Lecture Notes in Management Science (2012) Vol. **4**: 64–69
4th International Conference on Applied Operational Research, Proceedings

ISSN 2008-0050 (Print), ISSN 1927-0097 (Online)

A Simulation model of a hospital's clinical laboratory

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Abstract. We develop a simulation model of a clinical laboratory for a complete blood count (CBC) test in a large private hospital. The model will be used for experimenting with new lab layouts and new work processes for the CBC test. The turnaround time is defined as total time in process. The average value from the simulation model is 72.37± 87.9 minute compared with 73.08 ± 22.9 minute from the empirical data. We validate our model using the 2 sample *t*-test yielding the *p*-value of 0.8.

Keywords: turnaround time; clinical laboratory; stochastic discrete-event simulation

Introduction

The Royal Thai government announced a policy to promote Thailand as a medical hub in Asia. The number of foreign and Thai patients has increased steadily due to a growing interest in personal care. The number of foreign patients was 1,103,095 in 2005 compared with 973,532 in 2004 and 630,000 people in 2003 (Department of International Trade Promotion).

Discrete-event simulation utilizes a mathematical or logical model to represent the actual system. Both the nature of the state change and the time at which the change occurs require precise descriptions. Customers waiting for service, the management of parts inventory or military combat are typical domains of discrete event simulation Albrecht (2012).

Simulation modeling is chosen as an analysis tool because it is able to model complex systems. For example, Ahmed and Alkhamis (2008), Pirolo et al (2009),

and Venkatadri et al (2011) use simulation models to evaluate staffing policies. Perkiang (2010) study causes and remedies for reducing the return of blood specimen to the center and then assign solutions to the relevant agencies. Simulation modeling has been applied to solve various healthcare problems, including scheduling (Proctor 1996), admissions policy evaluation and operational improvements in outpatient facilities (Swisher et al 2001, and Duguay and Chetouane 2007). Blasak et al (2003), and Sinreich and Marmor (2005) use simulation models to reproduce the behavior of a healthcare system in order to evaluate its performance and analyze the outcome of different scenarios of the emergency department.

The hospital under study is a world-renowned private hospital in Thailand, offering many specialized service such as cancer centers, a dialysis center, a doctor golf clinic, and a spine center, serving both Thai and international patients. Questionnaires reveal that patients are not satisfied with long waiting time. Because doctors' prognosis require lab results, if the lab turnaround time is reduced from the current average of 73.08 minutes, the patient waiting times will be reduced. Note that the target turnaround time is 60 minutes, 17.8% smaller than the current average.

The laboratory has three test groups: composite hematology, immunology, and biochemical. In this paper, we only consider the complete blood count (CBC) test which is one type of the hematology tests. The CBC test process is semi-automatic, involving an automatic machine with lab staff. The CBC test includes counting the number of white blood cells, determination of hemoglobin guides, counting the type of blood cells, and estimating the number of platelets. The CBC test is done to determine the body abnormalities for the purpose of timely treatments. The CBC lab layout is shown in Figure 1, and the test procedure is as follows:

1. The Specimen is sent to the laboratory, and the assistant medical technologist (AMT) receives the specimen into the computer system by reading the barcode affixed to the specimen.
2. The AMT places the specimen at the station where the medical technologist (MT) is waiting.
3. The MT puts the specimen into the CBC test machine. The procedure depends on the order types:
   - 3.1 When the order is urgent
     - 3.1.1 The MT places the specimen at Station Blood Smear Manual.
     - 3.1.2 The MT chooses if she wants to do the tint slide auto or the tint slide manual.
     - 3.1.3 The tint slide manual is done at the Station Blood Smear Manual.
     - 3.1.4 The tint slide auto is done at the CBC test machine.
   - 3.2 When the order is not urgent
     - 3.2.1 The MT holds a specimen for putting in front of the CBC test machine, which runs automatically. If there are special cases, proceed to step 4.
     - a. If the test result is higher than the upper limit, start blood smear and tint by an auto machine.
     - b. If the blood smear machine fails, or the doctor wants to look at slides, the MT does the blood smear manual.

4. The specimen undergoes the blood smear process
   4.1 Slides are placed at the station for blowing and wiping
   4.2 Slides are moved to the microscope station. The MT scans the microscope and results are record into the computer system.
5. MT verifies the results and input into computer system.

