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The discrete-event simulation model of a health screening center

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Abstract. The health screening center is the first department that patients come into contact before going to other departments. Patients sometimes complain about long waiting times at this center. We develop a discrete-event simulation model of the health screening center to support the decision making process of the hospital management. It is designed such that it can readily be used for testing new patients' routing plans inside the health screening center. Input data is collected from electronic records and interviews with staff. The simulation model is validated by considering the average total times in the system of one health checkup package. The two sample *t*-test of the empirical data and the simulation results give the *p*-value of 0.1; therefore, the simulation model can adequately represent the actual system.

Keywords: discrete-event simulation model; health screening center; healthcare simulation

Introduction

Thailand is one of the medical hub of Asia. In 2006, it was estimated that all foreigners admitted to Thai hospitals are more than 1.2 million (Pearnmoree 2009). Some upscale private hospitals position themselves to directly attract medical tourists from countries with high purchasing power, such as Japan, the European Union and the East Asian countries. The main driving force on medical tourism in Thailand is the private sector which offers high technology treatments, some of which are in experimental stages. Various marketing plans have been launched to target international customers to emphasize the advantage of Thailand in terms of medical expenses and other services (Ranong 2011). Private hospital business is expected

to grow because more and more patients focus on preventive healthcare. Thus, a health screening center will receive greater number of patients because its main purpose is to identify future health risk so that the action can be taken immediately or highlight any problem areas. In addition, health screening can create or improve self awareness of health and fitness and provide referrals for further care when necessary. It is the first department that many patients come into contact with before going to other departments.

We study the health screening center at one of the forefront private hospitals of Thailand. The medical personnel is renowned for expertise in many areas and cutting-edge medical treatments. The health screening center is open from 6 AM to 5 PM. For check-ups, patients cannot eat or drink at least nine hours before; therefore, most patients arrive to the health check up center during 7 AM to 10 AM. Some medical tests take a long time, resulting in sometimes long waiting time for patients. The satisfaction survey done by the hospital indicate that it is one area that patients are not satisfied. Some factors that affect the waiting time are the variation of medical tests in the health screening packages, the number of hospital staff, and the patient scheduling. The hospital management would like to have a simulation model so that it can experiment with improvement schemes.

Discrete-event simulation (DES) models are computer programs that model the logical flow of complex processes occurring at discrete times (Kelton et al 2009). DES has become one of the most widely used Operations Research tools, including in healthcare applications. Everett (2002) describes simulation models that support the decision making process for scheduling of patients. Klein et al (1993), Jun et al (1999), and Jacobson et al (2006) provide a comprehensive literature review on simulation modeling and applications to health care.

Description of the health screening center

The health screening center under study consists of 6 stations. Figure 1 shows the layout of health screening center. Station 1 is the pre-assessment to inquire patients. Station 2 is the document preparation for medical exams. Station 3 is staffed by cashiers for making a payment. Station 4 is the vital sign checks and blood draw examination. Station 5 has two parts: the first part is the cardiac assessment consisting of the electrocardiogram (EKG) and the exercise stress test (EST), and the second part is radiology (Imaging services) consisting of chest x-ray, ultrasound of abdomen, a breast cancer exam and a mammogram. Station 6 is the physical examination and diagnosis, consisting of physical examination (PE), eye examination, pap smear and pelvic examination.

This health screening center offers 7 packages (see Table 1 for details of medical exams in each package). It operates from 6 AM to 6 PM every day. Patients make appointments before arrivals, or they are walk-in patients. When patients arrive to the health screening center, they go to Station 1 to register and do pre-assessment. If patients have made appointments, all the documents are readily prepared for them to sign. Patients proceed to Station 3 to make a payment after getting the

documents. Actual medical exams begin at Station 4 with the vital sign check and blood test. When patients finish with Station 4, they are split into two paths: the first one leads to Station 5 and then Station 6, whereas the second path goes to Station 6 first and Station 5 later, but patients need to return to Station 6 again to see physicians for diagnosis. Patients are directed to the second path when there are more than 10 persons in the ultrasound queue. Because Station 5 consists of cardiac assessment and imaging services (the order does not matter), patients are sent to the shortest queue. The patient flow diagram is summarized in Figure 2.

