Proceedings of the 2004 Winter Simulation Conference
R .G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters, eds.

FUNCTIONAL ANALYSIS FOR OPERATING EMERGENCY DEPARTMENT OF A GENERAL HOSPITAL

Soemon Takakuwa
Hiroko Shiozaki

Graduate School of Economics and Business Administration
Nagoya University
Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8601, JAPAN

ABSTRACT

An entire emergency department of a general hospital is simulated to examine patient flows. First, times needed for both outpatients and patients arriving via ambulance to be processed in the emergency department are examined. A special-purpose data-generator is designed and developed to create experimental data for executing a simulation. It is found that the patients spend the longer part of their time waiting, depending on the number of patients to be processed. In addition, it is found that the waiting time for available emergency-treatment beds, doctors, drips, and stretchers accounts for the major part of all the waiting time in the emergency department. A stepwise procedure of operations planning is proposed to minimize the patient waiting times, and numerical examples are shown to illustrate the procedure.

1 INTRODUCTION

The simulation of hospital systems has been conducted to provide hospital administration with tools that will give them the ability to predict the performance under some operational conditions in conjunction with hospital facilities (Austin and Boxerman 1995; Fetter and Thompson 1965). Especially, hospital emergency departments are frequent topic areas for applying simulation. Recent research has reported on such topics as the patient waiting times, reduction of the throughput time, and how to perform simulation experiments.

Several studies have focused on the patients who are processed at various stages in the emergency departments. From among them, patient flows and the throughput time are analyzed inside the emergency departments (Garcia et al. 1995; Mahapatra et al. 2003; McGuire 1994;Samaha, Armel, and Starks 2003). In addition, the issues of scheduling the emergency-department staff are treated for analysis, and are reported (Centeno et al. 2003; Draeger 1992; Evans, Gor, and Unger 1996). The issues focused on simulation models and experimental designs are treated (Miller, Ferrin, and Szymanski 2003; Wiinamaki and Dronzek 2003).

In this study, a simulation model of the emergency department of a general hospital is constructed and used to examine patient flows, especially the patient waiting times. First, the time intervals spent at each stage for both outpatients and patients arriving via ambulance are examined; where the patients wait for available doctors, drips and so on, where they are processed at the medical treatments, patient moves. Then, the patient waiting time is examined. In this study, a special-purpose data-generator is designed and developed to create experimental data to execute simulation. The experimental data to be created includes the arrival time of the patient and the category of the patient, based on the actual data. Preliminary simulation experiments indicated that when more patients are expected to be processed at the emergency department, the patient waiting time would become longer, unless the additional doctors and medical instruments are allocated. Then, a stepwise procedure of operations planning is proposed to reduce the patient waiting time. Through a series of simulation experiments, the patient waiting time can be minimized, by adding appropriate numbers of designated doctors and medical instruments.

2 THE PROCESS OF PATIENTS IN AN EMERGENCY DEPARTMENT

Gifu Prefectural Government of Japan is planning to rebuild the hospital wards, because the current building of the hospital becomes superannuated. The emergency department of Gifu Prefectural Hospital has spaces for processing outpatients as well as patients arriving via ambulance. The overall layout of the emergency department is shown in Figure 1. Resources such as the staff and medical facilities are summarized in Table 1. In this study, the patients are classified into nine categories, and each patient category is described in Table 2. The patients coming to the emergency department are classified roughly into ones

