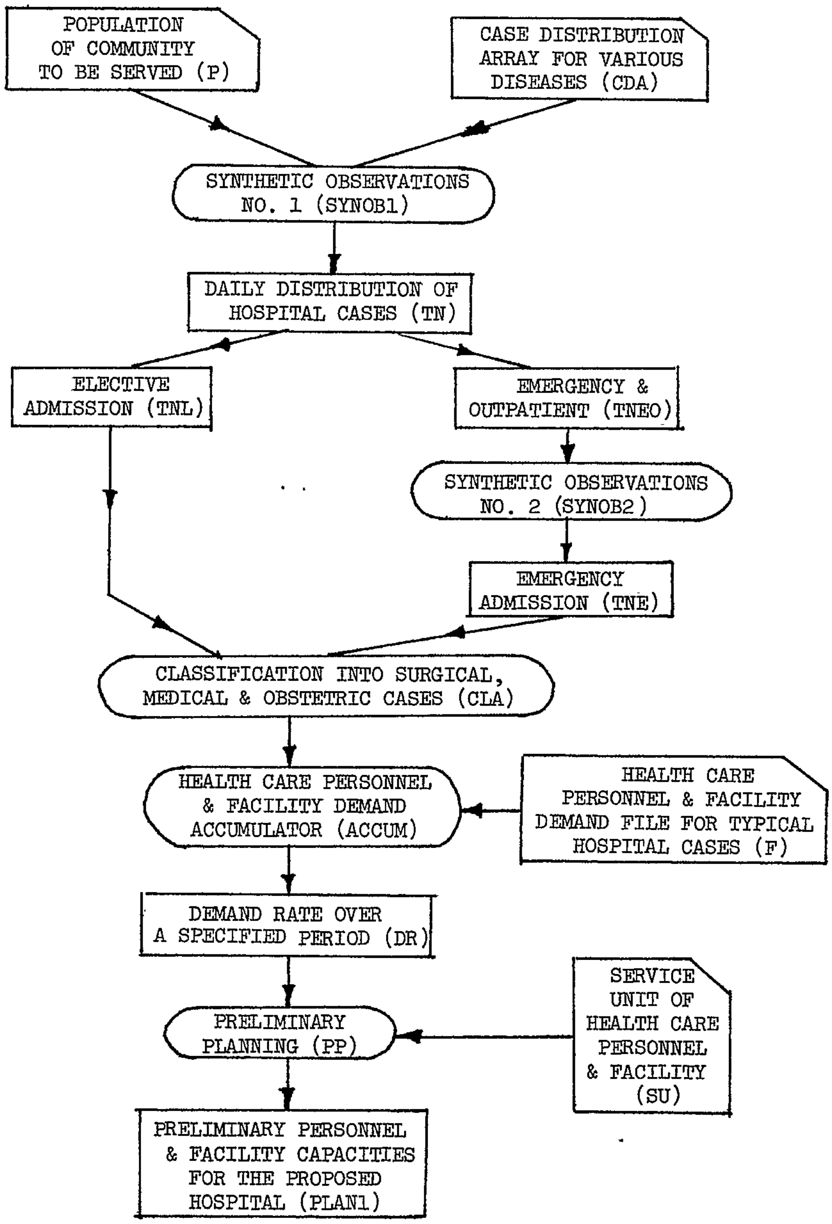

POPULATION OF COMMUNITY TO BE SERVED (P)
CASE DISTRIBUTION ARRAY FOR VARIOUS DISEASES (CDA)
SYNTHETIC OBSERVATIONS NO. 1 (SYNOB1)
DAILY DISTRIBUTION OF HOSPITAL CASES (TN)
ELECTIVE ADMISSION (TNL)
EMERGENCY & OUTPATIENT (TNEO)
SYNTHETIC OBSERVATIONS NO. 2 (SYNOB2)
EMERGENCY ADMISSION (TNE)
CLASSIFICATION INTO SURGICAL, MEDICAL & OBSTETRIC CASES (CLA)
HEALTH CARE PERSONNEL & FACILITY DEMAND ACCUMULATOR (ACCUM)
HEALTH CARE PERSONNEL & FACILITY DEMAND FILE FOR TYPICAL HOSPITAL CASES (F)
DEMAND RATE OVER A SPECIFIED PERIOD (DR)
PRELIMINARY PLANNING (PP)
SERVICE UNIT OF HEALTH CARE PERSONNEL & FACILITY (SU)
PRELIMINARY PERSONNEL & FACILITY CAPACITIES FOR THE PROPOSED HOSPITAL (PLAN1)

