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THE USE OF SIMULATION TO EVALUATE AUTOMATED EQUIPMENT FOR A CLINICAL PROCESSING LABORATORY

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ABSTRACT

A series of simulation models were created to evaluate several vendor proposals submitted for automation of the Central Processing Laboratory at Mayo Clinic in Rochester, Minnesota. The goals of automating Central Processing are to deliver a high quality product (medical specimen) to the appropriate testing laboratory at a lower cost, decrease turnaround time for test results, and reduce potential employee exposure to biohazards. In this paper we discuss the simulation models we developed to perform the evaluations.

1 INTRODUCTION

Mounting cost pressures in the health care industry are forcing health care providers to seek methods to reduce their costs in an increasingly competitive and regulated environment. A committee was commissioned to investigate the automation of Mayo Clinic's Central Processing Laboratory. The committee was composed of physicians, engineers, financial analysts, programmers, and administrative personnel. The goals of the team were to seek solutions that would:

1) Improve the service to the patients and physicians,
2) Lower the cost of processing samples, and
3) Lower the risk of infection to the employee

The Central Processing Laboratory is a critical part of the clinical support infrastructure. The first criteria is to ensure an automated system would improve the service to the patients and physicians by providing a high quality medical specimen to the analytical laboratories in a timely manner. .

Reduced cost is an ongoing challenge to medical care providers. The appropriate automated solution would reduce the long term costs of providing the pre-analytical functions of analytical tests.

The risk of spreading blood borne infection to the health care worker of concern. Reducing that risk of exposure was a consideration in evaluating the vendor proposals. Estimates of the cost of treating a single accidental exposure to blood or blood components put the cost into hundreds of dollars in testing, medical care, and lost work time.

2 MAYO CLINIC

Mayo Clinic in Rochester, Minnesota, has been in existence since 1904. Mayo Foundation also includes facilities in Jacksonville, Florida, and Scottsdale, Arizona. Mayo Medical Center in Rochester, site of the automation project, is comprised of Mayo Clinic (an outpatient examination and diagnostic facility), Saint Marys Hospital (1,157 beds) and Rochester Methodist Hospital (794 beds). It is the largest private medical group practice in the world. The Clinic is staffed by over 17,000 employees, including nearly 1,000 staff physicians, and 1,500 physicians in training. The staff provides service to 300,000 patients and nearly 400,000 hospital patient days per year. The Rochester campus consists of seventeen buildings spread over a twelve block area.

3 CENTRAL PROCESSING

The Central Processing Laboratory, located on the ground floor of the Hilton Building in Mayo Rochester, functions as an early processing step for the preparation of blood and other medical samples after collection. The samples are prepared by this laboratory before they are sent for examination and diagnosis to twenty-four analytical laboratory locations contained on ten floors of the Hilton Laboratory Building. Central Processing serves Mayo Clinic and both hospitals of Mayo Medical Center. The laboratory is located in close proximity to the analytical laboratories and the major blood collection area. The laboratory can receive test samples from over a

dozen locations within the Clinic and hospitals. In 1991, the laboratory processed 1.2 million samples.

An abbreviated flowchart of the Central Processing functions is shown.:

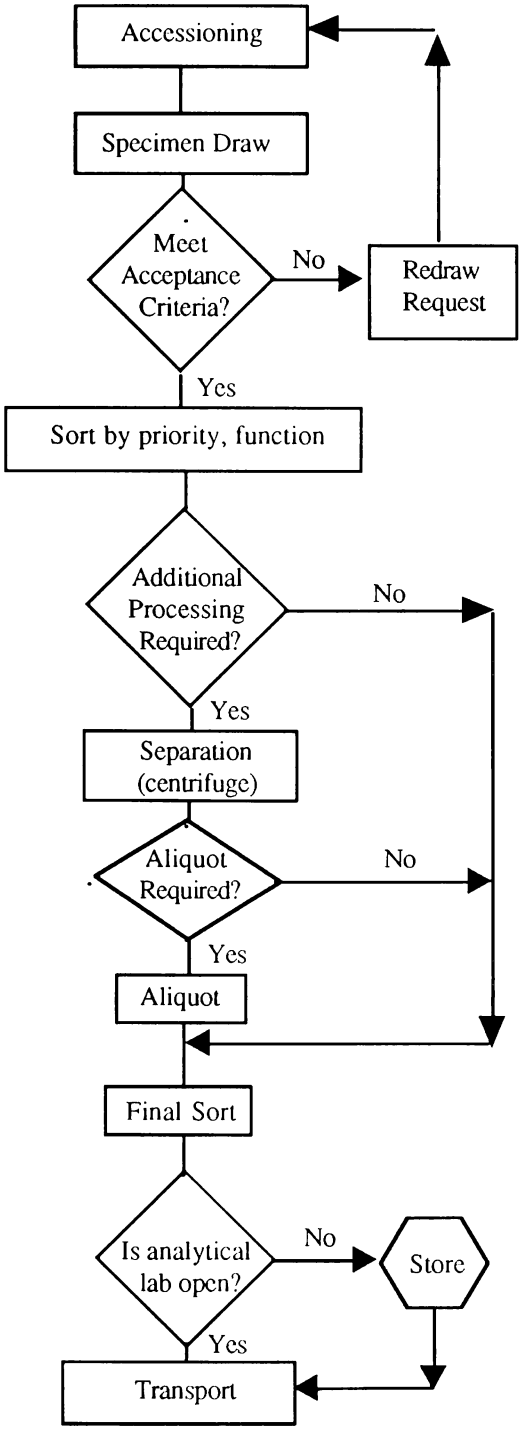

Figure 1. Current Process Flow - Central Processing

The functions performed in Central Processing include receiving, quality control inspection, sorting, centrifugation, aliquotting, delivery, and storage. (The aliquot process separates the original centrifuged blood specimen into smaller samples of blood serum or plasma).

Test samples (specimens) are delivered to Central Processing in any of the following methods: courier, pneumatic tube systems, or in-house electric track vehicle system. On a typical day, the personnel within Central Processing receive over 5500 samples for patients being seen at Mayo Clinic. The laboratory receives approximately 1,400 samples per hour during the busy periods of the morning.

4 REQUEST FOR PROPOSAL

The request for proposal (RFP) included detailed information on the current processes of Central Processing, current turnaround times, computer interface specifications, specimen characteristics, and other significant details of the operation. The RFP specified that each vendor evaluate the current manual operations of Central Processing and determine whether alternative technologies for the automation of the sort, centrifuge, and aliquot functions and the delivery of medical specimens to the various clinical laboratories exist. The RFP emphasized the need to streamline the sample preparation at lower cost. Each vendor was asked to include performance data for their equipment in order to simulate each proposal.

Eighteen companies responded to the initial request for proposal that was developed by the automation committee and sent to prospective vendors. After screening by the committee and clarification of the capabilities of each vendor, the committee narrowed the field of potential vendors to three. Simulation models for each vendor's proposal and for the current manual process were completed.

5 REASON FOR SIMULATION

During the evaluation of the vendor proposals, it was discovered that very few extensive applications of clinical laboratory automation exist. Therefore, operational data was not available. Some of the proposals consisted only of conceptual drawings that were sent to the committee. One vendor had only installed machinery overseas. Using the drawings, conversations with the vendors, and a videotape of the installation from overseas, we were able to obtain operational information, such as process times, needed for the simulation.

It was recognized that the automation project had risk and that the application of simulation to the project was

seen as a way to better evaluate alternatives and suggest modifications to designs. The vendors were supportive of the use of simulation in the evaluation of their respective proposals.

6 METHODOLOGY

The first step in the study was to develop a simulation model of the current labor-intensive environment within Central Processing. The model would serve as a base of comparison to the current performance of the laboratory. In addition, the initial model would serve as a baseline measurement against which to compare the other models. Law and Kelton (1991) point out that building a simulation model of the current system will increase the credibility of the simulation study.

One of the first steps in developing a simulation model is to define the entity, or object, within the simulation program that will be followed during the simulation. The entity will cause changes in the model and collect statistics as it travels through the model. We defined the entity for the simulation as the individual tubes of blood that arrived to the laboratory.

To reduce the complexity of the model, we concerned ourselves with the blood samples and disregarded the processing of other specimens. Each simulation model encompassed the activities that occurred within the Central Processing Laboratory. The activity of drawing the blood sample from the patient, the delivery of the specimen, and the post-processing of the sample in the analytical laboratories were not modeled. The model was structured in a modular design so changes in equipment or processing steps could be accomplished quickly.