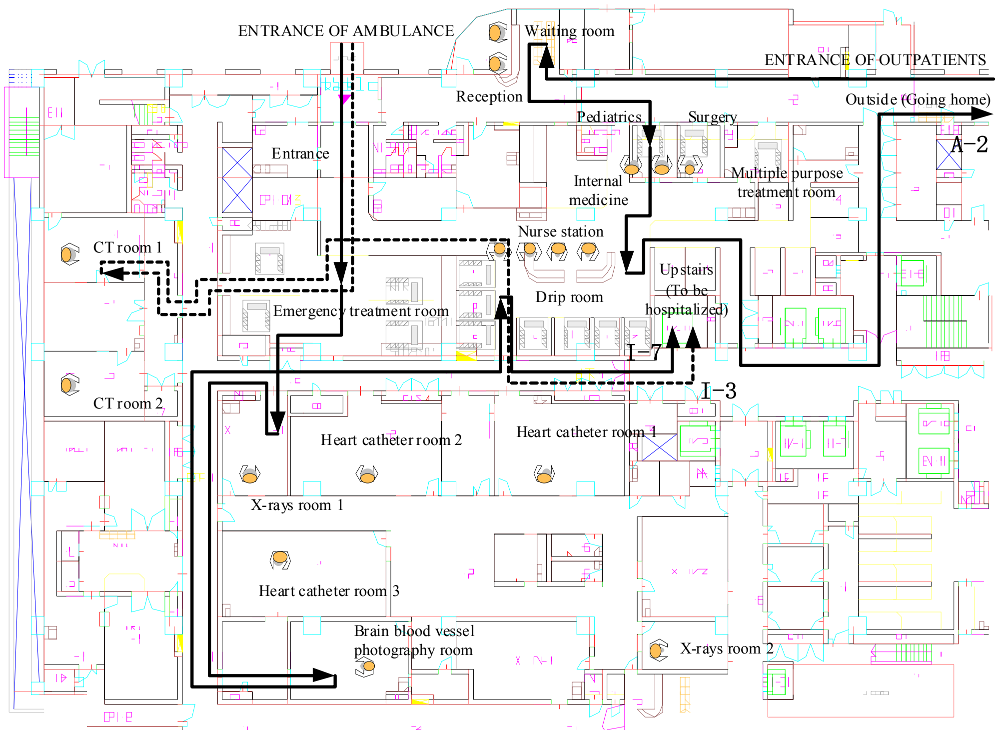


Figure 1: Overall Layout of the Emergency Department and Selected Patient Flows

transferred via ambulance, outpatients or ambulatory patients, and non-E.D. patients who need to take just medical examination. Furthermore, the patients are classified into three categories for both outpatients and patients arriving via ambulance, that is, the first-, the second-, and the third-degree symptoms, depending on seriousness of disease symptoms. In addition, outpatients are classified into ones on internal medicine and ones on surgery.

The outline of the patient flows and the associated processes in the emergency department are shown in Figure 2. There are two entrances for the emergency departments of the hospital; one is for patients arriving via ambulance, and the other is for outpatients. In either case, patients then proceed to the corresponding receptions. In Figure 1, three selected examples are illustrated to show the movement of the corresponding categories of patients. For example, a patient in category A-2 (an outpatient) takes a medical examination at an internal medicine consulting room, then is put on a drip, and leaves the emergency department. A patient in category I-7 arriving via ambulance takes medical examination at the emergency treatment room, and then goes to X-rays room, and takes brain blood-vessel photography and is to be hospitalized. In addition, a patient in category I-3 via ambulance is taken computerized tomography (CT),then is put on a drip, and is to be hospitalized. There are seventy (70) patterns on patient flows inside the emergency department for nine patient categories.

Table 1: Resources of the Emergency Department

Items	Number
Window	1
Clerk at the window	2
Seat in a waiting room	10
Internal medicine consulting room	1
Multiple-purpose treatment room	1
Surgical consulting room	1
Emergency treatment room	4
Drip room	7
Internist (full time)	1
Internist (supporting)	1
Internist (supporting; night time only)	3
Pediatrician (full time)	1
Pediatrician (supporting)	1
Pediatrician (supporting; night time only)	3
Surgeon (ful time)	1
Surgeon (supporting)	1
Surgeon (supporting; night time only)	3
Nurse	4
Nurse (Supporting)	6
Nurse (Supporting, night time only)	5
CT room	2
X-rays room	2
Endoscope room	5
Brain blood-vessel photography room	1
Heart catheter room	3
Stretcher	3

The travel times that are move-specific between selected pairs of locations inside the emergency department are summarized in Table 3. The travel times are given as

Table 2: Patient Categories

Symbol	Patient Category	Description	No. of Patterns
A	First-degree symptom, internal medicine	Internal medicine patients leaving on the day	11
B	Second-degree symptom, internal medicine	Internal medicine patients hospitalized	5
C	Third-degree symptom, internal medicine	Internal medicine patients hospitalized to an ICU	5
D	First-degree symptom, surgery	Surgery patients leaving on the day	9
E	Second-degree symptom, surgery	Surgery patients hospitalized	6
F	Third-degree symptom, surgery	Surgery patients hospitalized to an ICU	1
G	First-degree symptom, emergency	Patient via ambulance leaving on the day	16
H	Second-degree symptom, emergency	Patient via ambulance hospitalized	6
I	Third-degree symptom, emergency	Patient via ambulance hospitalized to an ICU	9
J	Drip-only patient	Patient hospitalized and drip-only patients leaving	1
K	Other types of patients	Non E.D. patients	-

