

MODELING OF PATIENT FLOWS IN A LARGE-SCALE OUTPATIENT HOSPITAL WARD BY MAKING USE OF ELECTRONIC MEDICAL RECORDS

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ABSTRACT

All departments of an outpatient hospital ward of Nagoya University hospital were simulated to examine patient flows and congestion. The method of gathering the required data on times for all outpatients and their routes is described in the performing simulation, especially by making use of the electronic medical records. An outpatient visits one or more clinical departments and/or one or more test/inspection rooms, the reception area, and the payment department. In this procedure, a series of data of terminal units and of test/inspection terminals was used to obtain the required input data for performing simulation as well as the electronic medical records. It was found that the proposed procedure was quite effective to perform a simulation of a large-scale hospital to examine patient flows by applying an actual case.

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 simulations. 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 through the emergency department. The patient flow and the throughput time were analyzed inside emergency departments (Garcia, Centeno, and DeCario 1995; Mahapatra et al. 2003; McGuire 1994; Samaha, Armel, and Starks 2003). In addition, the issues of scheduling the emergency-department staff were treated for analysis, and were reported in several studies

(Centeno et al. 2003; Draeger 1992; Evans, Gor, and Unger 1996). The issues focusing on simulation models and designs were treated (Miller, Ferrin, and Szymanski 2003; Wiinamaki and Dronzek 2003).

In this present study, a simulation model of the entire departments of the outpatient hospital ward of a university hospital was constructed and used to examine patient flows, especially the patient waiting times. The experimental data to be created included the arrival time of the patient and the patient type, based on the actual data. First, the time intervals spent at each stage for outpatients were measured, where the patients wait for available doctors, and test and inspection, and where they are processed at the medical treatments. Second, the patient waiting time was examined. In this study, a method of gathering required data on times for all outpatients and their routes is described to perform simulation, especially by making use of electronic medical records. Following this, the study shows the special-purpose data-generator designed to create experimental data to execute simulation. Through a series of simulation experiments, the patient waiting time and the congestion inside the hospital can be examined by applying the data generator.

2 NAGOYA UNIVERSITY HOSPITAL

The graduate School of Medicine of Nagoya University has a university hospital which comprises outpatient as well as inpatient wards with 29 clinical departments and 30 central clinical facilities. The university hospital has served as a general hospital. The average number of outpatients was 2061.5 and inpatients 844.1 persons in the fiscal year of 2005. The transition of the numbers of outpatients on a day of the week are shown in Figure 1. The mean number of outpatients on Wednesday and Friday are fewer than those on the other days of the week. In addition, the mean number of daily outpatients in the past three years are shown in Figure 2. Nagoya University hospital is planning to rebuild the hospital wards because

the current building of the hospital remains superannuated. The overall layout of the outpatient hospital ward is shown in Figure 3. The new hospital ward will consist of buildings with three stories above the ground and one below. With the coming new buildings, the number of the patients is certainly expected to increase after completion of the new hospital wards.

3 A PROCESS OF PATIENTS IN AN OUTPATIENTS HOSPITAL WARD

The university hospital has prepared a plan for the new hospital wards. Hence, the data on the current hospital wards are used to evaluate the performance on the new hospital wards in this study. The outline of the patient flows and the associated processes in the clinical departments are shown in Figure 4. Basically, the outpatient arrives at the reception, has a test, and consults a doctor. After that, the patient pays expenses, and goes home.

