THE SIMULATION OF HOSPITAL PATIENT TREATMENT SYSTEMS

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Abstract

A simulation model of function-oriented patient treatment systems in general hospitals is proposed for studying the effectiveness of scheduling diagnostic and clinical treatments for patients. The effectiveness of a system can be measured by a number of criteria. The simulation model is characterized by a computerized procedure for generating a tentative feasible schedule and for improving the schedule according to certain heuristics. Possible applications of the simulated model are briefly discussed.

1. INTRODUCTION

This paper presents a simulation model of function-oriented patient treatment systems in general hospitals. The primary objective of constructing such a model is to investigate the effects of patient treatment systems on proposed facilities of new hospitals or new alterations to existing hospitals. A second objective is to provide a practical procedure for improving the effectiveness of scheduling diagnostic and clinical treatments for patients in general hospitals.

There are some characteristics in the scheduling of patient treatments in hospitals which are similar to those in job shop scheduling. This latter problem has been treated extensively and a review of the published works on the subject has been succinctly given by Mellor.[1] Of particular interest in connection with the present investigation is a paper by Gere[2] in which the heuristics in job shop scheduling are discussed. A major distinction between the hospital patient treatment scheduling and job shop scheduling is the importance of the inclusion of transportation time for the former, as evidenced in a study of the commerce subsystem in hospitals made by Souder, Clark, Elkind and Brown.[3] It is also important, particularly for planning new hospitals or new alterations, to provide in the model the flexibility of allowing alternate sequences of treatments and for varying the sizes of treatment groups that provide services to patients.

The effectiveness of a hospital patient treatment system can be measured by a number of criteria, such as the total waiting time of the patients and/or the total idle time of the treatment groups in the hospital. The scheduling of patient treatments has been structured as a heuristic procedure based on a priority rating of the patient's treatments to generate a tentative feasible schedule although this priority may be superseded by a preferential treatment heuristic. The tentative schedule is then improved by the use of two other heuristics for selecting alternate sequences of treatments and treatment group sizes.

In the planning stage of new hospitals or new alterations, the information to be submitted to the system can only be hypothetical, using data from other similar hospitals as a guide. Even in the study of the effectiveness of patient treatment systems in existing hospitals, the available data must be reorganized in a manner that permits meaningful analysis by the procedure. Hence, at the start of the project, it was decided to concentrate on the construction of an idealized model first, leaving the tasks of collection and organization of data from existing hospitals to a secondary role. The term "simulation" is used here only to convey the notion of computer manipulation of a proposed model, and does not refer to the replication of an existing system.

2. THE CONCEPTUAL MODEL

The medical service that a patient receives at a hospital is characterized by a series of treatments performed on him. In order to generate a feasible schedule for a group of patients in a hospital at any given time, it is necessary to consider the functional structure of the patient treatment system. The major components in this function-oriented system are as follows:

(1) Treatment groups. The term "treatment group" is used to denote a functional group which is capable of performing a treatment on patients within the physical boundary of the group. The capacity, or size, of a treatment group is indicated by the number of patients that the group can treat simultaneously, and the capacity is generally constrained by the equipment, space, and personnel available to the group. Furthermore, each treatment group may be composed of individual treatment facilities. Each individual treatment facility within a treatment group is considered as a separate unit of specified capacity.

(2) Patient treatment files. The term "patient treatment file" is used to denote the information on all the work to be done in order to complete the required treatments for a patient as specified by the physician. For each patient admitted to the hospital, the file contains information on the number and type of treatments, the sequence of treatments, alternate sequences of treatments if allowed, and the desired completion time for all treatments.

(3) Patient transportation. The term "patient transportation" refers to the process of moving patients from one treatment group to another for the purpose of treatment. The amount of time that a patient spends in the process is recognized as the period in which he has a significant probability of encountering discomfort and exposure to cross infection.