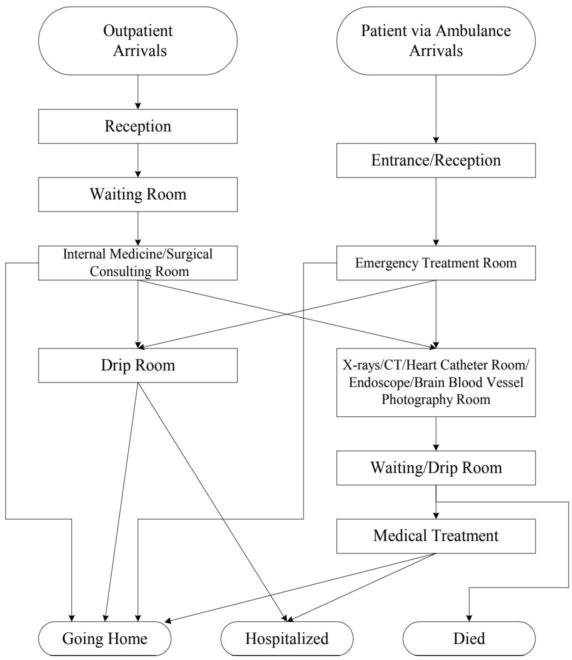


Figure 2: Outline of Patient Flows and Processes

the parameters for a uniform distribution (in seconds). For example, it takes somewhere between 8.7 and 11.6 seconds for a patient to move from the waiting room to the internal-medicine consulting room. The process times (in minutes) for examinations, tests, diagnosis, and explanation and treatment by doctors are summarized in Table 4. In addition, the inspection times to get the results of the designated tests after taking them are included in the table. The entries for the times are the parameters for a uniform (UNIF) distribution, a triangular (TRIA) distribution, or an exponential (EXPO) distribution. Now, take outpatients for surgery for example. First, a patient takes medical consultation. The time is distributed uniformly between 10 and 15 minutes. Then, the patient takes the initial diagnosis for EXPO(5) minutes, if he does not have taken it at the waiting area of the reception. In cases of the first- and second-degree symptoms, a surgery explains disease symptoms and a medical prescription to the patient. Twenty eight percent of the patients have injections. Then the patient leaves the hospital. In case of third-degree symptom, the patients take the test of drawing blood, and electrocardiogram test, depending on the symptoms. Then the patient goes to a CT room or an X-rays room, if necessary. After taking a series of required tests, the patient goes to the reception of the entrance and takes a seat to get the results of the tests. Finally, the patient moves to a consulting room to see the doctor in charge. Depending on the result of the diagnosis, the patient is to be hospitalized or leaves the hospital.

3 DATA GENATOR FOR SIMULATION

The emergency department inside the buildings of the current Gifu Prefectural Hospital covers an area of 1,000 square meters, and the one of the planned buildings will cover an area of 7,100 square meters, that is, approximately seven times as much as the current area. The main reasons to expand the area of the emergency department are to separate the entrance of patients arriving via ambulance from the outpatients, and to increase the capacity of the emergency department. The new buildings will be built a few years later; however, the number of the patients for the emergency department is certainly expected to increase after completion of the new hospital wards.

In case more patients are expected to be processed at the emergency department, it is necessary to perform simulation experiments under any possible situation. Hence, a special-purpose data-generator is designed and developed to create experimental data in order to examine more congested situations, taking the current situation in the emergency department. This data generator is written in Excel VBA. Experimental data created consist of the arrival time of the patient, the way of arrival (i.e., a patient arriving via ambulance or an outpatient), and the degree of the decease symptom.

The overall flow of the data generator proposed in this study can be itemized mainly as follows:

1. to specify a percentage of decrease or increase compared with the baseline condition;
2. to write the headings of cells A1 through D1;
3. to number the arriving patient in column A;
4. to write the arrival time in minutes in column B;
5. to write the patient category in column C;

Table 3: From-To Chart on the Travel Times (in Seconds)

From \ To	Entrance	Reception	Waiting room	Internal medicine	Surgery	Multiple-purpose treatment room	Emergency treatment room	Drip room
Entrance of outpatient		(42.6,56.8)						
Entrance of ambulance	(4.2,5.6)							
Entrance							(10.8,14.4)	
Reception			(0.0,0.0)					
Waiting room				(8.7,11.6)	(10.8,14.4)	(14.1,18.8)	(28.5,38.0)	(17.4,23.2)

