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SIMULATION MODELING IN HEALTH CARE FACILITIES

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ABSTRACT

Several simulation models have been developed by the authors dealing with specific applications in the health care field at the West Virginia University Hospital, as well as for the entire State of West Virginia. This paper illustrates the diversity of simulation as a decision making tool in the health care field, in areas such as operating room utilization, vertical transportation needs, radiology staffing, and emergency medical squad location and operations.

INTRODUCTION

In recent years health care costs have been increasing at twice the rate of increase of the cost of living. An increasing number of state governments are attempting to legislate ceilings on hospital charges. The federal government has regulated medicare costs by the use of Diagnostic Related Groupings (DRG's). It is also believed that at some point in the near future all patient charges will be regulated by DRG's thus putting a cap on the amount the hospital can charge the government or a private insurance carrier.

As a result of these regulatory influences health care administrators have stepped up efforts to reduce costs and improve productivity. However, in many cases, efforts to reduce costs may in some way have an adverse affect on patient care or service. With this careful balance of costs versus service level, simulation has proven to be an invaluable decision making tool. Simulation allows the administrator to formulate several different alternatives and select the proper tradeoff between costs and service levels.

The models presented in this paper represent diverse applications of simulation in the health care field. At the West Virginia University Hospital, simulation models have been written to analyze operating room utilization, vertical transportation needs, and radiology staffing. Simulation is also being used to analyze ambulatory squad location and operations for the State of West Virginia.

The following is a detailed account of each of the four applications as stated previously.

OPERATING ROOM UTILIZATION

West Virginia University Hospital (WVUH) is a state run teaching hospital with 450 beds and eleven (11) operating rooms. Few renovations and capital improvements have been made to the building since its opening in 1961, and the surgical suite was about to undergo expansion and remodeling. However, there were differing viewpoints between the hospital's administrators and medical staff as to the present utilization of the surgical suite, and how many new operating rooms should be added. In order to resolve this conflict a computer simulation model was developed to provide objective and quantifiable results in analyzing several different configurations.

After analyzing various simulation methods it was decided to use the resources available at West Virginia Unviersity computer services and develop the model using the General Purpose Simulation System (GPSS). GPSS was chosen primarily due to its simplicity and the short time needed for its program development, especially with the tight time constraints that were put on the project.

During the model development stage it was decided to examine each operating room separately, since each room has different surgical cases and different lengths of operation time. The assumption that all rooms are identical would distort the distribution of arrival of patients to the recovery room after the operation, and would lead to incorrect results and wrong conclusions. Conversely, the recovery room, consisting of several recovery beds, was modeled as parallel servers with each bed acting identically but independently of each other. The model was designed to perform the following functions:

1) Simulate the surgical suite operations displaying statistics on its current utilization.
2) Determine the maximum realistic capacity of the current operating room suite.
3) Determine the total number of operating rooms needed to meet a 20% increase in demand given the current room utilization.
4) Determine the total number of operating rooms needed to meet a 20% increase in demand given the optimal room utilization.

In order to perform the above functions the following data was calculated over a two months period for input into the simulation model:

1) A distribution of the time spent for an operation for each operating room.
2) Distributions for the length of time spent in the recovery room.
3) A distribution of the time spent to prepare each operating room for the next operation.

The simulation model generates the arrival of patients to the operating room. Depending on the type of surgery needed, the model sends the patient to an appropriate room and generates the necessary time for the operation as well as the recovery time period. At the completion of an operation the model checks for an available recovery bed: If a recovery bed is not available then the recovery starts in the operating room and waiting time statistics are tabulated for the recovery room. Once a recovery bed becomes available, the patient is moved to the recovery room to complete the recovery period, and the operating room is cleaned for the next operation.

The following statistics are generated by the model for analysis of the system:

1) The total number of surgical cases seen.
2) Amount of waiting time for a recovery bed.
3) Utilization of each operating room.
4) Utilization of the recovery room.

The output results were analyzed and the operating rooms and recovery beds were increased until the original surgical demand had increased by 20%. The key factors in monitoring the output were minimizing waiting time, and maximizing room utilization. The final results indicated that a total of 14 operating rooms and 15 recovery beds would be required to meet a 20% increase in demand.

