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AN ONLINE, SIMULATION-BASED PATIENT SCHEDULING SYSTEM

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ABSTRACT

In this research, the application of on-line simulation for patient scheduling decision support in a clinical environment is investigated. A prototype system was designed and constructed to demonstrate the concepts and to address various problems to be faced in implementation of the system.

1. INTRODUCTION

Delivering quality health care at a reasonable cost and in a timely manner has become a fundamental issue that must be addressed by all health care enterprises. Coordinating the administrative aspects of patient care delivery, however, is consuming more staff time and becoming increasingly complex. Detailed examination of Patient Care Coordinator (PCC) activities in a clinical service at the University of Washington Medical Center found that substantial time and effort are expended in coordinating patient and medical resources. The inefficient use of patient care professional time is mainly caused by complex issues concerning allocation over time of limited and highly interdependent resources, and uncertainty surrounding the prospect of treatment. Response to the dynamic allocation of resources above can be categorized as scheduling problem (Roberts 1981, Crowstone and Malone 1993). With an anticipated growth of out-patient service demand, the severity of these scheduling issues are expected to escalate.

A Mohs-micrographic controlled surgery for skin cancer treatment facility at University of Washington was selected as a case study for investigation of scheduling issues in health care organizations. The current approach to patient management is based on long-range calendar planning between patient and medical resources. However, because the real-time activities involved in coordinating health care delivery are subject to a great deal of variance and unexpected change, there is a need to study the dynamic behavior of the system and be able to prepare for the consequences of the changes to the patient treatment schedule.

In the research reported here, we examine a simulation modeling approach for scheduling patients in medical clinics. Traditional use of simulation to study the behavior of the system and address off-line decision making has been performed (Roberts, 1981 and Pardue, 1995). However, long-range scheduling developed off-line is static and will quickly lose its validity in a rapidly changing situation. Recently there has been an increasing interest in the development and use of simulation for real-time and continuous analysis in area of manufacturing, (Drake, Smith, Peters 1995 and Harmonosky 1990). This type of simulation is categorized as on-line simulation. Distinctively, an on-line simulation refers to continuous simulation run and update with data input and output from physical system in real-time. On-line simulation provides the advantages of a "look ahead" and "what-if" capabilities in real-time manner while continuously monitoring the system. The combination of both features provides continuous decision support to determine the next incident to occur and anticipate the actions to be executed (Harmonosky 1995).

The paper examines the coordination of multiple resource allocation and resource sharing dependencies among several closely related specialty clinics within the University of Washington Medical Center. We also report on development of a prototype for real-time scheduling using on-line simulation concepts.

2. PROBLEM DESCRIPTION

2.1. Workflow Overview

A Mohs-micrographic controlled surgery for skin cancer treatment includes the following basic treatments: 1) registration, 2) evaluation, 3) the Mohs surgery, and 4) reconstructive surgery. The initial visits by the patient are primarily concerned with administrative activities undertaken by a Patient Care Coordinator (PCC): gathering patient medical records, demographic data, and financial status (i.e., insurance policy/managed care). Once these activities are completed, the patient is scheduled for evaluation and/or examinations. Figure 1 illustrates the overall Mohs Treatment workflow for patients.

Evaluation, which includes detection, and test for malignancy, are performed between 1:00 PM and 3:30 PM, Monday, Tuesday and Wednesday. If the patient lesion is suspected of being cancerous, then a biopsy is performed. The tissue is sent to pathology laboratory for vigorous histological evaluation. Pathology results are available in about three days. If the biopsied tissue test result is a positive malignancy, the patient is scheduled for surgery.

The Mohs-micrographic controlled surgery hours of operation are 8:00 AM until 11:00 PM, Monday, Tuesday, Wednesday and Thursday. Once the patient arrives for surgery, the patient is assigned to one of the surgery suites and receives pre-biopsied treatment such as local anesthesia. Next, Mohs surgery is performed by removing a section (a section corresponds to a thin horizontal layer of the skin in a grid pattern) around the cancerous area. The layer then is examined microscopically by the histologist for evidence of cancer cells. During this investigation, the patient is taken into the post-treatment area, and the doctor will begin to treat another patient. If the inspection of the layer by the histologist is found to still contain malignant cells, the doctor continues to remove a layer