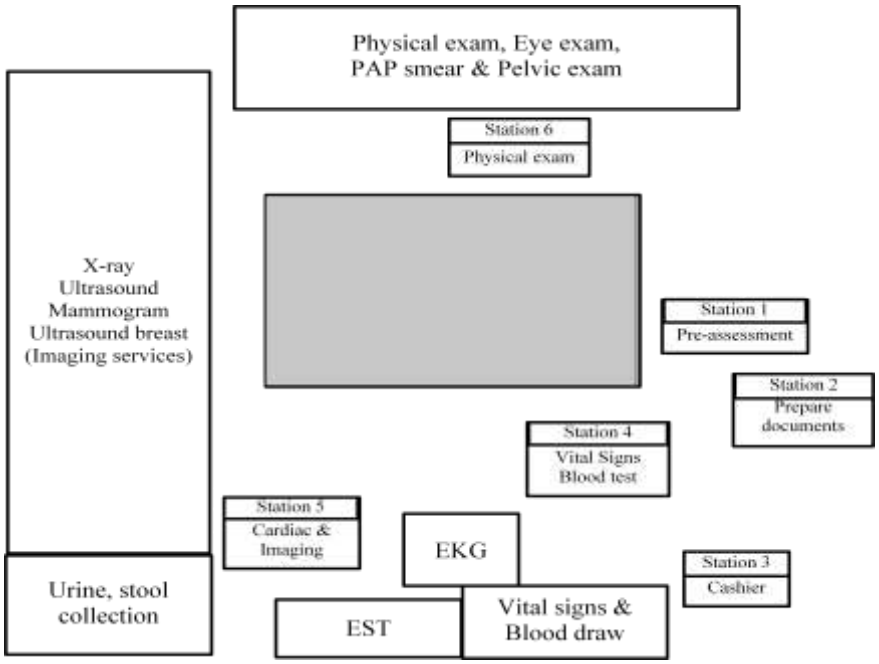

Fig. 1. Layout of health screening center

Simulation model development

We describe the data collection process in Section 3.1, the overview of the simulation model in Section 3.2 and the model validation in Section 3.3.

Data Collection

Empirical data was collected from computer recorded files, by interviews with doctors, nurses, and other hospital staff and by direct observation. Many issues arise during data collection. For example, hospital staffs are sometimes reluctant to provide data to us because they think we will use it to catch their mistakes.

Therefore, we discussed with the department manager what we needed and what they would get from our work. We also have to create good personal relationship with the staff so that they are willing to give us interview time. Moreover, they can also help us on data collection.

Table 1. Examination in each check up package.

	Regular	Executive	Executive female	Comprehensive male without EST	Comprehensive male	Comprehensive female age less than 40	Comprehensive female age more than 40
Vital Signs	●	●	●	●	●	●	●
Blood test	●	●	●	●	●	●	●
Electrocardiogram		●	●	●	●	●	●
Exercise stress test					●		
Chest x-ray	●	●	●	●	●	●	●
Ultrasound whole		●	●	●	●	●	●
Mammogram with ultrasound breast							●
Pap smear & Pelvic exam			●			●	●
Eye exam				●	●	●	●
Physical examination	●	●	●	●	●	●	●
					●	Examination	

For this model, we require input models for the patients' arrival, service time at each station, resource availability, and types of checkup packages. The distribution of patients on checkup packages is as follows: the Regular package accounts for 10% of patients, Executive package: 17%, Executive Female: 7%, Comprehensive Male without EST: 10%, Comprehensive Male: 27%, Comprehensive Female aged less than 40: 8%, and Comprehensive Female age more than 40: 21%. For the number of patient arrivals, we consider only weekdays and no holiday. The data is examined for seasonality and trends, and we do not find significant trends. We assume that the arrivals are independent of the day of the week and time of the year. The average number of patients is fixed at the average value of 170 per day, but we simulate their arrival time as follows: 2% during 6-7 AM, 22% during 7-8 AM, and the remaining hourly fractions until the center closes at 1 PM are 25%, 22%, 15% 10% and 4%, respectively.