The patient treatment system of general hospitals is, therefore, characterized by a decision process of scheduling treatment groups for patient treatments including the transportation of patients from one group to another. The information on the treatment groups, patient treatment files and patient transportation at any specified time will be contained in the hospital data file which constitutes the input to the system. A feasible schedule, which has been improved upon by using a number of

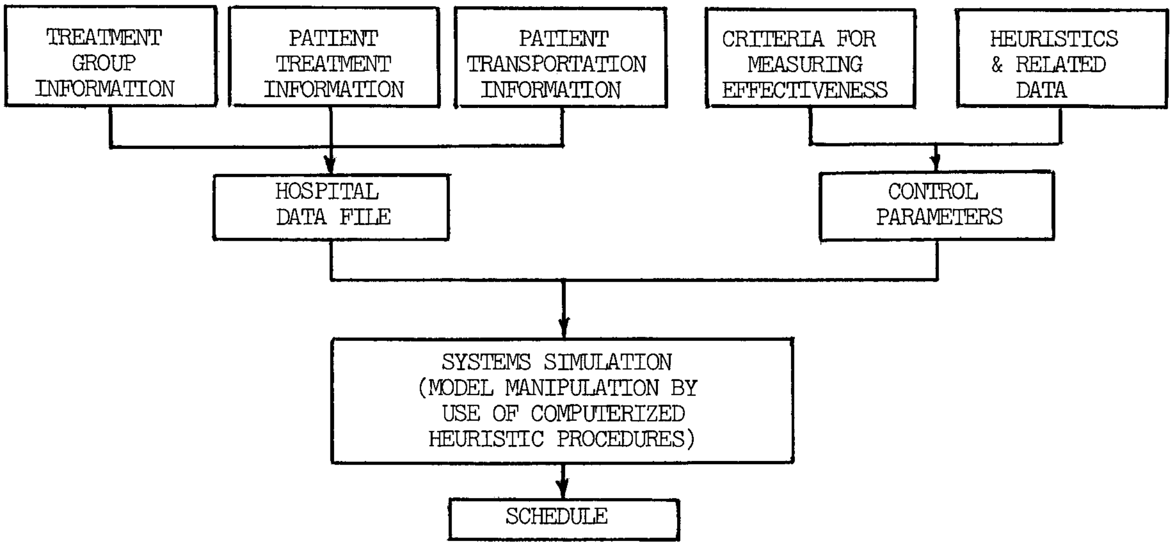

FIGURE 1
THE CONCEPTUAL MODEL

heuristics to search for better solutions in the solution space, will be the output of the system. An objective function selected by the hospital management will be used as a measure of effectiveness of the system. Thus, decision making for centralized scheduling remains the responsibility of the hospital management. The basic structure of the conceptual model is shown in Fig. 1.

The unit of throughput in the system can be expressed in time, cost, or other units, depending on the criteria for measuring effectiveness. In general, time is the prime unit since the throughputs for all components of the system can be calibrated in time, i.e., treatment time and transportation time. Less directly, the unit can also be converted into cost since all performances involve either equipment or personnel or both to which monetary value may be attached.

In order to match the function-oriented system with the actual treatment system in a hospital, actual data must be available. Furthermore, each hospital must use its own data in order to synthesize a system which is representative of its patient treatment activities. The degree of resemblance to reality certainly depends on the data collection and organization. Hence, some tradeoff must be made between the accuracy of information and the cost of data collection in the synthesis of the system.

3. ASSUMPTIONS AND HEURISTICS

Since the function-oriented patient treatment system just described is extremely complex and to a large extent depends on the organization of the functions in a hospital, the following simplifying assumptions have been made in the analysis of the model:

(1) Time for each treatment for a patient is predetermined and such treatment times are used in computing the time required to complete the total care of a patient.

(2) Treatment times are independent of the sequence of treatments. The time required for treatment preparations is not considered separately.

(3) No split treatments are permitted. Once a treatment is started it cannot be

interrupted. No patient can preempt another patient.

(4) Each patient can receive no more than one treatment at a time.

(5) The desired completion time for each patient is preassigned.

(6) The transportation time from one treatment time in the former group in computing the time required to complete the total care of a patient. No transportation time is added to the treatment time for the last treatment in a sequence of treatments.

(7) During the slack (waiting time) for the next treatment, the patient is assumed to return to his nursing unit.

