SIMULATION AND EVALUATION OF AN EXPERIMENTAL RURAL MEDICAL CARE DELIVERY SYSTEM*

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Abstract—A simulation model is developed for evaluating recommended changes in the operational configuration of a rural medical care delivery system. The model imitates the processing of patients at a rural clinic staffed by mid-level health personnel and linked by a communications system to supervisory physicians at an urban medical center. An explicit description of the patient-nurse practitioner-physician interactions which are relevant to system performance have been modeled. Simulated results of four experiments reflecting the influence of alternative operational policies are presented in a comparative framework.

INTRODUCTION

Many rural communities have difficulty attracting and supporting medical care providers. Residents of sparsely populated areas must frequently travel considerable distances to urban locations in order to fulfill their medical needs. Rural dwellers may often ignore or self-treat medical problems which require professional attention.

The extensive experience of the Frontier Nursing Service in Kentucky[1], nurse providers in remote areas of Canada[2], and recent successes of the pediatric nurse practitioner program of Silver and Ford in Colorado[3], prompted the School of Medicine at the University of New Mexico to develop and implement a new method for delivering medical services to rural communities[4–6]. This experimental medical delivery system links a rural clinic staffed with mid-level medical personnel to supervisory physicians at an urban location. The experimental system is designed to offer medical services to all family members and to fulfill a substantial proportion of the medical needs of a population. Immediate care for acute illnesses and accidents, maintenance of chronic conditions, and health check-ups are rendered on a routine basis. Selected laboratory procedures are performed locally to facilitate diagnosing and monitoring of frequently occurring patient problems. The system provides the capability of extending the services of urban physicians to patients residing in remote rural locations.

In February 1969, the concept of an experimental medical care delivery system became an operational alternative for residents of a sparsely populated rural community in New Mexico. To date, medical care has been provided to at least one member of over 70 per cent of the households in the county it was established to serve. During the past year, the delivery system managed an average of more than 200 patient encounters per month. Immediate and complete medical service has been provided for 90 per cent of all patient visits to the rural clinic facility.

The purpose of this paper is to describe a computer simulation model designed to evaluate alternative configurations of the experimental medical care delivery system. First, the operational components of the delivery system are described. Next, a description of the computer simulation model is presented. Finally, the results of four experiments conducted with the simulation model to evaluate variations in operational configurations are discussed.

DESCRIPTION OF THE EXPERIMENTAL MEDICAL CARE DELIVERY SYSTEM

The experimental delivery system can be partitioned into three basic components as shown in Fig. 1. The elements of the rural component include the clinic facility, the diagnostic and treatment equipment, and the midlevel medical personnel staff. The consultant component consists of supervisory physicians located in an urban
A communication component links the two operational components.

A schematic illustration of patient flows to available medical care providers for persons living in a rural area in which an experimental medical care delivery system has been established is shown in Fig. 1. Patients have been defined as that segment of the rural population who actively seek medical assistance for real or perceived health problems. Persons seeking medical care may obtain services locally or travel to a distant urban location. It is recognized that patients may visit more than one medical provider over a period of time. Some acute patient problems will result in a series of visits to one or more providers. Continual monitoring and treatment of chronic problems may require that certain persons make periodic visits to one or more providers. When the complexity or seriousness of a patient's condition is beyond the diagnostic or treatment capabilities of either the experimental medical care system or other local providers, the patient will be referred to a specialist located in the urban center.

The rural facility is an attractively designed building which was constructed in 1965. A schematic diagram of the physical layout is shown in Fig. 2. The facility contains a large waiting room; a centrally located reception desk and clerical area; two patient consultation rooms; five examination rooms, one of which is equipped as an emergency unit; a diagnostic laboratory; an X-ray room; and two restrooms. Two of the examination rooms are utilized by an independent dentist. One of the consultation rooms is used as a storage area.

The midlevel medical staff at the rural facility are local residents who have been trained to function in this experimental system. The family nurse practitioner (FNP) is an experienced registered nurse who completed a comprehensive 6-month training program in preparation for her primary role. Her particular responsibilities include: interviewing patients, performing physical examinations, consulting with supervisory physicians, administering therapeutic procedures and taking X-rays. The laboratory aide (LA) is a licensed practical nurse who was trained to perform selected laboratory tests. Special laboratory tests are performed by an independent urban laboratory. The LA also admits patients to the examination rooms, measures and records vital signs, and administers the telephone-linked electrocardiogram examinations. An experienced receptionist with one year of nursing school is the third member of the clinic staff. She registers patients, makes appointments, collects fees, files medical records, and performs other administrative tasks associated with operating the clinic.

