REDUCTION OF TURNAROUND TIME IN A HOSPITAL'S CLINICAL LABABORATORY BY SIMULATION MODELING

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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 to reduce the turnaround time which is defined as total time in process. The average value from the simulation model is 72.07 ± 0.9 minute compared with 73.08 ± 22.9 minute from the empirical data. A new CBC test layout was created by the Relationship Diagram method to improve the work flow of medical technologists. The new turnaround time is reduced to 57.03 ± 1.12 minutes.

Keywords: Turnaround Time, Clinical Laboratory, Stochastic Discrete-Event Simulation, Relationship Diagram

1. INTRODUCTION

The Royal Thai government announced a policy to promote Thailand as a medical hub of 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, Ministry of Commerce, the Royal Thai Government).

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 (Albrecht 2012). Simulation modeling is chosen as our 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. Deb and Bhattacharyya (2005) use the relationship diagram to design manufacturing facilities.

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 biochemistry. 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, the MT places the specimen at Station Blood Smear Manual. She chooses if she wants to do the *tint slide auto* or the *tint slide manual*. The *tint slide manual* is done at the Station Blood Smear Manual. The *tint slide auto* is done at the CBC test machine.
   - 3.2. When the order is not urgent, the MT holds a specimen to be put in front of the

CBC test machine, which runs automatically. If there are special cases, proceed to Step 4. If the test result is higher than the upper limit, start blood smear and tint by an auto machine. 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 recorded into the computer system.
5. MT verifies the results and input into computer system.

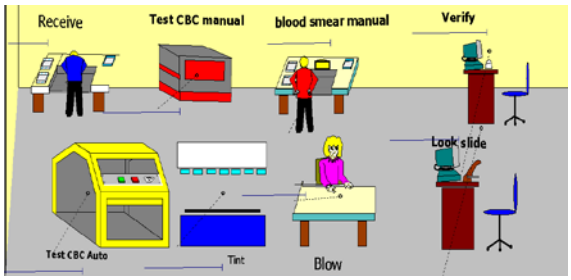

Figure 1: Physical Layout of the CBC Lab

2. 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.

2.1. 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, i.e., manually recording the process time with a stop-watch. The raw data was used to fit parametric probability distribution (Table 1). Table 2 shows the distance between work stations under the current lab layout. Figure 2 shows arrival rates to the CBC test, and the arrival rate during 07.00 AM – 01.00 PM is the highest.

The major problem in data collection is the number of timekeepers; 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.

2.2. Simulation Model Construction

The simulation model was developed using the Arena software package, version 12.0. 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. Staffs work on 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 number of resources stays constant: 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.

Table 1: Activity Time Distribution (unit: minute)

Process	Arena's expression
Receiving specimen (1)	TRIA(0, 0.26, 4.73)
Manual blood smearing (3.1)	TRIA(0.15,0.23,2.7)
Auto CBC test (3.2)	NORM(6.75,1.97)
Auto blood smearing (3.2)	NORM(3.22,0.36)
Auto tinting (3.2)	6.24+Expo(0.074)
Blowing and wiping (4.1)	NORM(0.275,0.129)
Scanning electron microscopy and results record (4.2)	TRIA(0.01,0.034,2.72)
Verifying (5)	0.07 + LOGN(0.153, 0.0972)

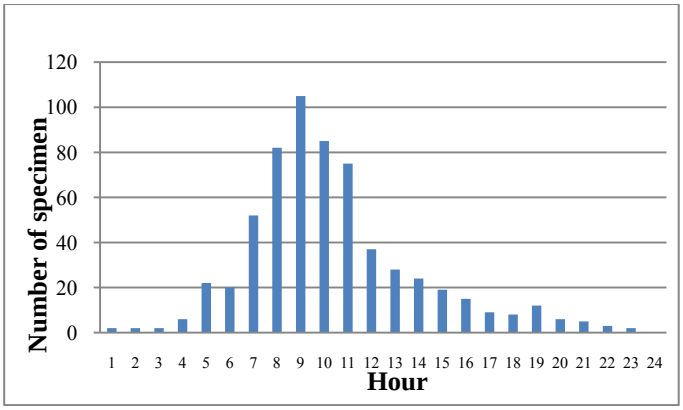

Figure 2: Arrival Rate in CBC Test

2.3. 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 logics 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 (see Rosetti 2010 for details). Table 3 shows the averages and standard deviation of turnaround time from simulation and that of actual data.

