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A SYSTEMS ANALYSIS AND MODEL OF REAL-TIME SKIN CANCER TREATMENT

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ABSTRACT

Savings in health care costs, system efficiency, and improved patient satisfaction accruing from a real-time (simultaneous) approach to treatment of skin cancer is examined. The hypothesized benefits of a real-time system design are estimated using a SLAM based simulation model of a typical dermatology clinic specializing in the treatment of basal cell and squamous cell carcinomas.

1 INTRODUCTION

Health care costs in the U.S. continue to rise at an alarming rate. The treatment of skin cancer accounts for a significant portion of this overall cost. It is estimated that there are over 600,000 cases of basal cell carcinoma and approximately 125,000 cases of squamous cell carcinoma treated per year in the U.S. making carcinomas the most common neoplasm (tumor) to affect our population. While there are numerous methods for treating carcinomas, a general approach involves four steps: (1) detection, (2) test for malignancy, (3) treatment, and (4) follow-up. In the standard approach, these steps are scheduled and performed separately requiring at least three or four clinic visits. When performed separately, these steps add up to a very costly approach to a very common problem. The real-time approach presented in this study offers a means of reducing this cost by performing the first three steps simultaneously. The operations of a typical dermatology clinic specializing in skin cancer treatment are modeled and analyzed through simulation to illustrate the relative cost-effectiveness, system efficiency, and level of patient satisfaction associated with this alternative system design for the treatment of skin cancer.

The referent system was a dermatology clinic specializing in the treatment of basal cell and squamous cell carcinomas. The collection and analysis of data on all procedures performed during a single year, interviews with the physician and staff, and two days of on-sight observation provided the basis for a simulation model. The system was modeled using the Simulation Language for Alternative Modeling (SLAM II) (Pritsker 1986). The flexibility SLAM provides through user-written allocation routines and probability distributions was well suited to the task of modeling the system's complex service scheduling and resource allocation algorithms, service durations, and arrival processes. This simulation model provided the vehicle for the system analysis and experimentation that is the focus of the remainder of this paper.

2 SYSTEM AND MODEL STRUCTURE

A diagram of the dermatology clinic is provided in Figure 1. The hours of operation are 6:45 A.M. until 4:40 P.M. Monday through Thursday and until 1:00 P.M. on Friday. The clinic's appointment scheduling algorithm results in a patient arrival distribution having a non-stationary mean. For example, the clinic typically schedules major or complex surgeries for the first three hours of operation. The mid-day lunch hour is typically reserved for simple, follow-up procedures such as suture removals. Routine visits and exams normally are scheduled in the afternoon hours. Walk-ins and referrals are worked in as necessary. The shifting arrival rates for each hour of operation were derived from interviews and an extensive review of past scheduling records. In all, a patient may require one or more of 94 different procedures. The relative frequency of each procedure and procedure combination was derived from an analysis of 10,033 procedures performed in a single year. Additional data related to procedure frequencies that could not be derived directly from this summary data were collected by randomly selecting the records of 100 patients treated in that year. With patient routing and service requirements, the 94 procedures are classified into five major groups: routine visit/exam, surgical destruction/excision, Mohs' micrographic controlled surgery, repairs, and follow-up.

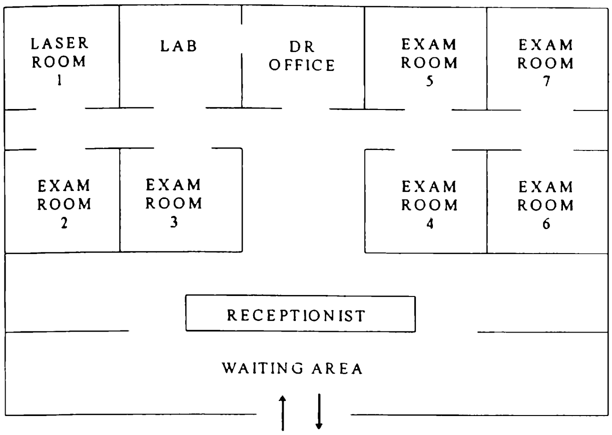

Figure 1: Dermatology Clinic and Resources

Service scheduling and resource allocation algorithms were derived from extensive interviews and two days of on-sight observation. The system resources are listed in Table 1. These algorithms were incorporated into the SLAM simulation model using user-written allocation routines. With the exception of the laser room, patients normally are placed in the first available room. The laser room is used for patient overflow only for procedures involving very short service durations.