No attempt was made to incorporate equipment downtime, employee illness, or specimen spoilage. All process times were based on average process times observed through time study of the manual process or engineering projections.

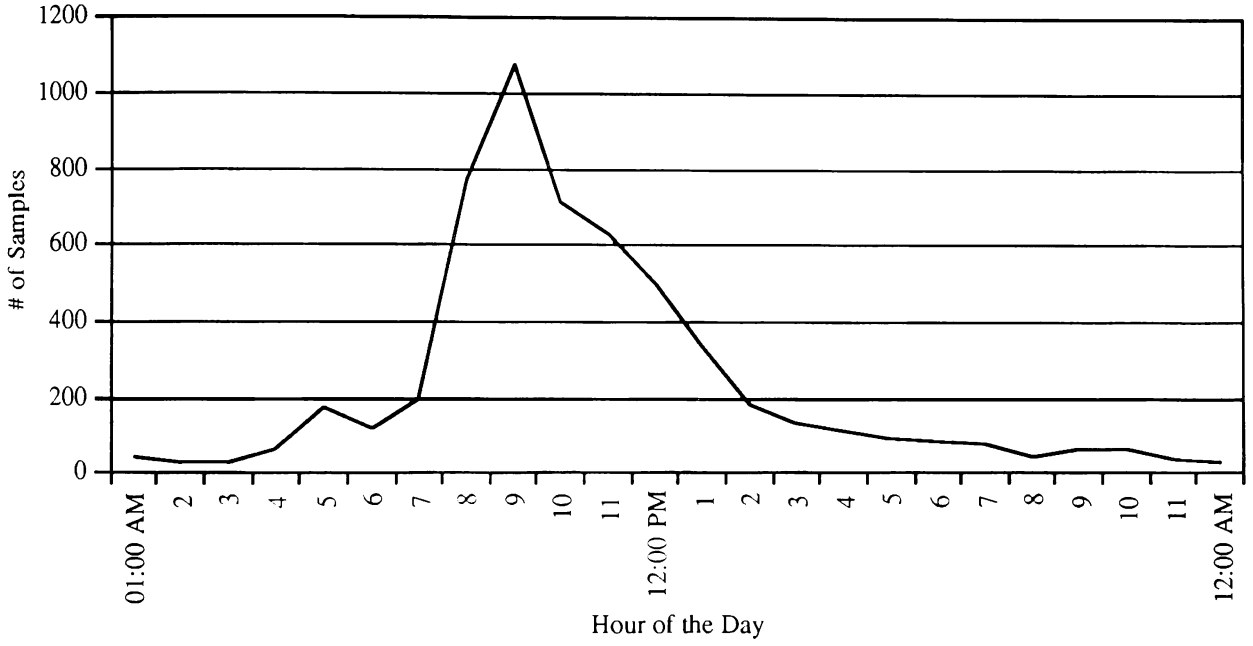

Figure 2. Hourly Arrival Rate of Samples to Central Processing

7 MODEL INPUT

Because the arrival pattern of blood test samples to the laboratory is heaviest during the morning hours, we modeled these arrivals by using the exponential distribution [Law & Kelton, 1991]. The exponential distribution is commonly used for modeling the interarrival times of customers into a system. Figure 2 shows the variability in the hourly inputs to the laboratory. Schriber [1991] describes a model in which the hourly arrival rate varies during the twenty-four hour period. The model incorporates the changes in the interarrival rate at different times of the day.

Each model was simulated with three volume possibilities:

1) An average day's sample volume
2) A peak day's sample volume
3) The projected daily volume five years in the future.

The committee wished to assure that the equipment purchased in 1992 would serve out a five year economic life.

At Mayo Rochester, an incoming sample is assigned a processing priority. Five priorities have been established.

1) Stat - 30 minute turnaround
2) Stat - 60 minute turnaround
3) Priority 1
4) Priority 2
5) Routine sample

(Stat is an abbreviation from the Latin *statim*, which means immediately).

These priorities describe the turnaround time needed for a sample and communicate the urgency of the request. In addition, the priority determines which physical location in the Central Processing Laboratory will receive the sample.