From \ To	Drip room	Waiting room (1)(for test)	CT room 1	CT room 2	X-rays room 1	X-rays room 2	Waiting room (2)(for test)
Internal medicine	(9.0,12.0)	(8.7,11.6)	(50.1,66.8)	(53.7,71.6)	(38.7,51.6)	(29.1,38.8)	(9.0,12.0)
Surgery	(11.4,15.2)	(10.8,14.4)	(47.4,63.2)	(51.0,68.0)	(36.6,48.8)	(27.0.,36.0)	(11.4,15.2)
Multiple-purpose treatment room	(13.2,17.6)	(14.1,18.8)	(49.8,66.4)	(53.4,71.2)	(38.7,51.6)	(28.2,37.6)	(13.2,17.6)
Emergency treatment room	(19.2,25.6)	(31.5,42.0)	(13.5,18.0)	(17.7,23.6)	(12.0,16.0)	(43.5,58.0)	(19.2,25.6)
CT room 1		(74.4,99.2)			(13.2,17.6)	(50.4,67.2)	(31.2,41.6)
CT room 2		(78.0,104.0)			(16.8,22.4)	(54.0,72.0)	(34.8,46.4)
X-rays room 1		(63.3,84.4)	(13.2,17.6)	(16.8,22.4)			(20.1,26.8)
X-rays room 2		(53.4,71.2)	(50.4,67.2)	(54.0,72.0)			(32.1,42.8)
Internal medicine (2nd)	(9.0,12.0)						
Surgery (2nd)	(11.4,15.2)						
Multiple-purpose treatment room (2nd)	(13.2,17.6)						
Emergency treatment room (2nd)	(19.2,25.6)						

From \ To	Internal medicine (2nd)	Surgery (2nd)	Multiple-purpose treatment room (2nd)	Emergency treatment room (2nd)	Brain blood vessel photography room	Endoscope room	Heart catheter room 1	Heart catheter room 2	Heart catheter room 3
Waiting room (1)(for test)	(8.7,11.6)	(10.8,14.4)	(14.1,18.8)	(28.5,38.0)					
Waiting room (2)(for test)	(12,15.2)	(11.4,15.2)	(13.2,17.6)	(19.2,25.6)	(42.3,56.4)	(66.6,88.8)	(9.0,12.0)	(16.5,22.0)	(43.8,58.4)
Internal medicine (2nd)						(67.2,89.6)			
Multiple-purpose treatment room (2nd)						(67.5,90.0)			
Emergency treatment room (2nd)						(75.3,100.4)			

Table 4: The Process Times

1. Initial examination (in minutes)

Type of patients	Time	Remarks
Pediatrics: slight degree	UNIF(10,15)	After that, the patient will leave.
Others	TRIA(10,15,30)	-

2. Initial diagnosis

Type of patients	Time
Patients not taking a diagnosis	EXPO(5)

3. Various tests

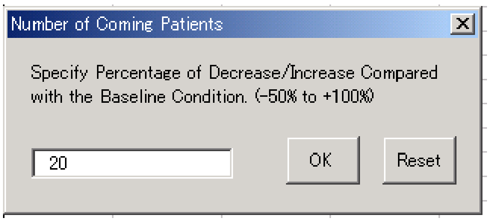
Type of test	Time	Inspection time	Place
Drawing blood	UNIF(1,2)	EXPO(30)	Medicine consulting room
Electrocardiogram	UNIF(2,3)	EXPO(30)	
Urin test	0	EXPO(10) or (20)	
Computerized tomography (C.T.)	EXPO(10) or (15)	EXPO(15)	C.T. room
X-rays	UNIF(5,10)	EXPO(10)	X-rays room
Heart catheter	UNIF(30,60)	-	Heart catheter room
Endoscope	UNIF(30,60)	-	Endoscope rom
Brain blood-vessel photography	UNIF(20,30)	-	B.B.V.P. room

4. Explanation and treatment

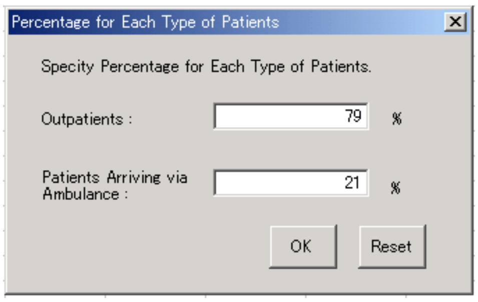
Item	Time
Explanation and treatment	UNIF(15,30)

6. to write the degree of symptom in column D; and
7. to sort the data of arriving patients in time order.