The second operational component of the delivery system consists of two physicians, an internist and a pediatrician, who provide remote medical supervision for patients being processed at the rural facility. The FNP is required to consult over the telephone with the internist on all problems presented by patients whose age exceeds fourteen years. With children, the FNP may consult the pediatrician or a standing orders manual. The supervisory physicians normally visit the rural clinic for one-half day per week to personally examine patients requested to return at that time for further examination of their non-urgent problems and to review the records of all patients who visit the clinic.

A telephone linkage between the two operational components is the third delivery system component. After an initial examination of a patient, the FNP initiates a telephone call which pages the appropriate supervisory physician via a portable electronic sensor. The physician responds by directly placing a telephone call to the clinic. As a result of reviewing the patient's condition during the telephone consultation, additional diagnostic tests or a specific treatment may be prescribed.

COMPUTER SIMULATION MODEL

A stochastic computer simulation model was developed to evaluate alternative operational configurations of the rural facility.
Simulation and evaluation of an experimental rural medical care delivery system

The model has been designed as both an aid for analyzing potential changes in the existing experimental system and for planning the installation of new delivery systems in other rural communities. It is programmed in General Purpose Simulation System (GPSS) language for an IBM 360/67 computer. The event-step simulation program uses less than 128 K bytes of core and requires approximately 0.15 sec to process an average patient.

The computer simulation imitates the interaction between the patient and the basic elements of the rural component during system operation. A schematic illustration of the patient flow and control is shown in Fig. 3. Although multiple patients may be simultaneously processed by the system, the FNP and the LA provide service requirements for a single patient at a given moment of time. The movement of patients through the system is governed by attributes initially assigned to each simulated patient and is controlled by the decision logic representing the midlevel medical personnel. The activities shown in Fig. 3 represent a basic processing pattern from the patient's perspective and do not indicate performance priorities programmed in the decision logic of the staff.

The model consists of a patient visit generator and three processor modules: patient, family nurse practitioner (FNP), and laboratory aide (LA). The visit generator creates the patients, assigns their visit characteristics, and schedules their arrival. The rate and type of demand for patient processing activities are determined through the initial assignments of visit and patient attributes by the patient visit generator. The patient processor module contains the logic which prescribes the sequence of activities involved in providing patient care. The duration of processing activities is basically controlled by the decision logic contained within the clinic personnel modules. The FNP logic module provides for the activities performed to determine and relate the patient's condition to the supervisory physician. The source of ancillary activities required to facilitate patient care is the LA logic module.

Time study data collected on the experimental medical care delivery system provide the probability distributions for the patients and visit attributes, the sequence and duration of processing activities, and the set of activity priorities and decision logic used in the personnel logic modules.

Patient visit generator

The patient visit generator assigns the following attributes to each patient and his visit:
1. Age and sex of patient.
2. Language spoken by patient.
3. Initial or follow-up visit for patient.
4. Number of patients in group to receive service during this visit.
5. Appointed or nonscheduled visit.
6. Punctuality for scheduled visit.
7. Arrival time for nonscheduled visit.
8. Type of medical service to be provided during visit:
   a. Examination or consultation with FNP.
   b. Number of laboratory tests.
   c. X-ray examination.
   d. ECG examination.
   e. Injection.
9. Scheduled arrival time for appointed visit.

These characteristics are used by the logic modules to determine the processing path of the simulated patient.

Patient processing module

A simplified schematic illustration of the patient processor logic module which provides the framework for guiding the patients through the clinic facility is shown in Fig. 4. The processing module considers the medical service requirements of each patient, the sequence in which these service activities are rendered, and the availability of the system resources required to fulfill the service demands of a patient. Patients are processed on a first-come, first-serve basis except for patients requiring roentgenogram or electrocardiogram examinations. These patients receive a priority for admission to the emergency examination room. If required system resources are being utilized by other patients, a patient will wait in a queue for their availability.