The electronic medical record is basically used for recording the history of medical treatment for the patient; in this study, it is utilized to prepare input data to perform simulation. A layout plan and the precise work shift of the staff are required for input data, and a time study on the test, inspection and treatment activities should be performed as necessary. The overall flow of the data processing proposed in this study is illustrated in Figure 5, and can be itemized mainly as follows:

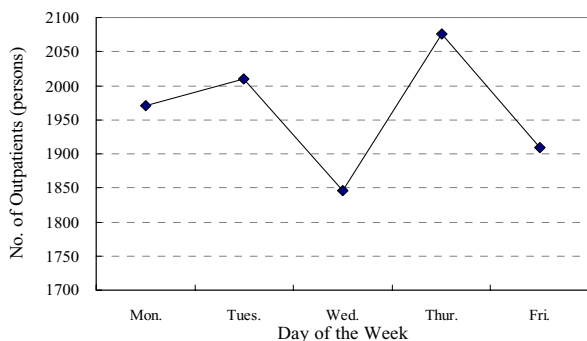


Figure 1: Average Number of Outpatients

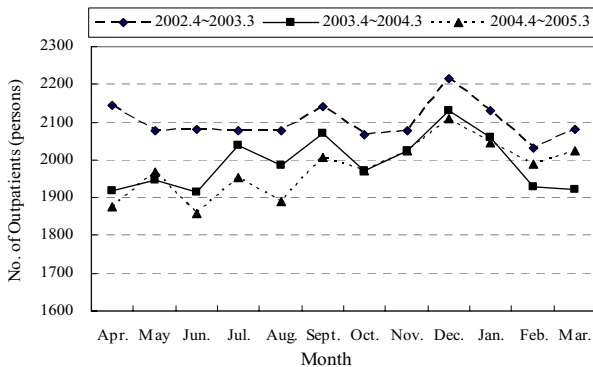


Figure 2: Average Number of Daily Outpatients

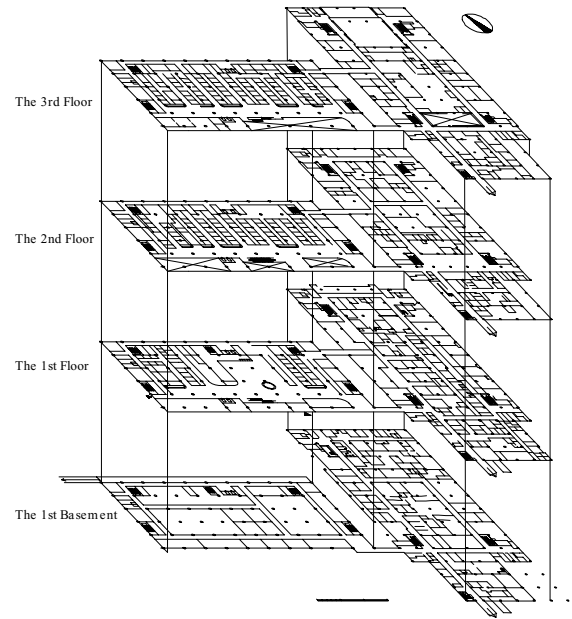


Figure 3: General View of Outpatient Hospital Ward

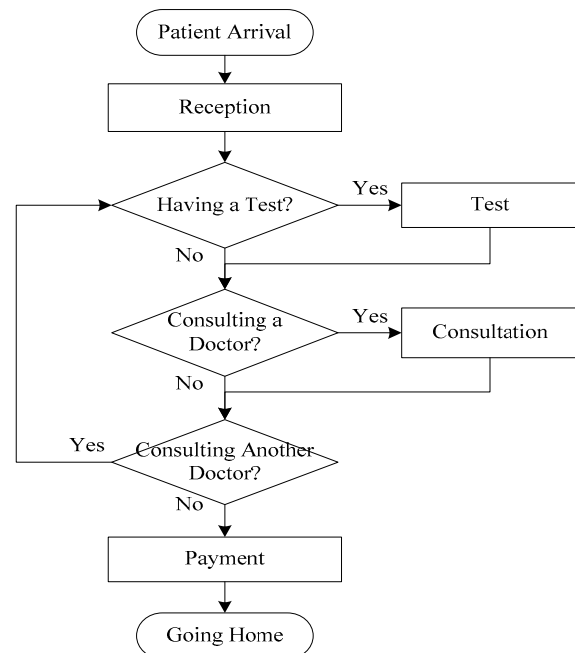


Figure 4: Outline of Outpatient Flows and Processes

- (1) Acquire a series of raw data, including reception/payment data, electronic medical record, terminal-unit data, and test/inspection data.
- (2) Process the series of raw data.
- (3) Prepare input data for simulation, using the data generator.
- (4) Perform simulation.
- (5) Obtain simulation output.