The results of the study were used in a bargaining session with administrative and medical staff to determine the number of operating rooms and recovery beds required for the hospital. Since the time of completion of this project WVUH has been transfered to a private, non-profit corporation that is undertaking complete replacement of its facility. The results of the simulation were used again during the design phase of the new hospital to verify the size of the surgical suite recommended by the design consultants.

VERTICAL TRANSPORTATION

Another simulation model was developed to analyze several scenarios of the service elevators for the ten floors of the WVUH. There are currently two service elevators which service the entire hospital for the movement of patients, equipment, dietary, supplies, housekeeping, laundry and laboratory specimens and results. All of these groups have their primary concentration of work during the hours of 7 a.m. to 4 p.m. Naturally, during this time period waiting times are excessive and range from a few seconds to 20-30 minutes. The average waiting time is approximately 2.1 minutes with 90% of all arrivals waiting at most 5.25 minutes. The acceptable standard for elevator waiting time is an average of 30 to 45 seconds with 90% of all arrivals being serviced within one minute. This excessive waiting time creates a three-fold problem. First, it degrades employee and patient morale to have to wait for an elevator. Secondly, the loss of productivity in employee time represents a significant cost. Lastly, there is difficulty in transporting critical patients in an expedient manner.

Data was gathered from within each elevator and consisted of the following information for each arrival: Time of entrance to the elevator, floors of origin and destination, percentage of the elevator space occupied by the arrival, and function being performed by the arrival. The data was grouped according to the arrival's functional characteristics which are as follows:

1) Health Related (Patient/Equipment Movement, Nursing Services, etc.).
2) Support Services (Housekeeping, Dietary).
3) Supply Delivery (General Stores, Sterile Supply, Laundry)

Next, the time period from 7 a.m. to 4 p.m. was categorized into periods of heavy, moderate, and slow activity time periods. For example, the time periods 9 a.m. - 10 a.m. and 3 p.m. - 4 p.m. comprised the heavy activity. The average arrival rate for each period was used as the mean of an exponential distribution to generate arrivals. An exponential distribution was assumed because arrivals occured independently and randomly, thus indicating a Poisson rate of arrival. For each arrival the following characterisitcs were generated by discrete distributions derived directly from the raw data:

1) Functional Category (as defined previously).
2) Floor of origin.
3) Floor of destination.
4) Percentage of elevator to be occupied by the arrival.

Due to the complexity of the model, a discrete event simulation approach was taken, using FORTRAN subroutines in cooperation with the SLAM [5] package. As an arrival is generated it is placed in a queue along with the four characteristics listed above. The two elevators were modeled as entitites each having the following attributes:

1) Direction of the elevator (up or down).
2) Next floor to stop at.
3) All the destinations selected from within the elevator.

Elevator downtime was also taken into consideration in the model and was generated using a year of historical data. The simulation program is currently in the development phase and once completed, will be generating the following results:

1) Average waiting times per functional category per floor.
2) Maximum waiting time and standard deviation of waiting times.
3) Percent utilization of each elevator.

After producing results for the existing operations of the elevators and validating the simulation model, a variety of alternatives will be explored. These alternatives are grouped into operational and equipment as explained below:

1) Operational Alternatives
   a) Move the transportation of supplies to the off hours (anytime other than 7 a.m. to 4 p.m.) and determine the impact on waiting times.
   b) Dedicate one elevator strictly to patient and equipment movement and determine the impact on the health related category's waiting time and total waiting time. This alternative is explored to decrease the waiting time of critically ill patients.
   c) At present the breakfast, lunch, and dinner meals are transferred on one of four passenger elevators. The third alternative is to move this dietary function to the service elevators and determine the impact to the waiting times.
   d) A combination of two or more of the above alternatives.
2) Equipment Alternatives
   a) Determine the impact on waiting times if the logic of the elevators were reprogrammed

to better facilitate service of calls.

b) Determine the waiting time as a function of additional elevators.