The simulation provides for the immediate availability of the receptionist for required processing tasks. The receptionist is responsible for registering the patient, receiving payments for services rendered, and scheduling system-initiated future appointments. On the other hand, required patient interaction with the other two members of the rural staff is determined by the availability of the personnel, the accessibility of system resources, and the patient's medical service requirements.

Typically, the simulated patient registers with the

Fig. 3. Schematic illustration depicting the patient-clinic staff interaction and patient flow which occurs during system operation.
The FNP will maintain patient records and engage in one which was initiated first receives primary attention. Between the patient and the supervisory physician, the primary role assigned to the FNP as the direct link administered and/or instructions related. The patient is demanded at a given point in time, the consultation have the highest priority. If two or more of patient examinations, X-ray procedures, and final patient treatment prescribed by the consulting physician is in a final consultation in the examination room where examinations are conducted by either the FNP or the LA. Interaction between the patient and the FNP is completed personal time only if requests for direct patient service are not a condition for completion of patient processing. Upon the completion of a patient service activity, all activities having higher priorities are queried for demands before requests of lower priorities may be fulfilled. If two or more service requests of the same priority are waiting, service is provided on a first-come, first-served basis. If there is not a request for a patient service, the LA is delayed for a 5-min block of personal time. The priority sequence is periodically queried at 5-min intervals for new service requests until the simulated day is completed.

At any time during the performance of an activity, an interruption by a telephone call from the supervisory physician may occur. This interruption represents the response to a page for consultation concerning a patient being processed at the clinic. After completing a time delay which simulates the telephone consultation, the priority sequence for requested service activities is reinitiated. The only exception to the procedure arises when the telephone interruption occurs during an X-ray examination. In this case, the decision logic requires an immediate return to the roentgenogram procedure.

LA processor module
A simplified logic diagram of the LA processor module is shown in Fig. 6. The simulation decision logic which is contained in this processor module depicts the major points of interaction between the LA and the patient being processed in the experimental medical care delivery system.

The decision logic in the module permits continuous service activities for different patients to be performed according to a prescribed priority of tasks. This priority sequence is presented in Fig. 6. The LA is bilingual and provides translation for patients who require the service of the FNP and speak only Spanish. Patients not requiring activities performed by the FNP are defined as "procedures only" patients. The service requirements of these patients are fulfilled through an interaction with the LA. Specimens for laboratory analysis are obtained from patients requiring diagnostic tests. Patients requiring FNP examination or consultation are admitted to available examination rooms where their vital signs are measured and recorded by the LA. The LA performs all service requests for electrocardiograms. High priority laboratory tests are those required prior to discharging the patient from the rural facility. Conversely, low priority laboratory tests are performed at the convenience of the clinic and are not a condition for completion of patient processing. Upon the completion of a patient service activity, all activities having higher priorities are queried for demands before requests of lower priorities may be fulfilled. If two or more service requests of the same priority are waiting, service is provided on a first-come, first-served basis. If there is not a request for a patient service, the LA is delayed for a 5-min block of personal time. The priority sequence is periodically monitored for new patient service requests during the simulated day.

Performance criteria
Measures of patient process form the basis for evaluating system performance. Standard queueing statistics and elapsed time indicators are collected during the simulation and presented at the completion of the simulated time interval. From the patient's perspective, relevant process criteria include total time in system, time to first service, and time spent in direct contact with clinic personnel. Other criteria included a monitoring of FNP and LA utilization. The influence of controllable administrative and medical policies on operational efficiencies may be assessed from these process criteria. In addition, noncontrollable input variables such as number and type of patient visitations per day affect measures of patient process. It is appropriate to consider the influence of

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**FNP processor module**

Figure 5 displays a simplified logic diagram for the FNP processor module. This decision logic imitates the primary role assigned to the FNP as the direct link between the patient and the supervisory physician.

Requests for direct patient service which include initial patient examinations, X-ray procedures, and final patient consultations have the highest priority. If two or more of these requests are demanded at a given point in time, the one which was initiated first receives primary attention. The FNP will maintain patient records and engage in personal time only if requests for direct patient service activities have been previously satisfied. Upon the completion of an activity, all activities having higher priorities are checked for requests before a request for service of lower priority may be satisfied. If there is not a request for patient service and records do not need updating, the FNP is delayed for a 5-min block of personal time. The priority sequence is periodically monitored for new patient service requests during the simulated day.