The p-value of the 2 sample t-test is 0.8 which is more than the significance level 0.05.

Table 2: Distance in the CBC test lab

From	To	Distance (m)	
		Current Layout	Proposed Layout
Receiving	Waiting for MT	5.20	1.25
Waiting for MT	Manual CBC test	6.15	2.81
Waiting MT	Auto CBC test	12.00	1.20
Waiting for MT	Manual blood smearing	5.65	2.35
Manual CBC test	Manual blood smearing	0.50	1.01
Manual CBC test	Verifying	2.00	1.00
Manual blood smearing	Auto tinting	8.00	0.70
Manual blood smearing	Microscope scanning	2.50	0.80
Auto tinting	Microscope scanning	6.10	1.61
Auto tinting	Verifying	1.30	2.41
Microscope scanning	Verifying	6.00	1.00

Table 3: Comparison of Turnaround Time from Simulation and the Actual System

Data type	Sample size	Average (min)	Standard deviation
Simulation	400	72.07	0.9
Actual data	13	73.08	22.9

3. LAB LAYOUT DESIGN

We use the Activity Relationship Chart and Relationship Diagram (Table 4) to design a new layout. The relationship diagram is a tool for identifying relationships between areas in a plant or pair activities by showing how closely two areas should be located with a rating level (A, E, I, O, U and X). The Relationship Diagram shows a location of each activity by converting the Activity Relationship Chart of "closeness-ratings" into a diagram (Muther 1961). and In this paper, closeness scores are provided by the MT. Layout planning rests on the three fundamental of relationship between the activity in layout, space for each activity area, and adjustment of relationship and space interested near of each stations. Closely related activities are assigned to be in proximity of one another.

Table 2 shows the distance between stations of the new layout and the old one. Stations that have high closeness ratings are placed closer to one other. For example, the distance between the manual blood smearing station and the microscope scanning station decreases from 8.00 meter to 0.70 meter.

Table 4: Activity Relationship Chart

	process CBC test	1 Receiving specimen	2 Receiving computer	3 Waiting for MT	4 Manual blood smearing	5 Manual tint	6 Manual CBC test	7 Auto test CBC	8 Auto blood smearing	9 Auto tint	10 Blow slide	11 Microscope scanning	12 Verifying
1	**Receiving specimen**		**A**	**I**	**U**	**U**	**U**	**U**	**U**	**U**	**X**	**U**	**U**
2	**Receiving computer system**			**A**	**U**	**U**	**U**	**U**	**U**	**U**	**X**	**U**	**U**
3	**Waiting for MT**				**U**	**U**	**U**	**I**	**U**	**U**	**X**	**U**	**U**
4	**Manual blood smearing**					**A**	**I**	**U**	**U**	**U**	**A**	**I**	**U**
5	**Manual tint**						**O**	**U**	**U**	**U**	**A**	**I**	**U**
6	**Manual CBC test**							**U**	**U**	**U**	**U**	**I**	**I**
7	**Auto test CBC**								**A**	**A**	**U**	**I**	**I**
8	**Auto blood smearing**									**A**	**U**	**I**	**U**
9	**Auto tint**										**U**	**I**	**U**
10	**Blow slide**											**I**	**U**
11	**Microscope scanning**												**A**
12	**Verifying**												

Defination
A :Absolutely Necessary
E :Especially Important
I :Important
O :Ordinary Closeness
U :Unimportant
X :Undesirable

4. PERFORMANCE MEASURES

The simulation run set ups are as follows: 400 replications, the run length of 24 hour and no warm up period. Tables 5 and 6 shows the comparison of simulation results under the current layout and the proposed layout. Under the proposed layout, the transfer times are significantly reduced. Turnaround time and total waiting time in queue decrease because the work flow of MT is changed. As is, after the MT obtains the microscope results, she writes it on a sheet of paper and leaves it in a basket for another MT who keys a batch of results into the computer system. We propose that MT who reads the microscope subsequently input the results into computer system right away, not placing it in a batch.

The simulation model returns low utilization of human resources because these numbers reflect the fraction of times they actually work on specimens. In reality, they do not have that much free time since they also perform other duties, such as filling out paper work or talking on the phone.