Table 1: System Resources

Quantity	Resource Description
1	Physician
1	Physician Assistant
3	Certified Medical Assistants
1	Licensed Practical Nurse
1	Mohs' Technician
1	Mohs' Technician Assistant
2	Section Freeze/slice/embed Equipment

Data on non-lab service durations were derived from interviews and on-sight observations. In the absence of any historical data, a triangular approach (Law and Kelton 1991) was used to determine the service durations for each procedure. During the interview process, estimates of the minimum, maximum, and most likely duration were elicited. These estimates agreed with the very limited, on-sight observations of the researchers. Service durations for lab procedures could be more precisely determined because the process involves a highly regimented and mechanized set of steps with several pre-specified durations. In addition, because the service time provided by the in-house lab is considered crucial to the overall performance of the system, its service time is regularly monitored and recorded.

The structure of the system is captured in the SLAM model diagram of Figure 2. A listing of the model and FORTRAN user inserts are available upon request. In the model, patients are generated from a non-stationary mean exponential arrival process with the mean value a function of the time of day. Patients are then scheduled to receive one of the five procedure groups enumerated above. Once scheduled, a patient is allocated a room and routed according to his or her procedure group. For a routine visit, a patient is allocated the physician resource and one of the four assistant resources. The allocation of an assistant resource is contingent upon a pre-established priority scheme and the current resource allocation status. The service is rendered and the patient exits the system. Follow-up procedures are dealt with in the same manner with the exception that the physician resource is freed after performing the initial examination and consultation. For example, the assistant resource is left to perform suture removals and to expedite the departure of the patient from the system.

Due to similar pre-operative procedures for surgical destruction/excision, Mohs' micrographic controlled surgery, and repairs, all three procedure groups are initially routed along the same path (SURGERY). Surgeries involve an initial examination and consultation by the physician in the presence of an assistant resource. The physician resource is freed and the assistant resource remains to administer pre-operative local anesthesia. The surgical procedure is performed by the physician with one assistant resource. Depending on the type of surgical procedure, the patient either proceeds to post-operative treatment and exits the system or receives in-house histological evaluation of biopsied tissue. If lab work is required, the patient is routed to the lab sector of the model. While the tissue is undergoing evaluation, the physician assistant closes the incision. The biopsied tissue is frozen, sliced into sections, stained, inspected, and mounted on glass slides. The finished slides are passed through a window that communicates with the physician's office (See Figure 1). After the physician evaluates the tissue, the patient either proceeds to post-operative treatment and exits the system or requires additional tissue excision and histological evaluation. If additional surgical treatment is required, the patient is routed back to the surgery sector of the model to repeat the cycle.

The structure of the model was validated through iterative in-depth interviews with the physician and support staff. Model behavior was validated