**Performance criteria**

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Fig. 5. Simplified simulation logic for FNP processor module.
noncontrollable demand factors in forecasting the performance of this delivery system in other rural communities.

**Verification and validation**

Verification insures that the simulation model operates as it was designed to operate [7]. A comparison between the detailed flow chart and the computer listing was made for each of the modules. Program logic was verified by tracing activities of the first two patients generated for processing. A Kolomogrov–Smirnov test was used to ascertain the degree of similarity between a random sample from each of the input probability distributions and the empirical distributions. The hypothesis that the sample came from its parent population could not be rejected for each input distribution.

The purpose of validation is to develop an acceptable level of confidence in the results generated by the simulation model. A valid model produces results which are comparable to observations collected on the actual process being imitated and possesses the dynamic characteristics of the real system [7]. The distribution of the total time the patient spends in the system is an important system characteristic for validation because it is affected by all the factors of the model. The distribution of patient total time in system for the simulation was compared with the empirical results from the time study. The distributions compared favorably under the Kolomogrov–Smirnov test for $\alpha = 0.05$.

**EXPERIMENTAL RESULTS**

The simulation model has been used to predict the results of various changes in the operation of the experimental medical care delivery system. The results reported in this section are illustrative of the type of experiment which can be performed to evaluate proposed system modifications in the delivery system. Although the
simulation model is general, the reported results are based on parameters derived from time series data collected at a rural New Mexico location.

The purpose of the simulation model is to evaluate alternative values of input parameters, changes in operational policies, and modifications in the system configuration. After the delivery system had been operationalized, management considered two major modifications in the operation in order to increase effectiveness. One change was to permit the physicians to initiate a telephone call to the clinic approximately every hour. This would alleviate the physician's burden of being constantly subject to a clinic-initiated page. The second suggested modification was to limit the system configuration which would result in an estimated cost savings of $2000.00 per month. These changes were considered under variable percentages of eligible patients requiring telephone consultations and numbers of daily patient visits. Average patient total time in the system was considered to be representative of the patient processing performance criteria for the managerial evaluation of the proposed changes.

Table 1 provides a comparative summary of the results from the four computer simulated experiments. The simulated results are discussed below.

Experiment 1
A comparison is made between the present policy of having the FNP initiate a request for consultation with the urban physician and a proposed policy which would require the supervisory physician to periodically initiate the telephone communication. Under the proposed policy, the physician telephones the rural facility once per hour within plus or minus 5 min of a predetermined time during which the conditions of all patients requiring telephone consultation are discussed. In addition, the percentage of patients requiring telephone consultation is varied to determine the relationship between this controllable policy variable and patient total time in the system.

The results indicate that under the current visitation rate which averages 9-5 patients per day, the present policy results in less total time in system per patient than the proposed policy. In general, as the proportion of patients requiring telephone consultation increases, both policies yield greater amounts of patient total time in the system. However, under the physician-initiated telephone consultation policy, the total system time per patient increases at a greater rate than under the current policy. Under an existing medical policy which results in telephone consultations for 89 per cent of patients examined by the FNP, the proposed modification would increase patient total time in system by an average of 18 min per patient. Clearly, if the proposed policy were implemented, no improvement would be expected in patient processing at the rural facility.

Experiment 2
The purpose of this experiment is to evaluate patient processing under a proposed limited operational delivery system configuration. The proposed configuration would reduce the number of working days from four and one-half to three per week while holding the total number of patient visits constant. Thus, the average rate of patient visits increases from 9-5 to 14-6 per day. Additional modifications of the proposed configuration include the elimination of the LA and the reassignment of her responsibilities to the FNP and the receptionist.

Although the proposed system configuration would yield a significant decrease in operational costs, the simulated results show a substantial increase in total time in the system for the average patient. In particular, under the present policy of having telephone consultations for 89 per cent of eligible patients, the limited operational configuration yields an increase of over 40 min for average patient total time in the system. As expected, both operational configurations produce increases in the processing criterion as the proportion of patients requiring telephone consultation increases. Based on the simulated results, the implementation of the proposed limited operational configuration would result in substantial increases in patient processing time, unless increases in patient visit rates produce significant decreases in task performance times by the system staff.

Experiment 3
A comparison is made between FNP and the physician-initiated telephone consultations as described in the first experiment under conditions of the limited operational delivery system configuration. The average patient visitation rate for the experiment is set again at 14-6 visits per day.