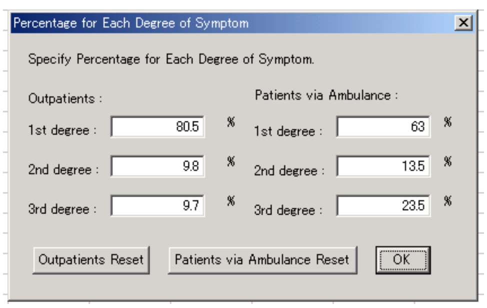
A similar idea for the data generator for simulation experiments appears in simulation of warehousing at distribution centers and the international-departure flights (Takakuwa et al. 2000; Takakuwa and Oyama 2003). The required input parameters are a percentage of decrease or increase compared with the baseline condition, where the baseline corresponds to the current condition on the current emergency department, and a percentage of each type of patients, i.e., outpatients and patients arriving via ambulance, and of each degree of the symptoms, as shown in Figure 3. By inputting these parameters, the corresponding schedule of patient arrivals would be created. Table 5 shows a sample output created by the proposed data generator. The generated data includes the arrival time of each patient, the way of arrival, the degree of the disease symptoms. By making use of these generated data as an external file input for the simulation model, experiments can be conducted under any specified condition.



(a) Specifying the Number of Coming Patients



(b) Specifying Percentage for Each Type of Patients



(c) Specifying Percentage for Each Degree of Symptom

Figure 3: Inputting Parameters

Table 5: Sample of Generated Data

No.	Arrival Time (min.)	Arrival Way 1: via ambulance 0: other	Degree of symptom (1,2,3)
1	96	1	3
2	219	0	2
3	271	0	2
4	529	0	1
5	653	0	1
6	617	0	3
7	763	0	1
8	756	0	1
9	836	0	1
10	792	0	1
:	:	:	:

4 PRELIMINARY ANALYSIS OF PROCESSING PATIENTS

In this section, all associated areas of the emergency department are included in a simulation model that is used to examine patient flows, and to collect important statistics including all the waiting time. The simulation models in this study were created using Arena (Kelton, Sadowski, and Sadowski 2003).

First, as the experimental conditions of the preliminary experiment, the numbers of patients are specified as 1.00, 1.20, 1.40, 1.60, 1.80, and 2.00 (i.e., Baseline+100%) times compared with the baseline model to examine the waiting time of the patients. The results of the experiments are shown in Figure 4. In this figure, the horizontal axis stands for the time length of one week starting from the midnight of Tuesday. It can be observed that the system starts at time 0 (minutes) with no patients present and all resources idle; hence, the empty-and-idle assumption would be moderate, and this emergency department can be regarded as a terminating system for executing simulation and performing statistical analysis. In addition, regarding the percentage of the waiting time to the time-in-system, summary statistics of the output variable are analyzed via a factorial analysis of variance program for an experimental design. The factor is the congestion of patients in the emergency department, and ten replications of the simulation have been executed for each condition. Summary results of the analysis of variance for the output variable are given in Table 6. The congestion of the patients has a significant effect on the output variable, that is, the waiting time in the emergency department.

Table 6: Analysis of Variance

Source of variation	Sum of squares	Degrees of freedom	Mean square	Computed f
Congestion of patients	72792.9	5	14558.6	40.6
Error	19367	54	358.6	
Total	92159.9	59		