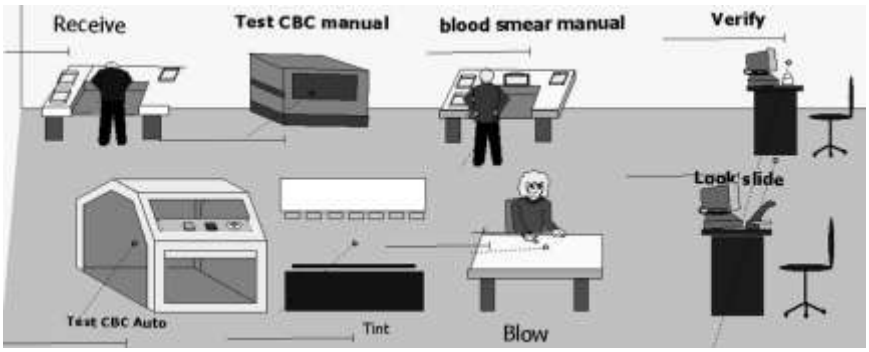

Fig. 1. Physical Layout of the CBC Lab

Simulation model development

We consider the data collection in Section 2.1, the simulation model construction in Section 2.2, and the model verification and validation in Section 2.3.

Data collection

The data under consideration consists of 615 blood samples that were collected over three months. The arrival process is divided into 24 one-hour intervals. We collect the number of resources such as MTs, AMTs, and the CBC test machine by interviews. The times required for various activities associated with the CBC test were collected by the stop watch time study.

Arena® contains additional tools that are valuable for simulation modeling. The Input Analyzer helps select an appropriate distribution for inputs to an Arena model. It allows users to take raw data such as time studies on process breakdowns, activity time and fit it to a statistical distribution. This distribution then can be incorporated directly into our model (Table 1).

The major problem in data collection is the number of timekeeper; there was only the author who did the job. To get their collaboration, we also need to build personal relationship with the MT and AMT by explaining the benefits to be gained from our work.

Simulation model construction

The Arena's *Entity* that flows through our simulation model is the blood specimen for the CBC test. The resources are MTs, AMTs, the blood smear machine, the CBC test machine, and a microscope. The working time consists of 2 shifts: the first shift is 07.01 AM – 04.00 PM and the second shift is 04.01 PM – 07.00 AM. The numbers of MT and AMT are 4 MTs in the first shift and 2 people in the second shift; 2 AMTs in the first shift and 1 AMT in the second shift. Other numbers of resources stay constant during both shifts: 2 blood smear machines, 2 CBC test machines, and 1 microscope.

Other Input data for the simulation model include the arrival process of specimens, the MT and AMT schedules, activity time distribution, and walking distance from one station to another. The simulation model was developed using the Arena software package, version 12.0.

Table 1. Activity Time Distribution (time in minute).

Process	*Arena's expression*
Receive specimen (1)	TRIA(0, 0.26, 4.73)
Blood Smear Manual (3.1.3)	TRIA(0.15,0.23,2.7)
CBC test Auto (3.2.1)	NORM(6.75,1.97)
Blood Smear Automatic (a.)	NORM(3.22,0.36)
Tint Auto (a.)	6.24+Expo(0.074)
Blow and wipe (4.1)	NORM(0.275,0.129)
Scan electron microscopy and result record (4.2)	TRIA(0.01,0.034,2.72)
Verify (5)	0.07 + LOGN(0.153, 0.0972)

Model verification and validation

Verification and validation are key steps in simulation model development. Verification is done to determine if the computer simulation model matches to the analysts' concept. Our model was verified by explaining the model logic to the lab staff. The validation step is the comparison of turnaround time received from the model and empirical values of the actual system. We use a two-sample *t*-test for validation. Table 5 at confident interval of 95% and model run 30 times get average turnaround time of model is 72.37 minute and average turnaround time of actual data is 73.08 minute from data 13 month. Table 6 shows the results of the 2sample t-test between the empirical data and that from the simulation model. The *p*-value is 0.8 which more than the significance level 0.05.

Table 5. Result of model and actual system.

Empirical Data	*Sample Size*	*Average*	*Variance*
Simulation Result	30	72.37	235.47
Actual Result	13	73.08	37.91

Table 6. The 2 sample t-test between reality and the simulation model.

Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Groups	11.2	1	11.21	0.06	0.80	4.07
Within Groups	7283.5	41	177.64			
Total	7294.8	42				

Other performance measures

Simulation outputs are 72.37 ± 87.9 minute of the turnaround time of the CBC test. Other performance measures that may be of interest are the total waiting time in queue of 54.27 ± 3.2 minute, 3.37 minute of transfer time. Table 7 show utilization of resources in the CBC test.

Table 7. Utilization of Resources in CBC test.

Resources	*Utilization of Resources (%)*
AMT first shift	12 ± 1.0
AMT second shift	30 ± 2.1
MT first shift	6 ± 0.7
MT second shift	31 ± 2.5
MT in microscope station first shift	4 ± 2.8
MT in microscope station second shift	45 ± 3.2

Conclusion and development approach

We show that our simulation model can adequately represent the actual system. We will use it to test our ideas of reducing turnaround time such as modifying the lab layout to decrease the walk time of staff.

Acknowledgments—This research is financially supported by the Office of the Higher Education Commission and Mahidol University under the National Research Universities Initiative.

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