(8) The size of each treatment group remains the same as initially specified, unless the group size heuristic is used as explained later.

The above assumptions are reasonably realistic although some of them are open to arguments. However, even with such simplifications, the task of solving the hospital patient treatment system as an integer programming problem is prohibitively complex. Hence, heuristic procedures are suggested.

A computerized heuristic procedure has been developed for generating a tentative feasible schedule and for improving the schedule in accordance with certain rules or heuristics. The priority rating of the patient's treatments is used to generate a tentative feasible schedule although this priority rating heuristic may be superseded by a preferential treatment heuristic which poses certain questions and provides different binary choices. The tentative schedule can be improved by the use of two other heuristics invoking questions on alternate sequences of treatments and treatment group sizes.

A tentative feasible schedule can be generated by screening the priority rating for each patient. The priority rating of a patient is not a constant but a variable that, at any instant, is a measure of the amount of slack time associated with a patient. The time required to complete the total care of a patient is computed by summing the times required for remaining treatments, at that instant, plus the times required for transportation between treatment groups. The priority rating for a patient is equal to the current clock time plus the time required to complete the total care for the patient (excluding delays) minus the desired completion time. A positive priority rating indicates that a patient's care cannot be completed by the desired completion time. A priority rating of zero indicates that a patient's care in the hospital can be finished by the desired completion time if no delays are encountered. A patient's care is said to be critical if his rating is positive.

As an illustration of the computation of priority ratings, consider the example that a patient requires 10 units of time to complete his care, the current clock time is 12, and the patient's desired completion time is 22. The patient has a current priority rating of zero ($12 + 10 - 22 = 0$), indicating that the patient's care can just be finished by the desired completion time if no delays are encountered. However, if the desired completion time were 24 instead of 22, the priority rating would be -2 ($12 + 10 - 24 = -2$). This priority rating would indicate that the patient's care could be finished by the desired completion time even if delays, totaling a maximum of 2 units of time, were encountered.

In scheduling patients for treatments, whenever two or more patients are eligible to use the same treatment group at the same time, preference is given to the patient with the highest priority rating except when the preferential treatment heuristic decides otherwise. The preferential treatment heuristic automatically screens the patient that has been selected for a particular treatment on the basis of the priority rating and asks the following two questions: (1) If this patient is scheduled for the treatment now, will the care of any other patient waiting for the same treatment group become critical because of the delay caused by this patient? (2) Is there another patient, in the queue for this treatment group, such that if the treatment for this patient were scheduled (instead of the one with the highest priority rating), the care of none of the other patients in the queue would become critical? For the sake of illustration, let the patient with the highest priority rating, referred to in question 1, be designated as A, and the other patient referred to in question 2, be designated as B. Then, the preferential treatment heuristic will impose the following choices:

(a) If the answer to the first question is no and that to the second is yes, schedule A.
(b) If the answers to both questions are no, schedule A.
(c) If the answers to both questions are yes, schedule B.
(d) If the answer to the first question is yes and that to the second is no, schedule A.

The alternate sequence heuristic provides a means for determining how the entire schedule will be affected by using alternate sequences of treatments. The alternate sequence heuristic examines the original and suggested alternate sequences, and substitutes, one at a time, the original sequence of one of the patients by an alternate sequence. A new schedule is then generated on the basis of the alternate sequence and evaluated against the best schedule found thus far. If the alternate sequence leads to a more effective schedule according to the criteria specified by the hospital management, the alternate sequence is kept; otherwise it is discarded. Any number of alternate sequences can be specified for each patient, and for each time an alternate sequence is examined, a schedule is generated.

The group size heuristic provides a means for evaluating the efficiency of treatment groups and altering their size. The efficiency of a treatment group is a measure of the percentage of time that the group is busy. This heuristic determines the percentage of time that a group is idle and compares it with the acceptable performance parameters. The performance parameters are (1) maximum percentage of time that any group should be busy, and (2) maximum percentage of time that any group should be idle. The size of any group can be specified as fixed. If the size of a group is specified as fixed, then the heuristic will not alter the capacity of this group under any circumstances. If the size of a group is not fixed, then the size will be altered if (1) the percentage of idle time is more than the maximum allowable, or (2) the percentage of busy time is more than the maximum allowable. In the first instance, the group size will be decreased by one. In the second instance, the group size will be increased by one. The same procedure will be followed for each group. After the sizes of various groups are altered, a new schedule is generated and the group size heuristic is used again. The same procedure will be repeated until the efficiency of every group falls within the acceptable performance range (except for those groups with a fixed size).