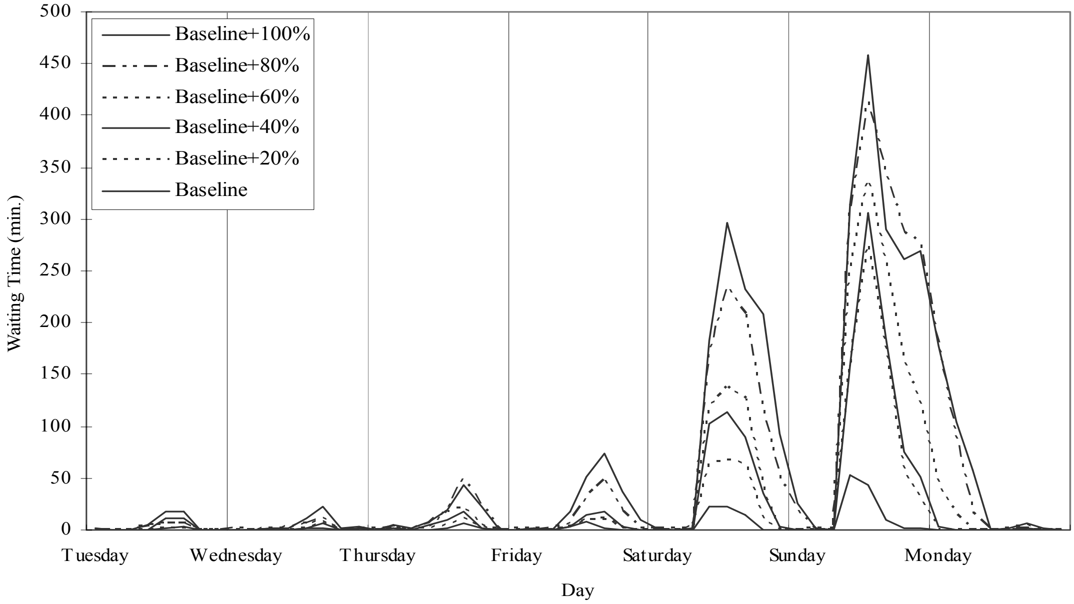


Figure 4: The Patient Waiting Time

Next, as the number of patients, 1.20 times of ones of the baseline model is specified to investigate times spent in the emergency department and the patient waiting time for one week, executing ten replications of the simulation. Times spent in the emergency department and the patient waiting time are summarized in Figures 5 and 6. The number of patients is 332, and the numbers of the first-degree, the second-degree, and the third-degree symptoms of outpatients are 205, 26, and 10, respectively, and the numbers of the first-degree, the second-degree, and the third-degree symptoms of patients arriving via ambulance are 45, 8, and 16, respectively. First, the amount of time at each stage where the patients wait for available doctors, test rooms, and so on, where they are to be processed, when they move, are examined for all patients. Of the total time spent in the emergency department (, i.e., 122.7 minutes), 32 percent was spent being put on a drip, 30 percent (i.e., 37.2 minutes) was waiting time, and 28 percent was spent in medical treatments by pediatricians, internists, and surgeons.

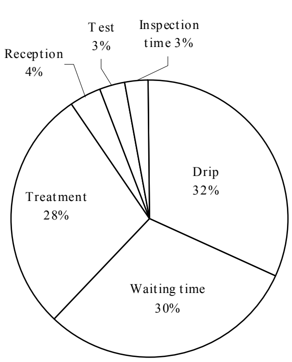


Figure 5: Time Spent in the Emergency Department

In addition, it is found that the waiting time for available treatment rooms accounts for 48 percent of all waiting time.

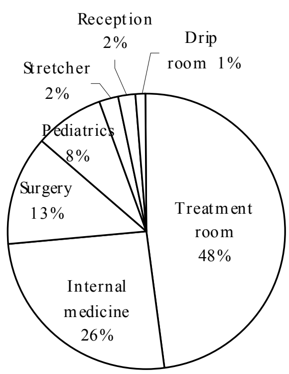


Figure 6: Breakdown of Waiting Time

5 SIMULATION ANALYSIS

In this section, a procedure of operations planning is proposed to reduce the patient waiting times, using numerical examples. Let us consider the case of the number of patients of (Baseline+100%) in Figure 4, that is, the number of the patients is 544, and is twice as many as in the current situation. It is observed that the patient waiting time is much longer in the nighttime of the weekend from the figure.

The decision variables of this problem are listed as follows, where the figures in the parentheses are the initial values under the current situation: (1) the number of the emergency-treatment room (4 units), (2) the number of the pediatricians (2 persons), (3) the number of the internists (2 persons), (4) the number of the surgeons (2 persons), (5) the number of implements at the drip room (7 units), and (6) the number of stretchers (3 units). The breakdown of the patient waiting time is examined as the performance measures of simulation experiments. The patient waiting time comprises the following items, where the figures in the parentheses are the percentages of the waiting time under the initial conditions: (1) the emergency-treatment beds (59%), (2) the pediatricians (6%), (3) the internists (19%), (4) the surgeons (11%), (5) drip (1%), and (6) the stretchers (1%). In addition, 54 percent of the time in system is waiting time, and this is much higher than under the baseline situation.

In the following procedure, decision variables indicating larger parts of the waiting time are selected to increase one unit of their values in sequence. First, because the patient waiting time for the emergency-treatment beds (i.e., 59%) is the longest among those in the breakdown, the number of the emergency-treatment beds is chosen to raise, that is, from 4 to 5 units, at the next iteration of a simulation experiment. After performing simulation, the percentage of the patient waiting time is reduced from 59 to 47 percent. Hence, it can be concluded that the patient waiting time would be drastically reduced by adding one more emergency-treatment bed. Next, in Iteration 2, the patient waiting time for the emergency-treatment beds (i.e., 47%) is the longest once again, the number of the emergency-treatment beds is chosen to raise to 6.