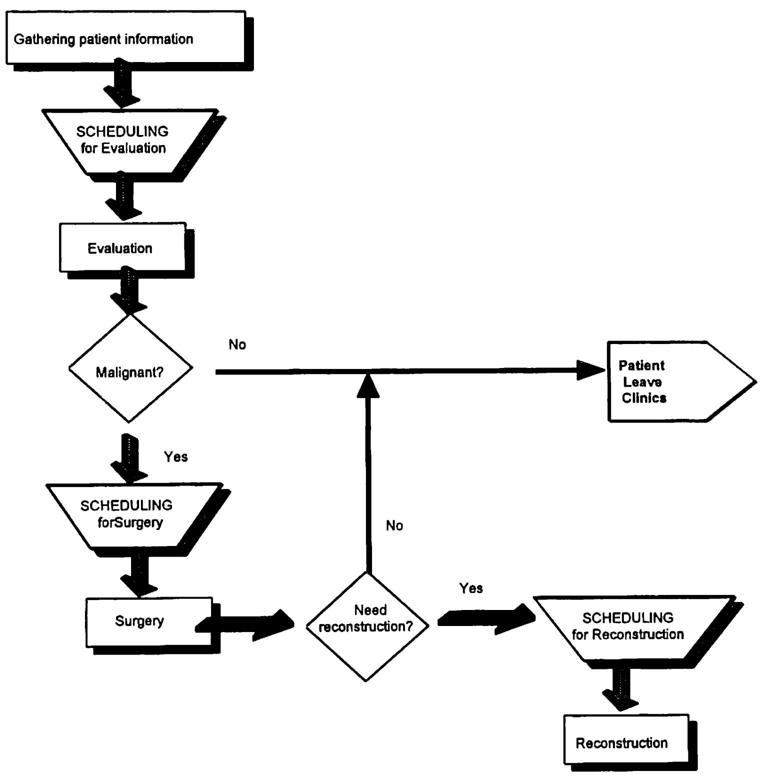

Figure 1. Mohs Treatment Workflow Overview

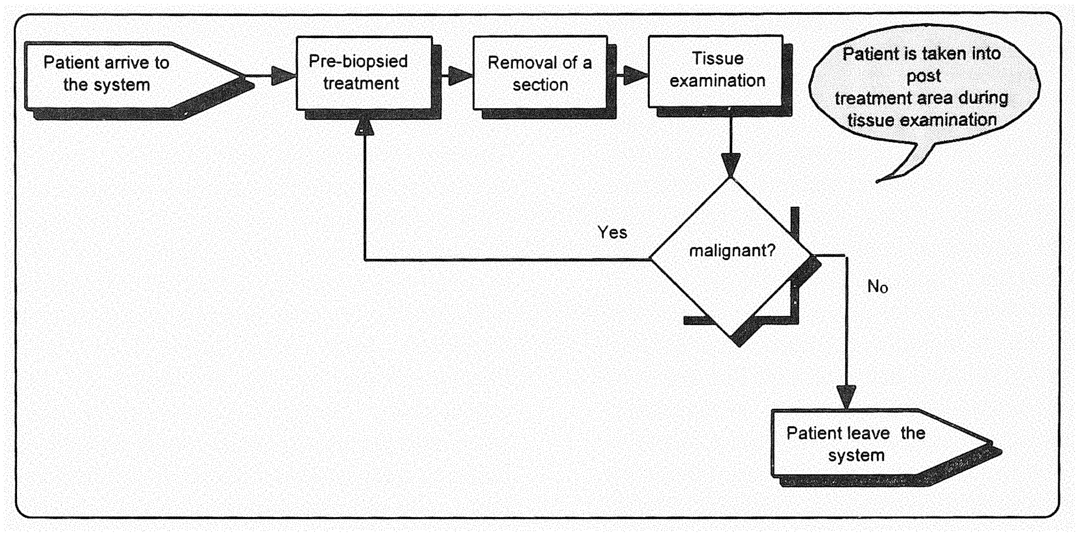

Figure 2. Mohs Surgery Process Flow

of tissue until no margin of malignancy exist (see figure 2).

A patient blocking situation may occur when the doctor has finished performing an excision, yet the histologist is still working on the previous patient's tissue. The number of sections to be removed are estimated during patient evaluation and subsequently used as the basis for scheduling time needed for the patient's surgery. Table 1 contains the treatment resources available.