FIGURE 1

occupancy-hours of facilities for a specified number of days) for each item in the demand file. The extent of demands for each type of disease is specified according to the average ranges that have taken place in the current medical practices and can be modified as the practices are changed by the health care professions.

The total health care demands for personnel and facilities are generated from the daily distributions of hospital cases and the demand file containing information for required service units in treating such cases. Since these demands generally spread over a number of days, the accumulative demands resulting from consecutive daily distributions are most significant. The average demand rate for all cases over a period of time and the peak demand rate for emergency and critical cases resulting from random synthetic observations can be regarded as reasonably good estimates of service demands in the proposed hospital.

the service units corresponding to the items in the health care personnel and facility demand file are to be specified according to the current standards of hospital operations. These service units are expressed in terms of usage hours for facilities, such as 9 usage hours per day for an operating room or 20 usage hours per day for a delivery room, and are expressed in terms of working hours for personnel, such as an 8-hour shift for a nurse or a technician. By determining the service rates for various cases on the basis of the information in the demand file and the service unit file, a preliminary plan for providing adequate personnel and facility capacities to meet the demand rate of the proposed hospital can be generated.

Dynamic Effects on Preliminary Plan

Although the preliminary planning model shown in Figure 1 is useful in estimating the health care services for a proposed hospital based on community needs, it does not provide a mechanism for adjusting admissions and service rates through feedbacks from preliminary plans. Hence, a dynamic simulation model for detailed planning is introduced. This model, shown in Figure 2, makes use of the results of the preliminary planning as well as other inputs that may or may not be included in the preliminary planning model. The additional inputs for the dynamic model include: (1) the priority rating for admission, (2) the modes of variation in health care performance that may affect the accumulative demands, and (3) the preliminary plan resulting from the previous stage. Since many steps in Figure 2 are identical to those in Figure 1, only the difference between the two functional flow charts need be elaborated.

In Figure 2, the admission control of elective cases is based on the priority rating and the feedback from the service performance in meeting the predicted demands. Since the daily total number of patients admitted to the hospital is generated randomly according to the frequency distributions of various diseases, it varies over a period of time, reflecting seasonal variations and other time-dependent effects on certain diseases. Some other modes of variation such as epidemics or natural disasters may also be injected as random factors that may influence the demands for services through increasing either the illness rate or the death rate. As long as the elective admission cases can be placed on a waiting list, the daily demand without admission control is less important than the accumulative demand resulting from daily admission which must be adequately serviced. The peak demand for emergency cases must also be met. If the personnel and facility capacities in the preliminary plan of the proposed hospital are exceeded slightly over short periods of time, the overflow in demand will be regulated through admission control and by the modification of the services within the existing capacities. However, if the accumulative demand cannot be met by the service rates provided by existing capacities over a long period of time, or when the waiting list exceeds the tolerable range, the preliminary plan of proposed hospital must be modified.

The service rate of the proposed hospital can be modified either by changing service units or the capacities of personnel and facility. For example, by increasing the usage hours per day of the operating room or delivery room or by adding overtime to a working shift of the personnel, the service rate can be increased without increasing the capacities. If such arrangements are impossible or impractical, then the service rate can only be improved to meet the predicted demand by increasing the capacities in the preliminary plan.