In the similar way, the procedure is continued until Iteration 9, as shown in Table 7. In the meantime, it is sometimes necessary to increase the numbers of more than one decision variable at the same time. In Iteration 4 in Table 7, for example, the numbers of emergency-treatment beds and the surgeons are increased simultaneously to 9 units and 3 persons, respectively, by experimental intuition. The 95% confidence interval on the average percentage of the waiting time in time-in-system for each iteration is shown in Figure 7. In Iteration 9, where the number of the emergency-treatment beds is 10 (units), the number of the pediatricians is 3 (persons), the number of internists is 4 (persons), the number of surgeons is 4 (persons) the number of implements at the drip room is 8 (units), and the number of stretchers is 4 (units), 8 percent of the total time spent in the emergency department is the waiting time, that is, 7.4 minutes. This figure is almost the same under the current situation (i.e., the baseline). In Iterations 4 through 9, some doctors would be occupied in their works in day shifts of the weekend. In applying the procedure actually, some constraints should be considered to increase the values of the decision variables; the patient waiting time can be minimized under the actual constraints.

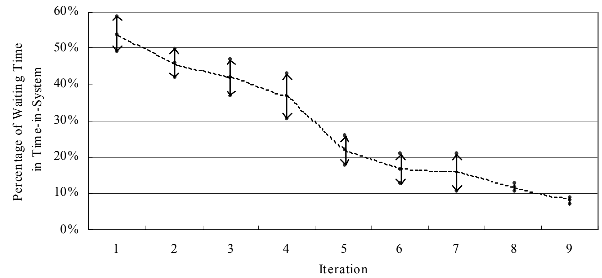


Figure 7: 95% Confidence Interval on the Average Percentage of Waiting Times

6 CONCLUSIONS

1. A simulation model of the planned emergency department of a general hospital is constructed and used especially to examine the patient waiting time in time-in-system.
2. A special-purpose data-generator is designed and produced in order to create experimental data to execute simulation experiments under the various conditions of congestion in the emergency department.
3. The total time spent in the emergency department comprises mainly drip, waiting, and treatment. Furthermore, the patients spend the longer part of their time waiting, depending on the number of patients to be processed. In addition, it is found that the waiting time for available emergency-

Table 7: Process of Implementing the Procedure

Iteration	Degree of Congestion	Percentage of Waiting Time in Time-in-System	Breakdown of Waiting Time for:						No. of Emergency-Treatment Beds (units)	No. of Pediatricians (persons)	No. of Internists (persons)	No. of Surgeons (persons)	No. of Implements at Drip Room (units)	No. of Stretchers (units)
			Emergency-Treatment Bed	Pediatrician	Internist	Surgeon	Drip	Stretcher						
	Baseline	8%	19%	5%	47%	22%	1%	2%	4	2	2	2	7	3
1	Baseline + 100%	54%	59%(*A)	6%	19%	11%	1%	1%	4	2	2	2	7	3
2		46%	47%(*A)	7%	26%	14%	1%	2%	5(*1)	2	2	2	7	3
3		42%	43%(*A)	8%	24%(*B)	18%	2%	3%	6(*3)	2	2	2	7	3
4		37%	34%(*A)	6%	22%	29%(*B)	2%	4%	8(*1,3)	2	3(*2)	2	7	3
5		22%	20%	14%	33%(*A)	18%	4%	7%	9(*1)	2	3	3(*2)	7	3
6		17%	21%	11%	18%	27%(*A)	7%	11%	9	2	4(*3)	3	7	3
7		16%	20%(*A)	19%	22%	10%	7%	17%(*B)	9	2	4	4(*3)	7	3
8		12%	11%	22%(*A)	24%	14%	14%(*B)	6%	10(*1)	2	4	4	7	4(*3)
9		8%	11%	14%	30%	16%	6%	8%	10	3(*2)	4	4	8(*3)	4

*1: To increase the number of the item as day and night shifts of the weekend.

*2: To increase the number of the item as day shift of the weekend.

*3: To increase the number of the item as day and night shifts of the all days.

*A: The largest value to increase the number of the corresponding item.

*B: The second largest value to increase the number of the corresponding item.

treatment beds, doctors, drips, and stretchers accounts for the major part of all the waiting time in the emergency department.