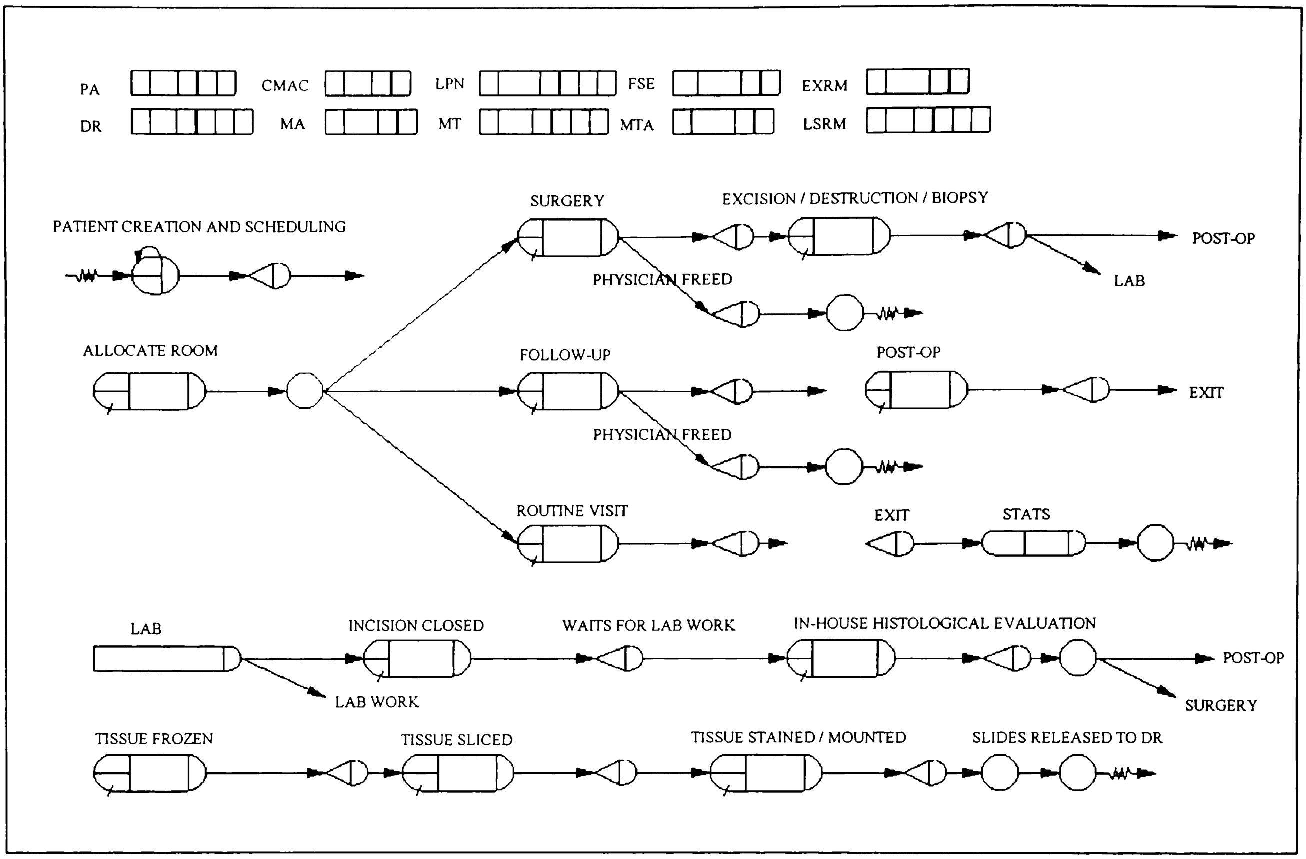

Figure 2: SLAM Model Structure

through a comparison with one year of historical data. Confidence was developed that the model exhibited structure and generated behavior similar to the referent system and would be an acceptable research vehicle for studying alternative system designs. Two system designs were explored. A comparison of the cost-effectiveness, system efficiency, and patient satisfaction of the two system designs comprise the content of the following section.

3 RESEARCH DESIGN AND EXPERIMENTATION

A general approach to treating carcinomas involves four basic steps: (1) detection, (2) test for malignancy, (3) treatment, and (4) follow-up. In the standard approach, these steps are scheduled and performed separately. For example, assume a patient enters the system with a self-detected lesion that is diagnosed as malignant and is subsequently excised. The patient is first scheduled for an examination. If the lesion is suspected of being cancerous, the patient is scheduled for a biopsy. The patient returns later, the lesion is biopsied, and the tissue is sent to a pathology lab for histological evaluation. Pathological results are returned, on average, in three days. Assuming the biopsy tests positive for malignancy, the patient is informed and scheduled for treatment. After the tumor is excised, marginal tissue is biopsied and sent to the pathology lab for histological evaluation. On sending it off to the conventional pathology lab, if excisions test positive for cancer, the patient must be called back in for an additional excision and resubmission of lab tissue. This process is repeated until all malignant tissue is excised.

The process described above is a very costly and time-consuming approach to a very common health problem. An alternative solution is to perform the first three steps simultaneously or in real-time. This simultaneity is achieved by providing in-house histological evaluation rather than relying solely on stand-by, second party pathology services. In practice, however, the real-time system design achieves only relative simultaneity. In some instances, the patient or physician elects to schedule a treatment for a later date. For example, a large portion of treatments involving major or complex surgery are routinely rescheduled. In practice, some physicians, based on clinical experience, may biopsy and treat lesions simultaneously, but this treatment is usually limited to destructive methods and can lead to under treatment if the skin cancer has a histologically aggressive variant or over treatment if it is a false positive.

It is hypothesized that four major benefits accrue from this alternative system design. First, given the reimbursement coding system associated with the health care industry, significant costs are saved by coding for a lump-sum, single-visit procedure rather than itemized, temporally separate, multiple-visit procedures. Second, system efficiency is improved due to reduced set-up costs and the elimination of redundant procedures. Third, patient satisfaction is increased due to greater convenience, time savings, and the elimination of multiple invasive procedures. Fourth, cure rates are improved through improved diagnostic accuracy resulting from having all pertinent information such as patient data, location of tumor, and histological subtype simultaneously available at the time of treatment. Improved cure rates are not tested directly using the simulation model.

The simulation model was first structured and parameterized according to the standard approach. Data for the standard approach were derived from in-depth interviews with the physician and support staff. Their knowledge was based on 6 years of previous operation under the standard approach. The system was simulated for 1 year (50 runs). The simulation model was then structured and parameterized to behave according to the real-time approach and simulated for another 50 runs. The data resulting from these two simulations were used to compare the two system designs and are summarized in Table 2.