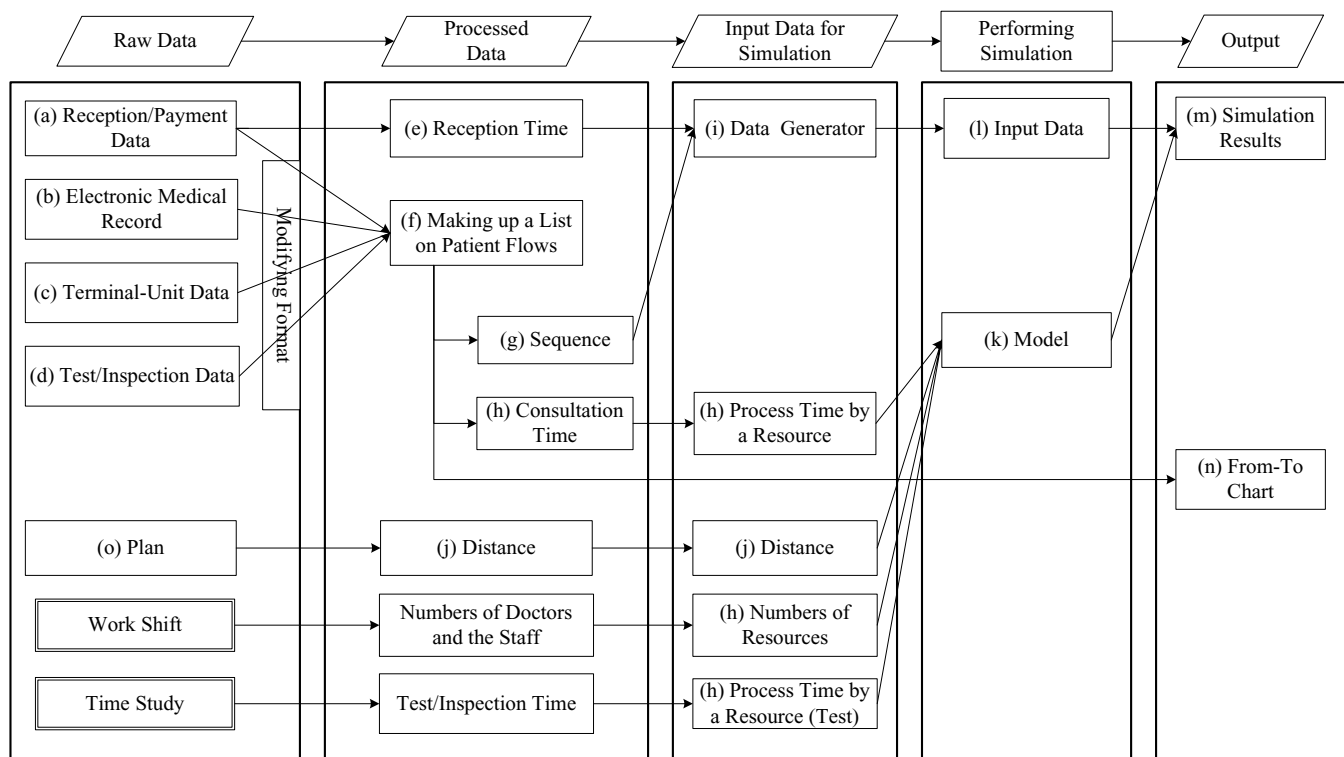


Figure 5: Overall Flow of Data Processing

First, a series of typical sequencing for the routing of approximately eight thousand outpatients was investigated on the electronic medical records for the specified five days. The frequency and the corresponding cumulative percentage for the sequence number are summarized in the ascending order in Figure 6. It is observed that the top 152 sequences account for 72.15 percent of all outpatients. Among them, the most frequent group of sequences are illustrated together with frequency and their routings in Table 1. For example, Sequence Number 90257991 appears 103 times in the electronic medical records of outpatients in five days observation, and its routing comprises the reception, the gastroenterology department, the orthopedic surgery department, and finally payment area.