After the service rate has been adjusted to meet the predicted demand, detailed information for case treatments as well as personnel and facilities will be generated in the final plan. The information for case treatments includes among other pertinent items the average number of trips per day made by various types of personnel in and out of a nursing unit, and the direct origin or destination to and from a nursing unit, as estimated on the basis of some statistical data on the commerce subsystem in a hospital.[3]

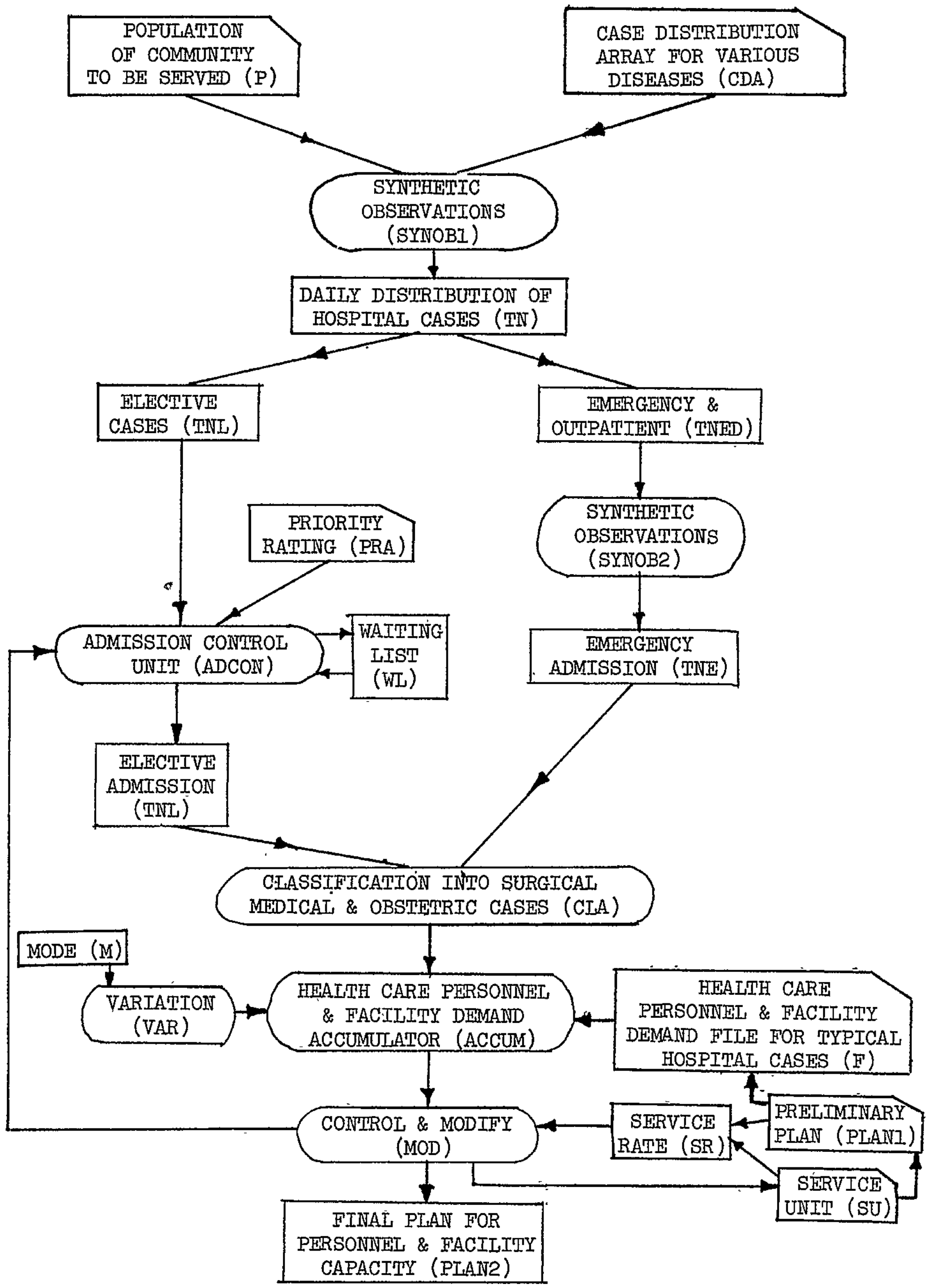
For fixed hospital personnel and facility capacities, the simulation model may also be used to improve the efficiency of operation by suggesting modifications to reschedule certain services. When peak personnel and facility demands are spotted, the intervals between various service or treatment requirements can be adjusted by the computer program to level off the health care personnel and facility demands. By manipulating the inputs to the dynamic model, the planner can investigate many pertinent factors affecting the design and operation of the proposed hospital.