The service time at each station is collected by the stopwatch time study. Table 2 shows the input models in Arena® expressions. When patients have ultrasound, they need to be full bladder, and the ultrasound test is done one at a time, on the lower and upper abdomen. The physical examination consists of 2 parts: consultation and diagnosis, both of which have to be done by the same physician.

The resources at the health screening center are *register nurses* (RN) who do pre-assessment at the registration, *nurse aids* (NA), *clinic associates* (CA) who are coordinators, *technicians* and *radiologists* work on imaging, and *physicians*. We assume that all staff of the same position are equally skilled. Resource availability during each time period is shown in Table 3.

Simulation model development

Waiting time in queue is the primary key performance index (KPI) that the hospital management is keenly concerned. Other KPIs include the total time in the health checkup center, average waiting time by package and by time period, total time by package and by time period, average total waiting time and total time of each path.

The simulation run length is 720 minutes (from 6 AM to 6 PM), no warm up period and 30 replications. The checkup center generally operates between 6 AM to 5 PM, but the additional time is to allow the department to clear the patients out of the system; it does not close until the last patient leaves. In the actual system, patients can request physicians that they would like to see. Sometimes they arrive to a health checkup center in a group. If they cannot wait for the diagnostic result, the hospital can send it by e-mails or by post. We make the following simplifications in our simulation model: we assume that patients do not make physician requests; patients arrive one at a time, and patients wait for their diagnosis results, except when they arrive at Station 6 after 4 PM.

Model validation

Validation is the process of checking if the simulation model can adequately represent with the real system. In this paper, we use the average total time of comprehensive male package going the first path (Station 5 first and Station 6 later) for validation. Rossetti (2010) describes the two sample *t*-test for comparing two means to validate the data from the simulation model with that from the actual system. The *p*-value of the test is 0.1; therefore, the simulation model can be used to model the actual system.

Results and discussion

We can use the simulation model to explain the actual system in the situation of 170 patients per day and 30 replications. The average total waiting time and total time for all patients, path 1 and path 2 in 95% confident interval (CI) show in Table 4. The path 1 (exam at Station 5 first) has total waiting time and total time less than path 2 (exam at Station 6 first) because path 2 has double physical examinations. The average total waiting time and total time of comprehensive male package in 95% CI require a longer time than other packages because it consist of many examinations (Figures 3 and 4). The average total waiting time and total time of arrival period during 6-7 AM in 95% CI require a shorter time than other periods because that period has the smallest number of patients in the system (Figures 5 and 6).