RADIOLOGY STAFFING

The Radiology Department at West Virginia University Hospital currently operates a satellite unit which services the Emergency Department and the Outpatient Clinics on a first come-first serve basis. Since the Clinics supply the majority of the patients to the satellite unit, the study and simulation were therefore based on the operation hours of the Clinics; 8 a.m. to 5 p.m., Monday through Friday. The Radiology Department received numerous complaints of excessive backlog of patients, lengthy waiting time for patients, and the lack of efficiency throughout the process. Administration was considering expanding the unit to include two examining rooms in order to eliminate the problems.

Through observation and analysis a new unit could not be justified, therefore it was decided to determine through a simulation model the effects of various approaches to task assignment on the level of service produced.

There are three distinct tasks that the radiology technicians perform while working in the satellite. First is typing the X-ray requisition form when the patient arrives, secondly is taking the X-ray, and lastly developing the X-ray film. After a brief observation period of the satellite operations it was found that when there were two or three technicians running the unit, each one would take a patient from start to finish. Problems would occur if the developer is being used when the next technician arrives with an exposed film. In this case, the second technician would wait for the developer rather than type a new requisition or shoot the X-ray for the next patient.

A simulation model was developed using GPSS to simulate the current operations of the satellite unit and test several alternatives as follows:

1) Change the number of technicians operating the unit.
2) Modify the mode of operation so that each technician would be responsible for one or more tasks (out of the three tasks defined previously) for all patients rather than perform all tasks for individual patients.

Results of the simulation are given in Table 1, and show how the modified system can help eliminate the existing problems. A Managment Information System is currently being developed to provide the unit manager with a projected number of clinic patients scheduled for X-rays for the proceeding day. With this information and the results of the simulation the manager should be able to determine the staffing level in order to operate the unit in an adequate and efficient manner.

EMERGENCY MEDICAL SERVICES

In addition to the simulation models developed for West Virginia University Hospital, the simulation approach was used to study and evaluate the effective location and operation of Emergency Medical Services (EMS) squads. Several models were developed by earlier researchers and practioners like Savas [6], Baker [1], Seiler [7], Gochenour [2], and Okeugo [4] who directed their effort at identifying the best EMS locations for either urban or rural settings. The model discussed in this paper, which is still in its developmental stages, takes advantage of a huge data base that consists of several years of information on each emergency call made in the state of West Virginia. This information includes the origin of the emergency call, the type and severity of the problem encountered, type of

TABLE 1: Simulation Results for Radiology Satellite Staffing

	Avg. No. Patients in System	Avg. Total Time in System (min.)	Avg. Entrance Wait (min.)
One technician (current operating procedures)	8.3	88.0	79.9
Two technicians (current operating procedures)	6.1	60.5	49.7
Two technicians (modified operating procedures)	1.7	17.7	4.3
Three technicians (current operating procedures)	2.1	19.3	8.5
Three technicians (modified operating procedures)	1.6	16.9	3.4

hospital care rendered, degree of medical training of the crew involved, and the hospital to which the patient is transported [3].

Since the model is developed on a small micro-computer (Apple IIE) it has proved to be much more beneficial to simulate the EMS operations of one of the seven regions the state was divided into (for planning reasons) rather than do it for the entire state. However, the model can easily be extended to include all the state. The region was sub-divided into a number of smaller zones (58 zones) that coincide with zones currently being used by the State Department of Transportation (DOT) in a statewide traffic assignment model [8]. The state DOT maintains a wealth of data about the socioeconomic properties of these zones. Of particular interest to this model are the following information: The X and Y coordinates for the centroid of each zone, the zone population, and the actual travel time between the centroids of any two zones.

One of the major components of the model is the generation of EMS runs. The following information needs to be generated: Time and date of the run, exact location of the incident, and type and severity of the medical problem involved. Two different approaches were available for the generation of this data. In the first approach, one can analyze the historical data available for EMS runs to obtain statistical distributions and develop appropriate methods to generate EMS runs from the different zones at different times and to define the associated medical problems. However, one major problem was faced here: Data was not available for 100 percent of the runs; instead quite a few runs were missing. The number of missing runs could be estimated; however these runs were not uniformely distributed over the entire population; instead, they were concentrated in few spots where some squads chose not to participate in the management information system through which all data were collected and maintained. In the second approach, which can easily be implemented, and actually was used in this model, the total number of EMS runs are estimated for the entire region and then distributed over the different zones in proportion to their individual population. Exact locations, timing and type and severity of medical problem are then statistically generated from historical trends.