The physician ordering the blood test determines how quickly the results are needed, and therefore the priority. The mix of blood sample priorities varies throughout the day. During the early morning hours (12:00 am to 5:00 am), the majority of the incoming samples will be high priority blood samples arriving from the hospitals. While during the morning hours, the mix of incoming tubes will be weighted heavily towards routine samples as outpatients are being seen at the Clinic. Table 1 gives an example of the incoming percentages by time of day.

Table 1: Example of changing priority mix from 7 am to 12 pm. Numbers shown are percentages.

Hour of day	Stat 30 min	Stat 60 min	Priority 1	Priority 2	Routine
7 -8 am	13.1	<0.1	15.8	26.3	44.7
8 -9 am	<0.1	<0.1	1.5	14.5	84.1
9-10 am	<0.1	<0.1	2.0	3.4	94.7
10-11 am	<0.1	<0.1	0.4	1.2	98.4
11-12 pm	1.4	<0.1	0.8	1.5	96.2

The processing steps required for each blood sample vary as well. An arriving blood sample will undergo one of the following processes:

1) Sort the sample and send to the analytical laboratories.
2) Sort, centrifuge and send to the laboratory.
3) Sort, centrifuge, aliquot and send to the laboratory.

The current processing of samples is labor intensive. Laboratory centrifuges are used to spin the blood sample to separate the serum from the blood cells. Twenty-four centrifuges are available during the entire day.

The same level of technician staffing is not available throughout the day. The majority of technicians are scheduled in the morning hours to match the peak sample arrival time. The laboratory is open twenty-four hours a day, 365 days a year.

Technician staffing in various areas of the Central Processing Laboratory was taken into consideration in simulating the manual processing of incoming tubes.

8 SIMULATION MODELS

Once the base model of the manual process was developed and debugged, the results were verified against actual time studies developed by the supervisor of the Central Processing Laboratory. At that point in the project, work began on developing models for the automation solutions proposed by the three vendors chosen for further technical and economic analysis. The committee decided that only the routine samples, which currently make up approximately seventy percent of all incoming tubes would utilize the automated equipment. Committee personnel were unwilling to change the current system of processing high priority samples. The current manual system of processing priorities works well.

The solutions proposed by each vendor were varied. One vendor proposed a solution that would automate the entire routine sample processing in half the space currently used. Another vendor proposed a solution making extensive use of articulated arm robotics. A third vendor proposed to automate only a portion of the laboratory.

Each of the three vendors utilized different material handling systems for moving the samples between the various pieces of equipment. Two vendors moved the samples in racks for holding the blood specimen tubes. The remaining vendor developed a unique carrier for moving each sample individually between pieces of equipment. This design also allowed the individual samples to be grouped before transport to the analytical laboratories.

The level of manual effort needed to support each vendor's machinery was different from today's environment. One vendor's solution only needed a technician to load the sample and to remove the finished sample. The other two vendors required manual intervention to move samples between pieces of equipment.

9 MODEL OUTPUTS

The primary concern of the automation committee was the throughput time of each sample. The ability to process each sample quickly, send the sample to the analytical laboratories, and return the test results to the ordering physician is of utmost importance for patient care. Customer satisfaction for both the patient and the physician is critical to the success of the operation. Satisfaction is defined as returning the results of the sample in a timely and accurate manner.

The committee was not concerned with queue lengths *per se* due to the small size of the samples (test tubes). Space exists in the facility for samples to be held until they can be processed.

The overall daily average turnaround time was important. However, the maximum turnaround time during the busy periods of the morning was even more important. Turnaround times that exceeded ninety minutes for any sample were unacceptable.

10 MODEL CONSTRAINTS

One of the critical resources in the laboratory is the availability of centrifuges. The centrifuges are used to spin the incoming blood samples to separate the blood serum from the blood cells and fibrin. In the current system, which has twenty-four centrifuges, there is a sufficient number of centrifuges to handle the current volume of incoming tubes. Today each centrifuge can accommodate up twenty-four tubes.

The number of centrifuges specified for each vendor differed. Vendor A recommended two centrifuges. Vendor B provided nine centrifuges and Vendor C designed in four centrifuges.

The problem encountered with fewer and larger centrifuges is outlined in Table 2.