Resource Description	Quantity
Mohs Doctor	1
Nurses	3
Histologists	1
Medical Assistance	1
Surgery Suites	2

Table 1. Mohs Treatment Resources

There are three types of carcinomas: basal cell carcinoma, squamous cell carcinoma, and malignant melanoma. Patients with malignant melanoma malignancy need to be treated in two sequential contiguous days. Patients with a larger lesion have to go through reconstruction in the Otolaryngology clinic. The hours of reconstruction are Tuesday and Thursday from 1:30PM to 3:30PM. Reconstructions usually are performed within two days after surgery and carried out in the operating room which is shared with other out-patient clinics. Currently, the activities in reconstruction including the interdependent scheduling for Mohs Surgery are not included in this study.

2.2. Scheduling Issues

For Mohs surgery, scheduling of patients is performed by a Patient Care Coordinator (PCC). Negotiation occurs in scheduling both the patient and the medical resources. To determine a schedule for surgery, the PCC has to estimate the processing time of the tasks, the time the patient has to arrive to the clinic and the availability of the medical resources.

The PCC also has to estimate the maximum time needed for the predicted number of sections to be removed for every patient. The maximum duration for all patients in a day contributes to the total completion time which should fit within the Mohs Treatment clinic hours of operation. Fitting this estimated duration of tasks to the hours of the operation is heavily dependent on the experience of the PCC. A delay in processing of one patient beyond the estimated time will cause delay in treatments for successor patients; hence, increasing the completion time and so the lateness of the Mohs surgery operation hours.

In more severe cases, a delay in Mohs surgery could postpone the schedule for subsequent reconstruction treatment. Reconstructive surgery is dictated by the availability of the resources which must be coordinated with Mohs surgery patients.

Complexities increase for patients with two contiguous days of surgery (in the case of malignant melanoma and reconstruction); any delay can cause the whole system to become congested. To avoid these circumstances, PCCs are forced to increase slack time in the Mohs surgery clinic schedule to accommodate the unexpected. Not only this relaxation of schedule is not optimal, but it also introduces significant clinic inefficiency. Externally, frequent changes of patient and medical resource schedule and duration of treatment require continuous schedule negotiation.

With the complexities of coordinating patient schedules to meet with the resource constraints in an efficient and adaptive response, the current physical system needs a way to *look-ahead* and perform *what-if* analysis in a real-time.

3. FRAMEWORK OF ON-LINE SIMULATION SCHEDULING SYSTEM

3.1. System Framework

In following section, we discuss the development of a real-time scheduling system using the concepts of on-line simulation. The generic scheduling system framework includes the following elements: the human user interface system, a database management system, and a discrete-events simulation engine. See Figure 3.

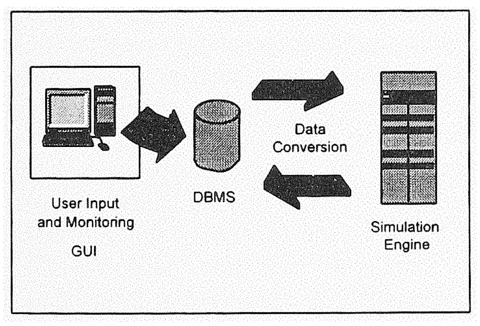

Figure 3. Patient Scheduling System Framework

The graphical user interface provides a means of entering an event schedule into the system. The database stores the value of variables such arrival times of the patients, the diagnosis of treatment, and, eventually, the time the patient leaves the system. The simulation engine provide the simulation capability to examine and predict the behavior of the system according to the variables stored in the database.

The value of major treatment variables are entered by the PCC : the arrival time to the Dermatology clinic, the number of sections to be removed, the type of malignancy (for each patient), and the availability of medical resources. When the user requests execution of the simulation model, the data is then feed to the simulation engine from the database. The simulation output then is stored back into the database and can be examined by the user in the monitoring window.

The simulation output provides statistical analysis on the departure time of the last patient, duration of each patient's treatments and characteristics of the system based on the selected patients. Using these *look-ahead* features, the PCC is able to evaluate decision alternatives on scheduling patients for the desired time period (i.e. the number of patients to be scheduled on a certain day, which patients are eligible based on number of sections to be removed, and when each patient should arrive to begin treatment).