Computer Programming

The computer program is written in APL (A Programming Language) which permits a flexible mode of processing.[4] The planning data can be expressed or reshaped into arrays by APL operators, which are defined for both scalar arguments and non-scalar arguments. The subroutines used in both stages of planning in Figures 1 and 2 are special APL functions which are constructed from the basic arithmetical and logical operators in APL. The functional operations of these special APL functions are listed in Table 1. The input data will be accepted and processed by these functions and the outputs are expressed in the form of arrays. The input and output can be handled in conversational mode on time sharing systems.

The APL functions in the computer program are short by conventional standards of algebraic computer languages since each APL statement is equivalent to many statements in the latter languages. Hence, it is convenient for manipulation in the development of programming logics of a new system. However, since the language is not compiled, it will be advisable to translate the completed program to a compiled language for production runs in order to reduce the running time.

Currently, the program is operational on IBM 360/67 time sharing system. Since the storage of the machine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EMERGENCY & OUTPATIENT (TNED)
PRIORITY RATING (PRA)
SYNTHETIC OBSERVATIONS (SYNOB2)
ADMISSION CONTROL UNIT (ADCON)
WAITING LIST (WL)
EMERGENCY ADMISSION (TNE)
ELECTIVE ADMISSION (TNL)
CLASSIFICATION INTO SURGICAL MEDICAL & OBSTETRIC CASES (CLA)
MODE (M)
VARIATION (VAR)
HEALTH CARE PERSONNEL & FACILITY DEMAND ACCUMULATOR (ACCUM)
HEALTH CARE PERSONNEL & FACILITY DEMAND FILE FOR TYPICAL HOSPITAL CASES (F)
CONTROL & MODIFY (MOD)
SERVICE RATE (SR)
PRELIMINARY PLAN (PLAN1)
SERVICE UNIT (SU)
FINAL PLAN FOR PERSONNEL & FACILITY CAPACITY (PLAN2)

FIGURE 2

Table 1 Operation of Special APL Functions

Special APL Function	Operation
SYNOB1	For generating occurrences of various hospital cases (elective, emergency and outpatient) based on statistical records by synthetic observations with the aid of a pseudo random number generator provided by the APL system.
SYNOB2	For including some outpatient cases for admission to the hospital and for discharging some emergency cases based upon synthetic observations of pseudo random numbers of certain probability distributions.
CLA	For breaking down hospital cases into surgical, medical and obstetrics cases according to the case percentages based upon statistical record.
ACCUM	For generating health care personnel and facility daily demand for all cases from synthetic observations over any specified period.
PP	For generating the average demand rate for all cases and peak demand rate for emergency and critical cases; and from these rates and the service unit file, generating the average and minimum demand units for the hospital over any period.
ADCON	For placing certain elective cases on the waiting list according to some prescribed priority rating when the predicted demand exceeds service capacity over a certain period of time.
MOD	For controlling admission of elective cases when certain predicted demand exceeds service capacity, for modifying service capacity or service units when the difference between the two exceeds certain specified criteria, and for generating detailed information for case treatments according to specified service rates.
VAR	For changing the demands for certain cases over a short period of time according to certain mode of case variation.

can accommodate arrays of up to one million bytes, the program can be modified to simulate essentially all aspects of health care planning for hospitals.