The clinical departments considered in this study are summarized in Table 2. In this table, the frequency stands for the average number that appeared in the sequences of outpatients in the electronic medical records. In addition, the numbers of the resource unit for clinical departments are summarized. Similarly, the parameters of the receptions of the clinical departments are summarized in Table 3, and those of the test/inspection departments are summarized in Table 4.

The selected resultant data are shown in Table 5:

- (1) Reception/payment data.
- (2) Electronic medical record.
- (3) Terminal unit.

- (4) Test/inspection data.
Blood test/urine test data.
Endoscopy data.
Radiation test.
- (5) Number and percentage of accepted patients.
- (6) Patient flow.
- (7) Sequence.
- (8) Resource.
- (9) Input data.

In addition, the selected parts of the distances between clinical departments are shown in Table 6. The distances of all possible pairs of routing between the clinical departments and sites should take accurate measurements to perform a simulation.

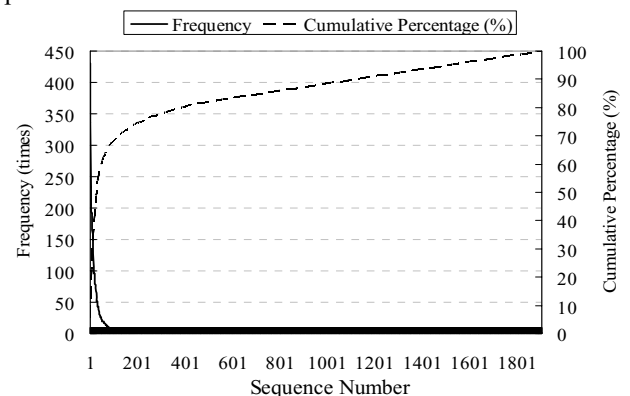


Figure 6: Sequence of Outpatient Flows and Frequency

Table 1: The Most Frequent Group of Sequences of Outpatient Flows

SeqNo	Frequency	Relative frequency	Destination 1	Destination 2	Destination 3	Destination 4
904991	431	7.60%	Reception	Ophthalmology	Payment	-
905191	336	5.93%	Reception	Psychiatry	Payment	-
901091	233	4.11%	Reception	Orthopedic Surgery	Payment	-
8291	214	3.78%	Radiation Test	Payment	-	-
905491	205	3.62%	Reception	Otorhinolaryngology	Payment	-
904791	194	3.42%	Reception	Obstetrics and Gynecology	Payment	-
902591	191	3.37%	Reception	Gastroenterology	Payment	-
901391	188	3.32%	Reception	Urology	Payment	-
902291	187	3.30%	Reception	Cardiology	Payment	-
906091	165	2.91%	Reception	Dermatology	Payment	-
906491	158	2.79%	Reception	Oral and Maxillofacial Surgery	Payment	-
902891	138	2.44%	Reception	Neurology	Payment	-
902491	130	2.29%	Reception	Diabetology and Endocrinology	Payment	-
902991	108	1.91%	Reception	Dept. of General Medicine	Payment	-
7991	106	1.87%	Collecting Blood	Payment	-	-
90257991	103	1.82%	Reception	Gastroenterology	Orthopedic Surgery	Payment
...	...	...	...	...	...	...
...	...	...	...	...	...	...