The physical surgery system, in a general sense, can be characterized as a stochastic job shop machine problem with two processing systems (excision and inspection of the tissue); recirculating, blocking, release dates (corresponding to arrival time of the patient), and carcinoma type as constraints. The goal of the system may involve minimizing the makespan of individual queue delay and minimizing the total completion time for the collective patient per day. Analytical approaches to this problem are found to be extraordinarily complex (Pinedo, 1995).

To facilitate the stochastic nature and the complexities of the scheduling problems, the models are designed to conduct multiple simulation runs, each configured to provide the maximum amount of information to the PCC trying to construct a clinic schedule. The parameters for number of sections, patient arrival time, number of patients and type of malignancy can be set to deterministic values or be stochastically determined by the simulation engine during the run.

3.2. Prototype Implementation

In the construction of the prototype, Visual Basic, ACCESS and ARENA were used for the user interface system, the database management system and the simulation engine respectively. Visual Basic was chosen as the interface software due to its ease of programming and its capability to communicate directly with ACCESS databases. ARENA, a general purpose discrete-event simulation environment, provided a flexible modeling facility.

The model include a loading module to transfer data from the database to ARENA v1.28 and vice versa. This is performed through ASCII code conversion. The data from ACCESS is assigned to the specific variables at the beginning of a simulation experiment.

The user interface provide a single point of contact for system control and analysis. This includes: 1) appointment and event calendars graphical user interface for instant user input to be incorporated to simulation run and 2) statistics on the "what if" condition from the simulation result. Controls are provided at the interface that allow the user to browse the existing schedule, to edit the schedule, and to run a simulation. For each block appointment time, the interface will prompt a window for additional information on the number of sections to be taken and type of carcinoma. Additional programming is embedded in the GUI (graphical user interface) to insure that the surgery and reconstruction will be done within two days of one another (this limits late week Mohs surgery when reconstructive surgery is not possible). Data entered with the GUI are stored directly to the ACCESS database. When the simulation is run, ARENA will be started from within the Visual Basic program. The output from ARENA is stored in ACCESS and displayed at the request of the user.

Data on service duration needed in the simulation engine consists of duration of patient evaluation, time for removing lesion, time for tissue processing and length of time needed for anesthetizing the section of skin to be removed. These data are derived from interviews and observations of clinical workflow and patient scheduling activities.

4.0 DISCUSSION

4.1 Initial Results

To gain insight on the usefulness of the simulation-based scheduling concept, a comparison between two parameter sets was developed. The first used patient arrival time data obtained from clinic observation and data collection efforts. The second was conducted with arrival time set as the *earliest time of the day* policy. Each scheduled five patients. Both were subject to the same resource constraints and the estimated number of sections to be removed for each patient.

The output shows that the same results on total completion time are obtained from both parameter sets. However, the patients in the second setting (as expected) experienced longer queue delays. A logical explanation of this is that the fifth patient in the second setting arrives at 8:00 A.M. in the morning and waited for the other patients to be processed. Hence, a longer waiting time was experienced. This also shows that the data obtained from the PCC for the first setting are quality judgment based on PCC experience in the scheduling area.

4.2 Future Work

Further development of online simulation scheduling system has focused on creating a tighter integration with the current database and making the model more broadly available and comprehensive. The model will be accessible on a data communications network where patients, medical resources, and medical center staff can remotely perform *what-if* analyses. With adoption of an object-oriented approach to simulation scheduling, classes of models can be developed, and patient scheduling with the related clinics to Mohs surgery will be able to interact with one another. And finally, by using time compression in simulation, we hope that the models will provide closer to reality model fidelity (Miller, Sheth, Kochut, Wang and Murugan 1995).

4.3 Conclusions

One of the primary concerns in health care is efficient utilization of professionals and the technological resources provided in their support. In this paper we have discussed a surgery clinic in which the stochastic aspects of patient disease, diagnostic unknowns and the variance of daily clinic operations combine to create a complex and time-consuming scheduling task. We believe that many of the concepts of on-line simulation, borrowed from manufacturing, but tempered by the human aspects of the problem, can be effectively used to support scheduling decisions when treating patients. A prototype simulation-based system for testing some of those ideas has been developed and we have discussed our preliminary results. It appears that a combination of qualitative professional skills and comprehensive planning tools can substantially improve the service and efficiency of the health care system.

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