4. THE SIMULATION PROCESS

The simulation process is used to portray the hospital management decision making in scheduling treatment groups for patient treatments, including the transportation of patients, by specifying the criterion of effectiveness and the heuristics for improving schedules. Thus, the input to the model can be divided into two main categories: (1) hospital data file and (2) control parameters. The hospital data file contains information about treatment groups, patient treatments, and patient transportation. The control parameters include criteria for measuring effectiveness, and heuristics for improving schedules and related factors.

The total number of treatment groups, the treatment group required for each treatment, and the capacity or size of each group are included in the treatment group information. The patient treatment information includes total number of patients, maximum number of treatments per patient, desired completion time for each patient, total number of treatments for each patient, and time required for each treatment of each patient. The information about patient transportation includes the nursing unit for each patient, distances between treatment groups including nursing units, and a conversion factor. This conversion factor is used to calculate the time required to travel between treatment groups given the distance between these groups.

The criterion for measuring effectiveness of a system may be selected from one of the four criteria included in the procedure as follows:

(1) Minimization of the total time for the schedule.
(2) Minimization of the total sum of all delays in the actual completion time beyond the desired completion time.
(3) Minimization of the total idle time of treatment groups.
(4) Minimization of the total waiting times for patients.

The information concerning the selection of heuristics includes the specifications of the use of alternate sequence heuristic and/or the group size heuristic, and the related factors such as the percentage of time that a treatment group should be idle, etc.

In the process of scheduling patients for treatments it is necessary to always have accurate answers to certain questions as follows: What is the latest time to which each patient is scheduled? What is the latest time to which each individual treatment facility is scheduled? What is the next treatment for each patient? The patient and treatment chosen for scheduling by the priority rating heuristic constitute the tentative selection which is actually scheduled, unless it is superseded by the preferential treatment heuristic.

In order to improve the tentative schedule, if possible, and to evaluate the improved schedule, the alternate sequence heuristic will be used to examine any number of sets of alternate sequences of treatments for any or all patients. If an alternate sequence of treatments improves the effectiveness of the schedule it is retained; otherwise it is discarded. The group size heuristic is a procedure that can be used to find the best size for each treatment group. In order to use this heuristic the acceptable performance limits for the service groups must be specified. These limits are: the maximum percentage of time that a treatment group should be idle, and the maximum percentage of time that a treatment group should be busy. The group size heuristic alters the size of each group, unless the size of a particular group is fixed, until all have acceptable performance ratings.

5. THE COMPUTER PROGRAM

The computer program consists of two main segments. The first segment generates a feasible schedule while the second segment evaluates and attempts to improve the schedule. The former contains the priority rating heuristic and the preferential treatment heuristic while the latter is composed of the alternate sequence heuristic and the group size heuristic. The program has been designed to handle problems of significant size. Any units of time desired can be used since the program is not based on any unit in particular (i.e., minutes, hours, or days).

The master flow chart for the computer program is shown in Fig. 2. The program is written in FORTRAN V for operation on a UNIVAC 1108 computer. Without exceeding the core storage, the program can be used for problems of the following combinations: (1) up to 200 patients, (2) up to 20 treatments per patient, and (3) up to 100 individual treatment facilities. The choice of the computer language has been influenced by the consideration of possibly combining the use of this program with other existing programs for allocation of facilities written in this language. An example is the heuristic algorithm for optimizing relative locations of facilities currently available in the form of CRAFT[4] (Computerized Relative Allocation of Facilities Technique), which can be adapted to generate preliminary hospital layouts as inputs to this program.

The input for the program includes: (1) desired completion time for each patient, (2) total number of treatments for each patient, (3) treatment group required for each treatment, (4) time required for each treatment, (5) a set of control parameters indicating which heuristics should be used, and (6) additional information for any alternate sequences included.