Table 2: Parameters on Clinical Departments

Clinical Department	No.	No. of Units in Resource	Percentage (%)	Consultation Time (min.)	Frequency (up to 5 times)
Orthopedic Surgery	10	7	4.61%	TRIA(1, 8.8, 391)	4.4
Hand Surgery	11	2	1.32%	TRIA(1, 5.36, 97)	22.4
Urology	13	2	1.32%	TRIA(1, 5.68, 179)	1.6
Radiology	15	3	1.97%	TRIA(1, 6.06, 92)	6.0
Dept. of Emergency Medicine	17	3	1.97%	TRIA(1, 16.4, 370)	8.8
Internal Medicine (Pre-Examination)	20	1	0.66%	TRIA(1, 9.12, 212)	4.8
Cardiology	22	5	3.29%	TRIA(1, 6.46, 252)	57.4
Nephrology	23	2	1.32%	TRIA(1, 7.54, 171)	18.8
Diabetology and Endocrinology	24	5	3.29%	TRIA(0.999, 5.25, 188)	54.2
Gastroenterology	25	5	3.29%	TRIA(1, 5.33, 209)	80.6
Hematology	26	3	1.97%	TRIA(1, 7.73, 149)	14.8
Respirology	27	3	1.97%	TRIA(1, 11, 322)	17.8
Neurology	28	3	1.97%	TRIA(2, 6.93, 150)	33.6
Dept. of General Medicine	29	3	1.97%	TRIA(1, 9.07, 227)	25.6
Geriatrics	30	2	1.32%	-	-
Dept. of Outpatient and Home Medicine	31	2	1.32%	TRIA(1, 10.8, 236)	17.4
Surgery Treatment	33	1	0.66%	TRIA(1, 4, 31)	0.0
Cardiac Surgery	34	2	1.32%	TRIA(1, 5.9, 99)	5.4
Gastroenterological Surgery	35	4	2.63%	TRIA(1, 5.79, 164)	30.4
Breast and Endocrine Surgery	36	2	1.32%	TRIA(1, 7, 109)	4.2
Pediatric Surgery	37	1	0.66%	TRIA(1, 7.18, 137)	10.6
Vascular Surgery	38	2	1.32%	TRIA(1, 15.5, 233)	6.2
Thoracic Surgery	39	1	0.66%	TRIA(3, 14.2, 115)	0.0
Transplantation Surgery	40	1	0.66%	TRIA(1, 15.6, 147)	0.0
Neurosurgery	42	3	1.97%	TRIA(1, 5.41, 142)	27.0
Obstetrics and Gynecology	47	4	2.63%	TRIA(1, 10.3, 373)	64.6
Ophthalmology	49	5	3.29%	TRIA(1, 5.21, 203)	94.8
Psychiatry	51	3	1.97%	TRIA(1, 7.45, 272)	75.8
Dept. of Psychiatry for Parents and Children	52	2	1.32%	TRIA(1, 9.55, 189)	19.4
Otorhinolaryngology	54	6	3.95%	TRIA(1, 6.03, 202)	51.4
Anesthesiology	56	1	0.66%	TRIA(0.999, 9.9, 179)	16.0
Pediatrics	58	5	3.29%	TRIA(1, 6.44, 175)	32.4
Dermatology	60	4	2.63%	TRIA(1, 6.67, 228)	44.8
Plastic and Reconstructive Surgery	62	2	1.32%	TRIA(0.999, 13.7, 204)	8.8
Oral and Maxillofacial Surgery	64	6	3.95%	TRIA(1, 9.81, 318)	43.2
Dept. of Surgical Center	77	1	0.66%	TRIA(1, 8.9, 80)	0.0
Dept. of Physiatics	85	3	1.97%	TRIA(1, 14.5, 136)	0.0