Average cost estimates for the standard approach were generated by coding each lesion as an itemized series of temporally separate, multiple-visit procedures. Lesions in the real-time system were coded as a lump-sum, single-visit procedure. The real-time system resulted in an average cost saving of $285 per lesion. The efficiency of the two system designs was compared by holding the total number of patients served per run equal for both designs and calculating the average resource utilization over all 50 runs. A more efficient design would require fewer resources to serve the same number of patients, so efficiency was compared by calculating the mean difference of resource utilization for each design. The statistical significance of the difference was determined using a paired t-test. The results in Table 2 indicate that for all resources the real-time system required less resource utilization to serve the same number of patients at the $\alpha = 0.01$ level of significance. Patient convenience and time savings associated with each system were compared by computing the elapsed time between detection and the final treatment of a lesion, that is, steps, 1, 2, and 3. The variable "Time-in-system," is based on a 9-hour work day and assumes steps 1 and 2 are performed simultaneously in both system designs. This assumption is made because, in practice, steps 1 and 2 are not always performed simultaneously in the real-time system; the physician and/or patient may elect to reschedule for various reasons. In addition, many standard approach implementations do not separate steps 1 and 2. This ambiguity does not, however, exist for steps 2 and 3. Biopsy and treatment are always separate in the standard approach and always simultaneous in the real-time approach. The data in Table 2 indicate that a patient can expect the average service time between the biopsy of a suspicious lesion and the completion of treatment to be 6.96 working days for the standard approach. In contrast, the real-time

Table 2: Statistics for Standard versus Real-time System Design

Output Variable	Standard		Real-time		Mean-diff	p-value
Cost per lesion	$483.70		$198.70		$285.00	
	Mean	Std.	Mean	Std.		
Resource Utilization						
Physician	0.751	0.160	0.728	0.011	0.023	0.000
Physician Assistant	0.856	0.024	0.700	0.016	0.156	0.000
Certified Medical Assistant	0.628	0.010	0.568	0.006	0.060	0.000
Licensed Practical Nurse	0.702	0.032	0.619	0.200	0.083	0.000
Medical Assistant	0.588	0.014	0.565	0.014	0.023	0.003
Exam Rooms	2.934	0.193	2.838	0.138	0.096	0.005
Time-in-system (working days)	6.960	3.274	0.153	0.062		
Time-in-clinic (hours)	1.483	0.321	1.382	0.278	0.101	0.0970
Number of reschedulings	3.653	1.320	0.000	0.000		

approach requires an average of 0.153 working days The variable "Time-in-clinic" is designed to provide an additional measure of convenience and time-savings by determining the average time a patient spends in the clinic. The results of this comparison suggest that patients can expect to spend slightly less time in the clinic under the real-time approach due to the avoidance of repetitive set-up delays. Finally, the number of multiple invasive procedures is compared by determining the number of times a patient is rescheduled for additional treatment. In the standard approach, each subsequent clinic visit following the initial biopsy and before the follow-up procedures normally involves a biopsy and/or an excision. Under the real-time approach, an average of 3.653 multiple invasive procedures are eliminated.

4 CONCLUSIONS

The comparison of the two system designs demonstrates that a real-time approach to treatment of skin cancer can reduce health care costs, increase system efficiency, and improve patient satisfaction by simultaneously detecting, testing, and treating cancerous lesions. The larger societal benefits of this alternative system design are reflected by extrapolating the results of this study to the majority of skin cancers treated in the United States. For example, cost savings for the entire U.S. health care system could be as high as $206,625,000 per year if a real-time approach were widely adopted. Approximately 2,648,425 costly and unnecessary clinic visits could be avoided annually. In many instances, the patient enters the system with a companion (for example, a relative, friend, or co-worker) which serves to double the effect. A less tangible, though equally significant, benefit is the elimination or reduction of the physical and mental anxiety and stress associated with waiting for test results and undergoing multiple invasive procedures. This anxiety and stress can have very real and deleterious effects on overall worker productivity and performance. With the real-time system design, a protracted and potentially stressful experience is avoided.

The adoption of a real-time approach also has implications for the training of physicians and the structure of clinics. Simultaneity is achieved by performing in-house histological evaluation. The ability to perform this evaluation will require physicians specializing in skin cancer treatment to receive more extensive training in histopathology than current curricula provide. The results of this study also suggest that the clinic layout depicted in Figure 1, the resource mix, and the resource allocation algorithms provide a generalizable model for the configuration of an efficient skin cancer treatment system.

The research contribution of this study lies chiefly in its demonstration of the usefulness of simulation modeling in the study and management of business problems. At the micro-level, the model presented in this paper provides a research vehicle for analyzing system design options and management policies regarding service scheduling and resource allocation algorithms in both standard and real-time approaches to skin cancer treatment. At the macro-level, the model provides a means of estimating the larger societal impacts of these alternative system designs.

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