4. A stepwise procedure of operations planning is proposed to minimize the patient waiting time, by increasing the number of decision variables indicating longer part(s) of the waiting time. Numerical examples are shown to illustrate the procedure.

ACKNOWLEDGMENTS

The authors wish to express sincere gratitude for Gifu Prefectural Government of Japan for the acknowledgment of this study.

REFERENCES

Austin, C. J. and S. B. Boxerman. 1995. *Quantitative Analysis for Health Services Administration*, Ann Arbor, Michigan: AUPHA Press/ Health Administration Press.

Centeno, M., R. Giachetti, R. Linn, and A. M. Ismail. 2003. A simulation-ILP based tool for scheduling ER staff. In *Proceedings of the 2003 Winter Simulation Conference*, ed. S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice, 1930-1937. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Draeger, M. A. 1992. An emergency department simulation model used to evaluate alternative nurse staffing and patient population scenarios. In *Proceedings of the 1992 Winter Simulation Conference*, ed. J. J. Swain, D. Goldsman, R. C. Crain, and J. R. Wilson. 1057-1064. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Evans, G. W., T. B. Gor, and E. Unger. 1996. A simulation model for evaluating personnel schedules in a hospital emergency department. In *Proceedings of the 1996 Winter Simulation Conference*, ed. J. M. Charles, D. J. Morrice, D. T. Brunner, and J. J. Swain. 1205-1209. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Fetter, R. B. and J. D. Thompson. 1965. The simulation of hospital systems. *Operations Research*. 13 (5): 689-711.

Garcia, M. L., M. A. Centeno, C. Rivera, and N. DeCario. 1995. Reducing time in an emergency room via fast-track. In *Proceedings of the 1995 Winter Simulation Conference*, ed. C. Alexopoulos, K., Kang, W. R. Lilegdon, and D. Goldsman. 1077-1080. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Kelton,W,D., R.P.Sadowski, and D.A.Sadowski. 2003. *Simulation with Arena.* 3rd ed. New York, New York: McGraw-Hill.

Mahapatra, S., C. P. Koelling, L. Patvivatsiri,, B. Fraticelli, D. Eitel, and L. Grove. 2003. Pairing emergency severity index5-level triage data with computer aided system design to improve emergency department access and throughput. In *Proceedings of the 2003 Winter Simulation Conference*, ed. S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice, 1917-1925. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

McGuire, F. 1994. Using simulation to reduce length of stay in emergency departments. In *Proceedings of the 1994 Winter Simulation Conference*, ed. J. D. Tew, S. Manivannan, D. A. Sadowski, and A. F. Seila. 861-867. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Miller, M. J., D. M. Ferrin, and J. M. Szymanski. 2003. Simulating six sigma improvement ideas for a hospital emergency department. In *Proceedings of the 2003 Winter Simulation Conference*, ed. S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice, 1926-1929. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Samaha, S., W. S. Armel, and D. W. Starks. 2003. The use of simulation to reduce the length of stay in an emergency department. In *Proceedings of the 2003 Winter Simulation Conference*, ed. S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice, 1907-1911. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Takakuwa, S., H. Takizawa, K. Ito, and S. Hiraoka. 2000. Simulation and analysis of non-automated distribution warehouse. In *Proceedings of the 2000 Winter Simulation Conference*, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 1177-1184. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Takakuwa. S., and T. Oyama. 2003. Simulation analysis of international-departure passenger flows in an airport terminal. In *Proceedings of the 2003 Winter Simulation Conference*, ed. S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice, 1627-1634. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

Wiinamaki, A. and R. Dronzek. 2003. Using simulation in the architectural concept phase of an emergency department design. In *Proceedings of the 2003 Winter Simulation Conference*, ed. S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice, 1912-1916. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

AUTHOR BIOGRAPHIES

SOEMON TAKAKUWA is Professor in the School of Economics and Business Administration at Nagoya University in Japan. He received his B. Sc. and M. Sc. degrees in industrial engineering from Nagoya Institute of Technology in 1975 and from Tokyo Institute of Technology in 1977 respectively. His Ph.D. is in industrial engineering from The

Pennsylvania State University. He holds Doctorate of Economics from Nagoya University. His research interests include optimization of manufacturing and logistics systems, management information system and system simulation. He has prepared the Japanese editions of both *Introduction to simulation using SIMAN* and *Simulation with ARENA.* `<takakuwa@soec.nagoya-u.ac.jp>`.

HIROKO SHIOZAKI received his B. Sc. Degree in Economics at Nagoya University in 2003. Her research interests include simulation of the large-scale general hospitals.