Simulation for Planning

The planning of health care for a proposed hospital may be viewed as a two state operation as represented by the functional flow charts in Figures 1 and 2. After a preliminary plan is generated for a proposed hospital, the operation under such a plan may be simulated over a long period of time in the second stage. Consequently, the short-term and long-term effects of various proposed alternatives for providing patient care can be thoroughly investigated.

The possible alternatives that can be investigated through the modification of inputs for the dynamic model in Figure 2 may be broadly classified into two categories: (1) environmental factors, and (2) administrative policy decisions. The former includes inputs for P, CDA and M, while the latter includes inputs for PRA, F, SU and PLAN1. The characteristics of the population (P) in the community to be served by the hospital, the case distribution array (CDA) of various types of diseases listed and the modes (M) of spontaneous variations will all be changed with respect to time. If some of the anticipated changes such as the growth or aging of the population, the rise and decline of certain disease rates, the trends of occupational hazards and safe guards, etc. are injected into the appropriate inputs, the effects of such environmental factors on service demands can be analyzed. For example, the change of the average number of days of hospitalization for any type of disease as prescribed by new medical practices can drastically affect the demand rate. On the other hand, the priority rating (PRA) for elective admission, health care personnel and facility demand file (F), service units (SU) and the preliminary plan (PLAN1) can be revised through administrative policy decisions in accordance with the changing health care practices. For example, if home health care for senile patients with no acute ailments becomes more prevalent and available in the community, the elective admission policy for routine checkups of this type of patient may be more restrictive. Similarly, the typical demands for health care personnel and facility for many types of diseases may be quite variable both with respect to individual cases and with respect to financing for hospitalization through third-party payment. The changes on these demands, including the methods of treatments, sequencing of treatments and length of hospitalization, are also influenced by the changes in medical practices. The service units for meeting demands including the commerce patterns in the proposed hospital are often dictated by administrative policies on the usage of facilities and personnel that are compatible with local conditions; and the final decision on the capacities may be based partly on the financial commitment of the institution as well as the health care needs of the community.

By injecting any or all of the above mentioned factors into the model, a complete cycle of planning can be simulated. The time period used can be one month, one year or five years. For the purpose of planning actual operations in an existing hospital, a one month period is quite sufficient. For the long range planning of new hospitals or an extensive addition to a new hospital, the capability to simulate over a long period of time, say one year or five years, will enable the planner to make plans for meeting current demands but also for the preparation of future expansions.

The simulation process for planning health care in a proposed hospital can best be illustrated by means of an example. While the data used are not taken from any specific real project, they are within the ranges of current hospital design practices.[5] Only the most significant steps in the process will be described in detail.

Suppose that a hospital is planned to serve a "typical" community with a population of a quarter of a million. In preliminary planning, the annual averages of daily case distributions of various types of diseases per 100,000 population which are given for each of the elective, emergency and outpatient hospital cases may be used. The following is an example of an array for emergency cases:

Disease Type	1	2	3	4	5	6 ...	12	13	14
Mean	1	2	17	14	1	12 ...	14	6	3
Deviation	1	1	2	2	1	1 ...	4	1	1

The daily distribution of hospital cases per 100,000 population can be generated randomly by synthetic observations and converted into the number of cases for the given population. The number of emergency admissions is also generated by taking certain percentages of various emergency and outpatient cases by synthetic observation, and elective admission will be permitted when there are vacent beds in the specified category. (Obstetric beds are separated from other beds in this case, but more classifications can be added.) Since the hospital is assumed to be empty at the beginning, it takes approximately 14 days to stabilize the number of admission cases which are automatically classified into medical, surgical and obstetric cases according to the nature of the diseases. The health care personnel and facility demand file contains typical treatment of each type of disease in an array showing the 15 items of demand in appropriate units for each day required for hospitalization. For example, for a surgical case with 7 days of hospitalization, the first five of the 15 items in the file appear as follows:

1.	General bed (bed)	1	1	1	1	1	1	1
2.	Obstetric bed (bed)	0	0	0	0	0	0	0
3.	Operating rooms (hrs)	0	3	0	0	0	0	0
4.	Delivery rooms (hrs)	0	0	0	0	0	0	0
5.	General Lab. (hrs)	2	0	1	1	1	0	0
⋮								

Thus, the demand rates for services over a specified period of time can be accumulated through the accumulator. In general, the services rendered to all emergency admission cases in the first three days must follow the typical treatment profile but after this initial period, services will be scheduled when personnel and facility become available. The service units for the 15 items of personnel and facility are specified by numbers corresponding to appropriate units as follows:

1 1 9 20 8 8 8 12 12 8 8 8 8 8 8

in which the first two numbers have the unit of beds, the next seven numbers have the unit of usage hours, and the last five numbers have the unit of hours per shift per person. Finally, the preliminary plan lists the required capacities of the same 15 items on the basis of the average demand rate for all hospital cases and the peak demand rates for emergency and critical cases in the form of:

976 246 10 8 12 10 12 10 8 3 180 360 120 60 80

in which the first number represents 976 general beds, the second number represents 246 obstetric beds, etc.

The adequacy of the preliminary plan thus generated may be checked by using the dynamic model. For example, if the seasonal averages of daily case distributions of various types of diseases instead of the annual averages are used, different results will be obtained for a 30 day simulation. The priority rating for elective admission in the dynamic model will be based on two criteria: (1) a specified percentage for certain types of diseases which are deemed more likely to become critical, and (2) the remaining percentage with highest priority for cases with shortest expected length of hospitalization. The control-and-modify function will check the accumulated demand rates against the service rates. If the predicted accumulative demand rate in the next fourteen days for any item of service exceeds the latter by 10% or more, it will cause the adjustment of service units, or the change of capacities in the preliminary plan when the adjustment of service units is restricted up to certain allowable ranges. The control-and-modify function also performs the task of deriving additional information for the personnel and facility capacities finally adopted.

Problems Related to Application

The dynamic model for planning health care presented in this paper contains essentially the logics and formats of a computer program necessary for application to hospital planning. However, each planner may wish to introduce some specific refinements to the model, several of which merit special attention.

The statistical data on case distributions of diseases are based approximately on a "typical" population participating in a group health insurance plan. If other data that are more representative of the health statistics of the community are available or obtainable, naturally more reliable data should be used. The assumption of normal distribution for the case distributions of diseases in the generation of random synthetic observations is justifiable when the daily hospital cases generated are large, such as in the case of the example cited. For small daily hospital cases, the Poisson distribution will be a more logical representation so that the rarer disease type will occur occasionally even though the number of occurrence may be zero most of the time. (In using normal distribution, any daily number of occurrence less than one will be truncated.)

The output data on personnel and facility capacities can be converted to space requirements if desired. For example, the capacity of 10 operating rooms can be converted to square feet of floor area once the sizes of such rooms have been established. Similarly, four units of X-ray equipment each operated by one technician working one shift daily will permit the estimation of floor area required. Refinements such as these examples can easily be incorporated in the model if pertinent data are available.

In planning for a new hospital, the prediction of community growth and other future events is inherently uncertain. Hence, the probabilistic nature of the planning problem should be recognized when experimenting with the model for decision making. In adapting the model to planning of health care in an existing hospital, actual data instead of randomly generated synthetic observations may be used as inputs on a day to day basis. Some of the features in the model may also be modified for such specific purpose.

Conclusion

The dynamic simulation model for planning health care presented in this paper is a step forward to provide a general procedure or methodology in planning adequate personnel and facility capacities in hospitals to meet ever-changing health care demands and technologies in the modern society. It allows the planner to experiment with various alternatives on the simulation model without paying the price of making erroneous decisions in the real world.

Although the logics and the formats of the computer program are essentially applicable to real problems, the running time will be considerably reduced if the computer program is converted to a compiled language. Further refinements may be made by individual planners to suit their own preferences, particularly if the model is to be adapted for application to planning health care operations in existing hospitals.

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