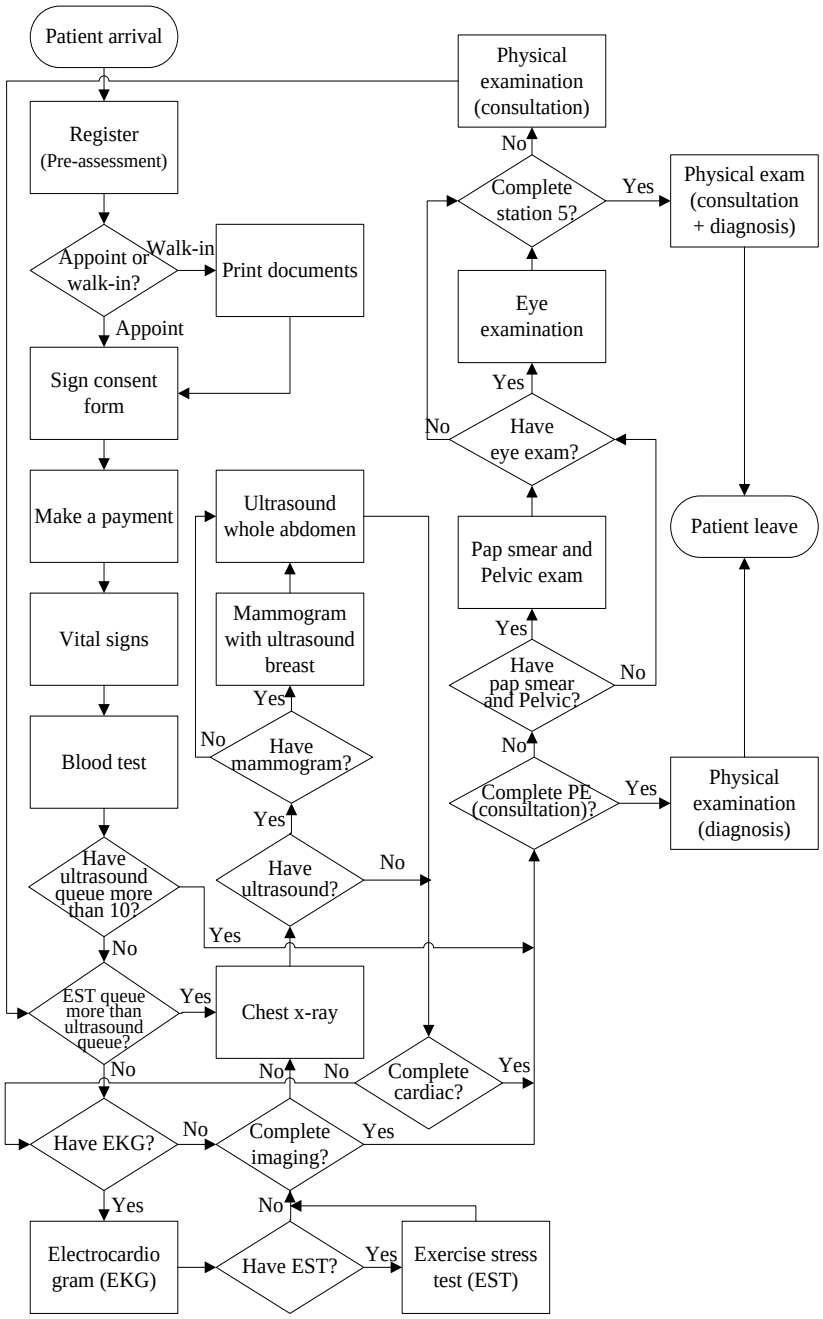

Fig. 2. Patient flow diagram

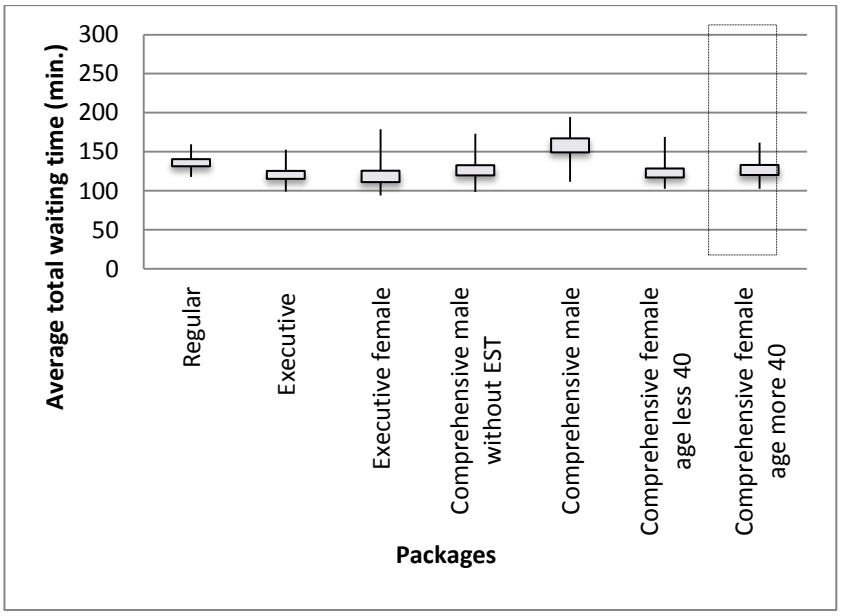

Fig. 3. Average total waiting time of each package

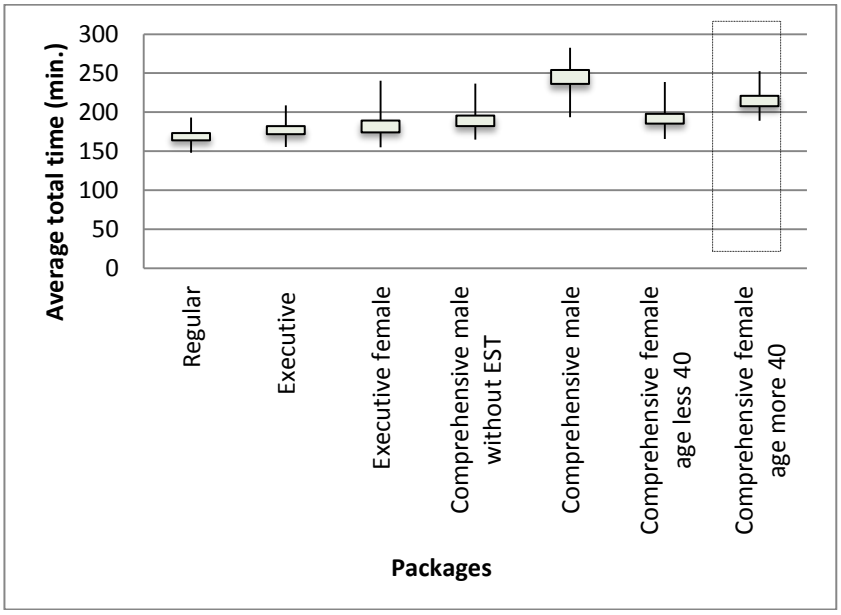

Fig. 4. Average total time of each package