The results of the simulated configurations indicate that as the daily visitation rate increases, the physician-initiated telephone consultation becomes a viable alternative. More specifically, in the proposed medical policy modification which yields telephone consultations for 30 per cent of the patients, the physician-initiated telephone consultation produces only about a 5 min increase in total time in the system for the average patient.

Experiment 4
The normal and limited system operational configurations were compared under varying rates of average patient visits per day in this experiment. The FNP initiated all telephone consultations which amounted to 89 per cent and 30 per cent of eligible patients for the normal and limited system configurations, respectively.

As anticipated, the average time in system increases with increased levels of daily visitation rates. However, the rate of increase was only 5-9 min per unit increase in average daily visitation rate for the limited system configuration while the rate of increase was 6-8 min in total time in system per patient for the normal system configuration. The decrease in amount of system processing time for the limited system configuration can be attributed to the decreased requirement for telephone consultation existing in the limited system configuration.

In summary, the results of the simulated alternative policies and configurations demonstrate the importance of the relationship between the processing criterion of total system time per patient and the communication component. It appears that system processing times are significantly influenced by the delay resulting from required communication between the urban and rural system components. The simulated decrease in system capacity and operating costs resulting from the limited system configuration yielded an expected increase in time required for patient processing. Additional support regarding the relevance of the communication linkage was ascertained in the final experiment where, under similar rates of daily patient visits, the configuration requiring less telephone consultation produced a more desirable performance in patient processing. Thus, modifications in medical policy and increases in operational efficiencies...
Table 1. A descriptive summary of the results from four computer simulation experiments

<table>
<thead>
<tr>
<th>Description of experiments</th>
<th>Simulated conditions</th>
<th>Graphical relationships</th>
<th>Linear regression equations</th>
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<tbody>
<tr>
<td>1. Contrast FNP and MD as initiators of telephone consultations under normal system configuration</td>
<td>Average number of patient visits per day = 9.5. Per cent of patients requiring telephone consultation was varied from 0 to 100% under normal configuration</td>
<td>a. $TTS = 63.3 + 0.25x$ with $F = 124$</td>
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</table>
|                                                                                           | *Two policies considered:*  
|                                                                                           | a. FNP initiates telephone consultation  
|                                                                                           | b. Supervisory MD initiates telephone consultation                                  | b. $TTS = 64.2 + 0.45x$ with $F = 183$ |                           |
| 2. Evaluate normal and limited system operational configuration with FNP initiating telephone consultations | Total patient visits are held constant to yield average daily rates of 9.5 (normal) and 14.6 (limited). Per cent of patients requiring telephone consultation varied from 0 to 100%. | a. $TTS = 63.3 + 0.25x$ with $F = 124$ |                           |
|                                                                                           | *Two policies considered:*  
|                                                                                           | a. Normal (present) operational configuration  
|                                                                                           | b. Limited operational configuration                                                  | b. $TTS = 82.8 + 0.50x$ with $F = 183$ |                           |
| 3. Contrast FNP and MD as initiators of telephone consultations under limited system configuration | Average number of daily patient visits = 14.6. Per cent of patients requiring telephone consultation varied from 0 to 100%. | a. $TTS = 82.8 + 0.50x$ with $F = 183$ |                           |
|                                                                                           | *Two policies compared:*  
|                                                                                           | a. FNP initiates telephone consultation  
|                                                                                           | b. Supervisory MD initiates telephone consultation                                   | b. $TTS = 85.6 + 0.67x$ with $F = 308$ |                           |
| 4. Evaluate normal and limited system operational configuration with FNP initiating telephone consultations | Proportions of patients requiring telephone consultation are held constant at 89% and 30% for normal and limited configurations, respectively. Average daily visit rate varied from 8 to 20 patients per day. | a. $TTS = 14.3 + 6.8x$ with $F = 194$ |                           |
|                                                                                           | *Two policies are considered:*  
|                                                                                           | a. Normal (present) operational configuration  
|                                                                                           | b. Limited operational configuration                                                  | b. $TTS = 16.4 + 5.9x$ with $F = 44$ |                           |

*The performance criteria for each experiment was average total time in system ($TTS$) per simulated patient. Run length for each variable value per experiment was 25 simulated days.*
which streamline the communication process should yield reductions in patient processing times.

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REFERENCES