The output includes (1) total number of patients processed , (2) size of each treatment group, (3) time required for each treatment of each patient, (4) time required to travel between treatment groups, (5) total number of treatments, desired completion time, and minimum total treatment time for each patient, (6) a complete schedule for all patients, and (7) total idle and busy time for each individual treatment facility.

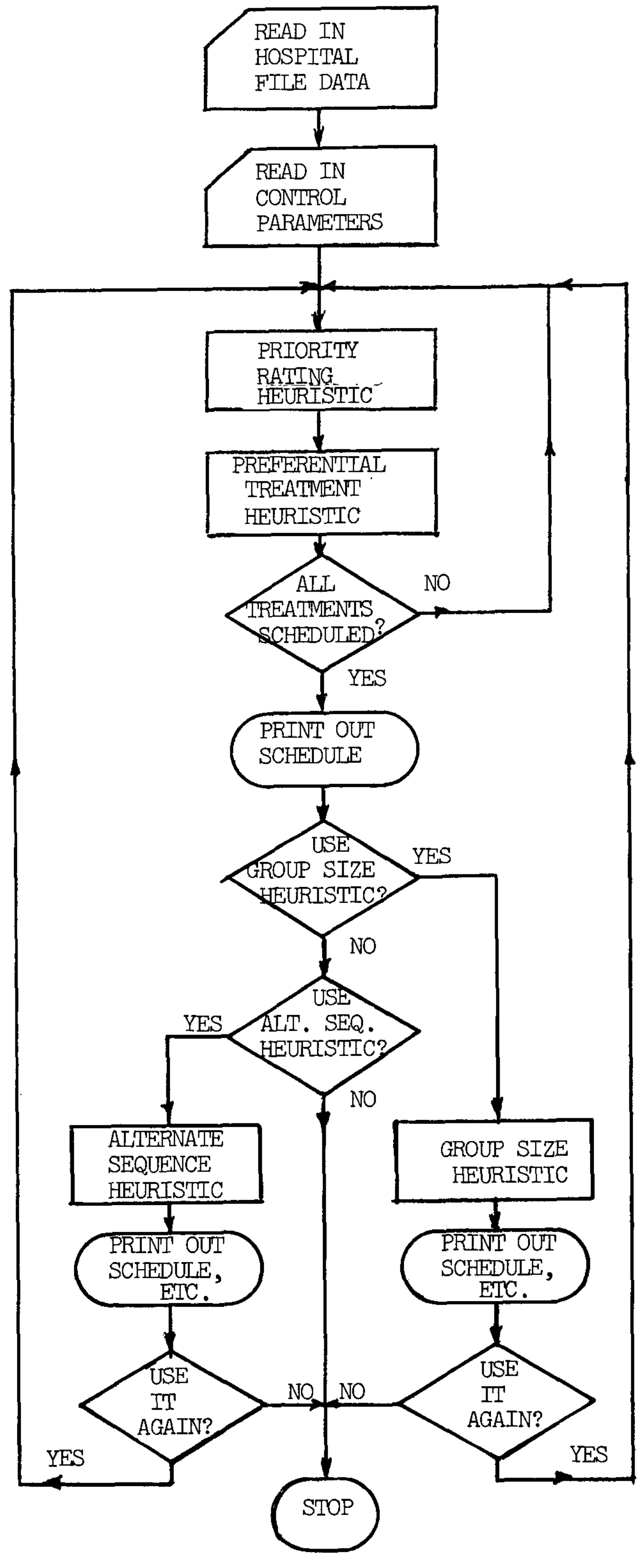

FIGURE 2

MASTER FLOW CHART OF THE GENERAL PROGRAM

Trial runs have been made with synthetic data to test the program by generating feasible schedules. In addition, the group size heuristic has been used in these runs to determine the proper size for each group, and the alternate sequence heuristic has also been used to select alternate sequences of treatments that improve the schedule. The former heuristic suggests proper sizes of treatment groups in order to meet the desired completion times for all patients. On the other hand, the total treatment time for all patients can be adjusted by using the latter heuristics. Thus, by the manipulation of these two heuristics, information on the adequacy of treatment group sizes can be determined. This information is particularly useful for planning new hospitals or new alterations to existing hospitals.