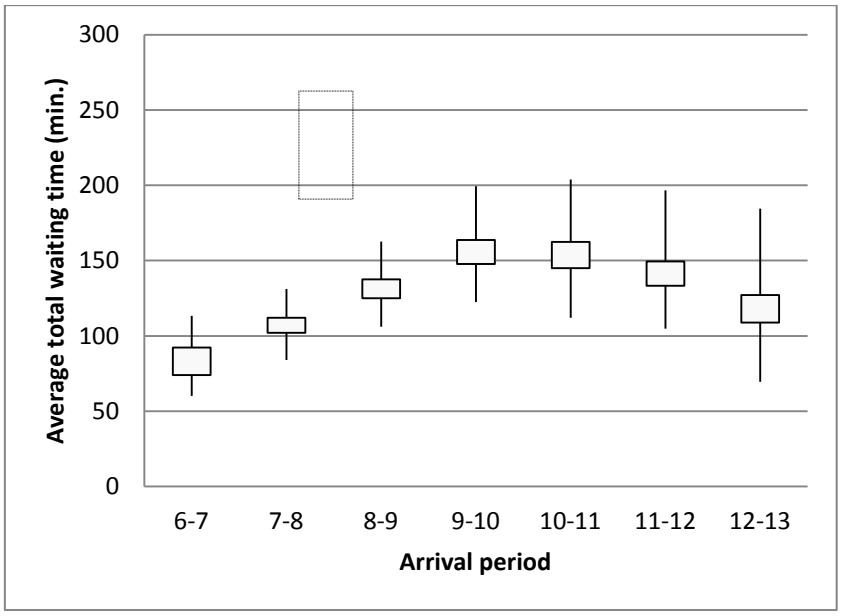

Fig. 5. Average total waiting time of each arrival period

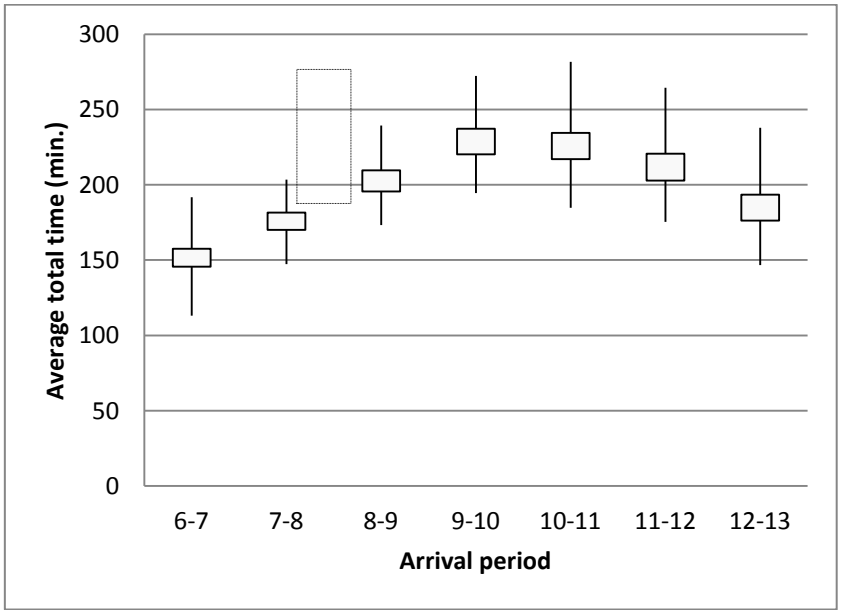

Fig. 6. Average total time of each arrival period

Table 2. Process time data and distribution.