The model can be used in two ways, one as a simulation model to evaluate the performance of one or more squads under different configurations in order to better plan for the squad operations, and the other way is to use the computer for quick evaluation of squad locations and determination of approximate locations where new squads may be needed.

As a quick tool to evaluate the squad locations, no simulation takes place. Instead the model simply scans all the zones in the region and calculates the following statistics: Percentage of the population served by each squad within a predetermined time period (a call is always answered by the nearest squad), distribution of response times to calls for each squad as well as an overall distribution for the entire region, and the distribution of response times to calls for each advanced life support squad.

These statistics are then given to the user to analyze the squad locations, or optionally the model, using this information, determines which squad is least important to the region and can be removed without affecting the distribution of response time or the load of individual squads. The model can also, upon request of the user, apply a specially developed algorithm to determine the best location for possible addition of a new squad.

As a simulation model, the exact operation of the squads can be duplicated. In this case the following additional input is required: The X and Y coordinates for all hospitals that serve the region, and squad information regarding the number of vehicles, vehicle equipment, number of personnel, and personnel training. Whenever a call is received, the nearest ambulance, that has the proper equipment and personnel, is dispatched to the scene. If either the vehicle or personnel is not available then another ambulance is dispatched from the next nearest squad. Upon arrival to the scene, the patient is treated and then, if necessary, transferred to the nearest hospital that can take care of him. The vehicle and its crew then return to their base or to another scene.

The simulation model, as briefly explained above is very simple, but is extremely helpful in generating statistics that are very important to the squad operation. These include the following (mean and standard deviation of frequency diagrams):

1) Dispatch Time
2) Time to Scene
3) Total Response Time (1+2)
4) Time at Scene
5) Time to Hospital
6) Time to Return
7) Total Trip Time (1+2+4+5+6)
8) Mileage to Scene
9) Mileage to Hospital
10) Mileage from Base to Hospital
11) Mileage to Return
12) Total Mileage (8+9)
13) Frequency and Distribution of EMS Runs
14) Number of Calls Received/Answered by Each Squad
15) Vehicle Utilization
16) Number of Persons Taken to Each Hospital

The above model is still being developed. Upon its completion, the model will be used to produce the above statistics for different possible scenarios including the following cases for which investigation is planned:

1) Existing arrival rate of EMS runs.
2) Increasing arrival rate of EMS runs (different increments).
3) Decreasing arrival rate of runs.
4) Eliminating one or more squads
5) Adding one or more squads (with different levels of personnel and equipment).
6) Modifying equipment (e.g., adding new vehicles or eliminating unused vehicles).
7) Modifying level of personnel training (e.g., Basic Life Support [BLS], Advanced Life Support [ALS], Registered Nurse [RN], Emergency Medical Technician [EMT], Medical Support Assistant [EMSA], etc.).

For each of the above scenarios, the simulation model will be used to provide valuable statistics about the level of performance and the degree of emergency medical care provided. Running the simulation model under different conditions should result in excellent information that helps in identifying the best conditons to run the EMS system and to provide the ultimate level of service and emergency health care within the budget and personnel constraints. Specifically the model should help in EMS operation planning and especially in identifying the following:

1) Vehicle requirements per squad.
2) Personnel requirements per squad.
3) Training needs for squad members.
4) Location of new EMS squads.
5) Support equipment needs.
6) Budget requirements.
7) Performance evaluation..

CONCLUSION

The projects presented in this paper display the diversity of simulation in the health care field. In the case of West Virginia University Hospital the use of simulation models allowed for quick, quantifiable answers, rather than subjective reasoning. Decision making can be a very difficult task for complex systems such as the Emergency Medical Services (EMS) System. The simulation model presented above should provide a valuable tool for the control and operation of the EMS squads.

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