Table 3: Parameters on Reception/Machines

Reception/Machine	No.	No. of Units in Resource	Percentage (%)	Processing Tome (min.)	Frequency (up to 5 times)
Orthopedic Surgery	10	1	0.66%	TRIA(0.999, 3.28, 33)	95.2
Urology	12	1	0.66%	TRIA(1, 4.1, 32)	52.4
Radiology	14	-	0.00%	-	-
Dept. of Emergency Medicine	16	-	0.00%	TRIA(1, 3.33, 29)	1.2
Internal Medicine	19	1	0.66%	TRIA(1, 2.45, 33)	1
Surgery	32	1	0.66%	TRIA(1, 2.62, 43)	4.6
Neurosurgery	41	1	0.66%	TRIA(1, 2.83, 34)	3
Obstetrics and Gynecology	46	1	0.66%	TRIA(1, 2.5, 16)	1.6
Ophthalmology	48	-	0.66%	TRIA(1, 2.86, 27)	8.6
Psychiatry	50	1	0.66%	TRIA(1, 3.79, 40)	8.2
Otorhinolaryngology	53	1	0.66%	TRIA(1, 3.29, 33)	10.2
Anesthesiology	55	-	0.00%	-	-
Pediatrics	57	1	0.66%	TRIA(1, 5.23, 94)	13.4
Dermatology	59	1	0.66%	TRIA(1, 2.67, 31)	8.2
Plastic and Reconstructive Surgery	61	1	0.66%	-	-
Oral and Maxillofacial Surgery	63	1	0.66%	TRIA(1, 2.6, 17)	0
Payment Machine	90	5	3.29%	TRIA(19, 32.9, 80)	1128.6
Reexamining Reception Machine	91	5	3.29%	TRIA(0.5, 1, 1.5)	1005.2

Table 4: Parameters on Clinical and Test/Inspection Departments

Clinical Dept.	No.	No. Units in Resource	Percentage (%)	Treatment Time (min.)	Frequency (up to 5 times)
Collecting Blood	79	5	3.29%	TRIA(0.07, 1.8, 7)	207.6
Urine Test	80	1	0.66%	TRIA(0.5, 1, 1.5)	35.8
Endoscopy	81	1	0.66%	TRIA(2.03, 2.93, 11)	36.2
Radiation Test	82	5	3.29%	TRIA(1, 1.66, 8.9)	115.8

In case more patients are expected to be processed at the clinical departments, it is necessary to perform simulation experiments under any possible situation. Hence, a special-purpose data-generator was 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 was written in Excel VBA. Experimental data created consisting of the arrival time of the patient, the arrival time, and the route sequences (Takakuwa and Shiozaki 2004; Wijewickrama and Takakuwa 2005; Wijewickrama and Takakuwa 2006). A similar idea for the data generator for simulation experiments appears in simulation of warehousing at distribution centers and at the international-departure airport (Takakuwa et al. 2000; Takakuwa and Oyama 2003). The generated data includes the arrival time of each patient and the sequence of the routing. By making use of these generated data as an external file input for the simulation model, experiments can be conducted under any specified conditions.

4 SIMULATION EXPERIMENTS

In this section, the above-mentioned procedure of preparing simulation data explains the process of obtaining the patient waiting times and consultation times, using numerical examples; consider the case of two thousand patients or the typical congestion in a hospital. In this case, all associated areas of the outpatient hospital ward were included in a simulation model that was used to examine patient flows, and to collect important statistics including all waiting time. The simulation models in this study were created using Arena (Kelton, Sadowski, and Sadowski 2006).

In order to investigate the waiting times, the consultation times, and the degree of congestion inside the hospital ward, the ten replications of the simulation were executed. The 95% confidence interval on the average percentage of the waiting time and the consultation time for 26 clinical departments are shown in Figures 7 and 8, respectively. The numbers of the clinical departments in these figures correspond to those in Table 2. As expected,

these figures show that the waiting time at the clinical department generally is much longer than the consultation time. The waiting times for consultation of the urology and the psychiatry departments are especially longer compared to those of all clinical departments.

The proposed procedure of gathering required data from electronic medical records is found to be quite effective

to perform simulation of a large-scale hospital to examine patient flows and congestion. Furthermore, any situation can be simulated flexibly under the specific scenario by varying the number of expected outpatients and their mix, and/or the number of any resource units at the clinical departments in the hospital.