Process	*Time (min.)*
Sign consent form	NORM(5,2)
Print consent form	0.5 + EXPO(1.04)
Print order documents	0.5 + EXPO(0.857)
Charge program	DISC(0.95, 1, 0.99, 2, 1.0, 3)
Assessment for appoint	0.5 + LOGN(2.35, 2.36)
Assessment for walkin	0.5 + GAMM(1.71, 1.53)
Cashier	8 * BETA(3.54, 8.24)
Vital signs	2 + GAMM(0.745, 2.43)
Draw blood	1.1 + LOGN(1.48, s0.743)
Electrocardiogram (EKG)	2 + WEIB(1.82, 1.5)
Exercise stress test (EST)	NORM(24.9, 3.59)
X-ray	0.08 + LOGN(1.75, 0.696)
Mammogram	NORM(8.78, 2.14)
Ultrasound whole abdomen	5 + 26 * BETA(1.47, 1.77)
Ultrasound upper abdomen	9 + WEIB(9.44, 1.45)
Ultrasound lower abdomen	3 + 11 * BETA(1.32, 2.34)
Ultrasound breast	TRIA(6, 8.25, 18)
Eye exam	NORM(4.57, 2.14)
PAP smear and Pelvic exam	NORM(5.95, 2.46)
Physical examination (consultation)	NORM(5.71, 1.69)
Physical examination (diagnosis)	NORM(8.00, 2.74)
Physical examination (consultation and diagnosis)	NORM(10.30, 6.36)

Table 3. Resource availability per period.

	6-7	*7-8*	*8-9*	*9-10*	*10-11*	*11-12*	*12-13*	*13-14*	*14-15*	*15-16*	*16-17*	*17-18*
RN at station 1	3	5	5	3	3	2	1	1	1	1	1	0
CA at station 1	1	5	4	3	1	0	0	0	0	0	0	0
CA at station 2	3	4	4	4	4	4	4	4	4	4	4	0
CA at station 3	1	3	3	3	3	3	3	3	3	2	1	0
NA vital signs	1	3	3	3	3	1	1	1	1	1	1	0
NA blood draw	1	3	3	3	3	1	1	1	1	1	1	0
NA EKG	1	3	3	3	3	2	2	2	2	1	1	0
NA EST	1	2	2	4	3	3	3	3	3	1	1	0
RN EST	1	1	1	4	3	3	3	3	3	1	1	0
Technician x-ray	1	1	1	1	1	1	1	1	1	1	1	0
Technician ultrasound	0	4	7	8	8	8	8	6	6	3	3	0
Radiologist ultrasound	0	2	3	4	4	4	4	2	2	1	1	0
Technician mammogram	1	1	1	1	1	1	1	1	1	1	1	0
Radiologist mammogram	1	1	1	1	1	1	1	1	1	1	1	0
Eye physician	0	1	1	1	1	1	1	1	1	1	1	1
PAP physician	0	1	1	1	1	1	1	1	1	1	1	1
Physician	0	1	1	1	1	1	1	1	1	1	1	1

Table 4. Total waiting time and total time.

	Waiting time (min.)	*95% CI*	*Total time (min.)*	*95% CI*
All patients	135.79	(129.91,141.67)	207.18	(201.08,213.28)
Station 5 first (path 1)	123.28	(119.34,127.22)	193.57	(189.46,197.68)
Station 6 first (path 2)	155.33	(148.58,162.08)	229.34	(222.41,236.27)

Conclusion and future works

We can use our simulation model to experiment with other patient routing plans and scheduling the personnel of the health screening center to see what type of improvement scenarios will be the best for reducing the average total waiting time. The current target of average total waiting time is less than 1 hour.

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