Table 2: Advantages & Disadvantages of Centrifuge Scheduling

Centrifuge Schedule	Advantages	Disadvantages
Run with smaller loads	First tube that arrives does not wait as long	Tubes arriving after centrifuge is spinning wait longer
Fill centrifuge to capacity	Full utilization of equipment Shorter queue lengths of waiting tubes	First arriving tubes may wait a long time waiting for centrifuge fill

In our models, we modeled the centrifuge by running a check on the status of those blood tubes waiting to be centrifuged. If the first tube that arrived to the centrifuge was ten minutes or older, the model collected all the waiting blood tubes and started the centrifuge. If the centrifuge had already filled to capacity before the ten minute check, then the centrifuge was started.

11 MODEL RESULTS

After receiving the vendor specifications and examining each proposal, the coding process began. We utilized the SIMAN® Simulation Language from Systems Modeling Corporation. SIMAN® offered flexibility in modeling the conveyor aspects of each design. In addition, we utilized the file output capabilities to output statistics. This program contains the SIMAN® Experimental Frame that allowed us to make the necessary changes in volume. We found the 'schedules' block particularly helpful in modeling the changing capacity of the technician resources throughout the work day.

The investment of time in developing each model was significant. Part of the reason for this was our lack of experience with the SIMAN® syntax. In addition, we found that the application of simulation to this problem was not straightforward.

We ran the model under the proposed volume scenarios and produced the following results of turnaround times for those samples that needed to be aliquotted before being sent to the laboratory. (Statistics were also produced for the remaining processing steps).

Table 3. Daily Average Turnaround Times (in minutes) for samples that needed to be aliquotted under the three volume scenarios

Model	Average Volume	Peak Volume	1996 Volume
Current	72.8	78.9	N/A
Vendor A	67	65.7	88
Vendor B	54.8	59.3	N/A
Vendor C	70.1	71.6	N/A

N/A - model was not run under this scenario

Because it is critical to the successful operation of Central Processing, we utilized the external file capabilities of SIMAN® to isolate the peak hour throughput times and evaluate the proposed automation performance. Table 4 shows those results for the 8 - 9 am period.

Table 4. Hourly Average turnaround times for aliquotted samples during the peak hours of the day

Model	Average Volume	Peak Volume	1996 Volume
Current	77.3	78.4	N/A
Vendor A	68.9	67.1	63.6
Vendor B	55.8	58.1	N/A
Vendor C	66.5	66.4	N/A

The computer statistics package, SAS® was used to compute these hourly statistics (1988).

The difference in times reflects the dynamics of how often the centrifuges are filled and run. We are continuing to work on optimizing the timing of loading and operation of the centrifuge.

Results from the simulations indicated that each vendor's equipment could provide a turnaround time roughly equivalent to today's system.

12 CONCLUSIONS

Results of the simulations were included in the final report of the committee that recommended an automation solution for the Central Processing Laboratory. These results, along with the facility requirements, financial effects analysis, site visit information, and requirements for interfaces with our current laboratory information systems, were among the information included in the final report and presentation made to the Department of Laboratory Medicine. The report concluded that the purchase and installation of automated clinical laboratory equipment should be pursued.

Using the SIMAN® Simulation Language, we were able to successfully model our current system and the three proposed vendor solutions. Since this was the first simulation model that had been developed over the past few years, we learned from our experience and offer the following advice.

1) Provide vision and resources.

Identify an advocate knowledgeable of simulation and allocate the resources to develop successful model(s).

2) Develop a simulation model soon after learning the language.

Do not delay in developing the first model. The enthusiasm from the class experience will wear off and ideas learned will quickly fade.

3) Develop a core group of at least two to three individuals familiar with simulation and the simulation language.

It is helpful to able to bounce ideas off colleagues who are somewhat familiar with simulation and the language in use at your organization.

4) Confirm the validity of your simulation model against the real system.

Keep the ultimate users involved in ensuring the model is reasonable and accurate.

REFERENCE

Law, A.M., Kelton, W.D.,1991, *Simulation Modeling & Analysis, McGraw-Hill*, New York.

Pegden, C.D., Shannon, R.E., Sadowski, R.P., 1990, *Introduction to Simulation Using SIMAN*, McGraw-Hill, New York.

SAS User's Guide, Basics, Version 5, SAS Institute Inc. Cary, NC., 1988

Schriber, T.J., 1991, *An Introduction to Simulation Using GPSS/H*, John Wiley & Sons, New York.

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