Table 5: Comparison of the Current Layout and the Proposed Layout

Time	Current layout (minute)	New lab layout and work process (minute)	Percent decrease
Turnaround time	72.07 ± 0.9	57.03 ± 1.12	21%
Total waiting time in queue	44.27 ± 3.2	30.00 ± 0.98	32%
Transfer time	3.37 ± 0.1	0.28 ± 0.2	92%

Table 6: Utilization of Resources (%) in CBC Test

Resources	Old Layout	New Layout
AMT in the 1st shift	25 ± 1.0	26 ± 1.5
AMT in the 2nd shift	60 ± 0.1	65 ± 1.1
MT in the 1st shift	12 ± 0.7	18 ± 2.3
MT in the 2nd shift	22 ± 0.1	29 ± 0.3
MT at microscope station in the 1st shift	8 ± 0.8	12 ± 1.0
MT at microscope station in the 2nd shift	49 ± 1.0	60 ± 0.1

5. CONCLUSION AND DEVELOPMENT APPROACH

We show that our simulation model can adequately represent the actual system. We use it to test our ideas of reducing turnaround time by modifying the lab layout to decrease the walk time of staff. We use relationship diagram for create new lab layout. The turnaround time of new lab layout decreases from 72.07 ± 0.9 minute to 57.03 ± 1.12 minute or 18.4% with the CBC test capacity of 615 specimens per day. Reducing the turnaround time will increase CBC test's capacity to meet the demands of increased patient volumes.

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REFERENCES

Ahmed, A. and Alkhamis, M., 2008. Simulation optimization for an emergency department healthcare unit in Kuwait. *European Journal of Operational Research*, 198, 936–942.

Albrecht, MC. Available from: http://www.albrechts.com/mike/DES/index.html [accessed 8 March 2012]

Banks, J., Carson, J.S., Nelson, B.L. and Nicol, D.M., 2005. *Discrete-event System Simulation*. 4th ed. U.S.A.: New Jersey.

Blasak, R.E., Armel, W.S., Starks, D.W. and Hayduk, M.C., 2003. The use of simulation to evaluate hospital operations between the emergency department and a medical Telemetry unit. In: S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice, ed. *Proceedings of the 2003 Winter Simulation Conference*. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, 1887–1893.

Deb, S.K., and Bhattacharyya, B., 2005. Fuzzy decision support system for manufacturing facilities layout planning. *Decision Support Systems*, 40, 305–314.

Department of International Trade Promotion. Available from: http://www.ditp.go.th/Default.aspx [accessed 1 September 2011]

Duguay, C. and Chetouane, F., 2007. Modeling and Improving Emergency Department Systems Using Discrete Event Simulation. *Simulation*, 83, 311-320.

Muther, R., 1961. *Systematic Layout Planning. Industrial Education Institute*. Boston.

Perkliang, M., San-ae, S., Chawaku,l D., Rutti, T., Prasongsab, T., Pocathikorn, A. 2010. Root Cause Analysis of Specimen Rejection for Hematology Testing. *Songkla Medical Journal*, 28, 267-274.

Pirolo, J., Ray, A., Gadzinski, M., Manese, M., Garvert, B., Scoville, G., Walpole, H., Amland, B., Boos, R., Mamminga, I., Brown, J. and Donlon, K., 2009. Utilization of Discrete event simulation in the Prospective Determination of Optimal Cardiovascular Lab Processes. In: M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin and R. G. Ingalls, ed. *Proceedings of the 2003 Winter Simulation Conference*. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, 1916-1926.

Proctor, T., 1996. Simulation in Hospitals. *Health Manpower Management*, 22, 40-44.

Rossetti, M.D. 2010. *Simulation Modeling and Arena*. John Wiley & Sons Ltd. United States of America.

Sinreich, D., and Marmor, Y., 2005. Emergency department operations the basis for developing a simulation tool. *IIE Transactions*, 37, 233–245.

Swisher, J., Jacobson, S., Jun, B. and Balcid, O., 2001. Modeling and Analyzing a Physician Clinic Environment Using Discrete-Event (Visual) Simulation. *Computers and Operations Research*, 28, 105-125.

Venkatadri, V., Raghavan, V.A., Kesavakumaran, V., Lam, S.S. and Srihari, K. 2011. Simulation based alternatives for overall process improvement at the cardiac catheterization lab. *Simulation Modeling Practice and Theory*, 19, 1544-1557.

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