6. POSSIBLE APPLICATIONS

The objectives of the hospital management are as multifold as its responsibilities to the patients, to the profession and to the community. In order to place all of these objectives in a single criterion for decision making, the relative scale of values must be quantified. Since this is not a realizable goal at the present time, several criteria for measuring effectiveness have been included. The hospital management may select one of them at a time and compare the consequences of selecting different criteria. Once a criterion for measuring effectiveness is specified, the program may be used to generate and evaluate schedules for patient treatments.

This program may be used to study the effect of patient treatment systems on hospital layouts, particularly when it is linked to other programs for optimizing relative locations of facilities such as CRAFT. Since the interdepartmental commerce in a hospital in general, and the transportation of patients in particular, are dependent on the layout of the hospital, the total cost of interdepartmental commerce should be a major consideration in selecting a layout for a new hospital. For example, if the total cost of interdepartmental commerce is found to be near minimum for a number of layouts, it is then possible to use each layout as input to the patient treatment system to determine the relative merit of each layout. Thus, by using synthetic data, different factors affecting the effectiveness of the system may be investigated by varying each of these factors, in using the computer program. For example, several hospital layouts which are deemed to be reasonably satisfactory may be compared against each of the criteria for measuring effectiveness and/or against an anticipated set of hospital data files which are time-dependent. Thus, the planners of the hospital may decide intelligently which layout should be chosen. On the other hand, for a given hospital layout and a specified criterion for measuring effectiveness, the simulation model may be used to help the hospital management in scheduling patient treatments in various departments of the hospital.

In using this program for scheduling patient treatments in an existing hospital, actual data for that particular hospital must be accurately gathered and systematically organized for the function-oriented patient treatment system. Since a schedule generated from the current hospital data file will cover a period of time, the changes of required patient treatments during that period often make it necessary to update the schedule periodically. Thus, the hospital data file should be updated periodically and the new information can be input into the system for rescheduling. For example, the schedule generated in the first run may cover a period of one week, but a new run can be made every day, each resulting in a schedule covering a period of one week beginning from the day of the latest run. The updated hospital data file for each new run will contain not only the treatments yet to be performed from the previous run but also new treatments added to the file. Treatments that have been completed or cancelled since the previous run will be deleted. The addition of treatments may be caused by changed orders for the existing group of patients and/or by new patients admitted to the hospital; similarly, the deletion of treatments may be caused by changed orders for the existing group of patients and/or by the unexpected departure of some patients from the hospital in the time period. With slight modifications of the computer program, partial rescheduling instead of complete rescheduling can be made, if desired. Thus, certain treatments already scheduled for the existing group of patients will not be disturbed by the influx of new patients and/or new treatments over a specified period of time.

7. CONCLUSIONS

This paper has presented a pilot study for the patient treatment system in general hospitals. The study involves the simulation of a proposed model which is guided by heuristics that have been constructed for the manipulation of different variables in scheduling patient treatments in general hospitals with the objective of improving the effectiveness of the patient treatments. The difference between a function-oriented patient treatment system and the department-oriented patient treatments in a hospital must be recognized in order to make use of this model. Thus, the data from any hospital, when they are available, must be reorganized for this purpose.

A number of improvements of the conceptual model can be made. For example, in this present model, the scheduling has been done on a continuous time basis until the scheduled treatments are completed. In order to schedule treatments for 8 hour workdays, periodical non-working intervals must be included in the scheduling to account for the time when the treatment groups are closed to patients. If the simulation model is to be used on a day to day basis by a particular hospital for generating schedules, modifications must be made.

In spite of the exploratory nature of the study, the simulation model provides a useful framework for testing the relative significance of various factors in the patient treatment system in general hospitals, and for providing guidance to collect field data for a better model. The task of collection and reduction of actual data from hospitals, of course, remains to be performed for the fulfillment of a realistic simulation model.

8. ACKNOWLEDGMENT

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10. BIOGRAPHIES

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