Table 5: Selected Resultant Data Obtained by Data Processing

(a) Reception/Payment Data

>10:00:22 Data aquired.(006989772,40 , Reception done.,09:58:58)

>13:54:04 Data aquired.(006989772,40 , Payment done.,13:52:42)

Patient ID	Clinical Department	Log on	Log off
6989772	Reception	9:58:58	
6989772	Payment	13:52:42	

(b) Electronic Medical Record

The Date and Time	millisecond	Terminal Unit	-	-	Patient ID	User ID
2005/8/1 13:26	727	FMV15079	Patient Selection	Patient Log-on	Name	1253278
2005/8/1 13:35	70	FMV15079	Patient Selection	Patient Log-off	Name	1253278
Patient ID	Terminal Unit	Log on	Log off			
6989772	FMV15079	13:26:29	13:35:53			

(c) Terminal Unit

Computer Name	TermName	
FMV15079	Outpatient Ward 3rd Fl.	
Terminal Unit Name	Consultation Room	Clinical Dept.
FMV15079	Outpatient Ward 3rd Fl.	Ophthalmology

(d) Test/Inspection Data

Blood Test/Urine Test Data

Department C	Department Name	Patient ID	Order No.	System Date	System Time	User C
40	Ophthalmology	00006989772	04216938	20050801	1355	01
40	Ophthalmology	00006989772	04216938	20050801	1407	02
Patient ID	Clinical Department	Log on	Log off			
6989772	Blood Test	13:55:00				
6989772	Urine Test	14:07:00				

Endoscopy Data

Date	Patient ID	Time	Requested by	Room
2005.08.01(Mon.)	6989772	13:09	Ophthalmology	Electrocardiogram Room
Patient ID	Clinical Department	Log on	Log off	
6989772	Endoscopy	13:09		

Radiation Test

Requested by	Date	Patient ID	Time	Clinical Department (Patient)	Room	Appointment
Orthopedic Surgery	2005.08.01 (mon.)	3216217	0:00	Orthopedic Surgery	No.22 Room	2005.08.01(Mon.)

Patient ID	Clinical Department	Log on	Log off
6989772	Radiology		

(e) Number and Percentage of Accepted Patients

Time Interval of Reception

Time Interval	Number of patients	Percentage
7:30 - 8:00	0	0.00%
8:00 - 8:30	269	3.49%
8:30 - 9:00	669	8.68%
9:00 - 9:30	1088	14.11%
9:30 - 10:00	1031	13.37%
10:00 - 10:30	1013	13.14%
10:30 - 11:00	878	11.39%
11:00 - 11:30	774	10.04%
11:30 - 12:00	511	6.63%
12:00 - 12:30	380	4.93%
12:30 - 13:00	237	3.07%

Time Interval	Number of patients	Percentage
13:00 - 13:30	232	3.01%
13:30 - 14:00	183	2.37%
14:00 - 14:30	163	2.11%
14:30 - 15:00	100	1.30%
15:00 - 15:30	82	1.06%
15:30 - 16:00	38	0.49%
16:00 - 16:30	38	0.49%
16:30 - 17:30	18	0.23%
17:00 - 17:30	5	0.06%
17:30 - 18:00	0	0.00%
Total	7709	100.00%

(f) Patient Flow

Patient ID	Code 1	Clinical Dept.	Code 2	Room Name	Terminal Unit	Log on	Log off
0003239	86	Reception	750	Reception		8:45:39	
0003239	38	Vascular Surgery	140	Outpatient Ward 2nd Fl. Surgery No.9 B	FMV05034	9:19:51	9:23:51
0003239	41	Neurosurgery	147	Outpatient Ward 2nd Fl. Neurosurgery No.2	FMV06033	9:56:42	10:00:05
0003239	87	Payment	751	Payment		10:10:24	

(g) Sequence

SeqNo	Frequency	Percentage	Accumulative %	Destination (1st)	Ditto (2nd)	Ditto (3rd)
904991	431	7.604%	7.604%	Reception	Ophthalmology	Payment
905191	336	5.928%	13.532%	Reception	Psychiatry	Payment
901091	233	4.111%	17.643%	Reception	Orthopedic S.	Payment

(h) Resource

Clinical Dept.	No. of Resource Units	Mean Time	Consultation Time
Orthopedic S. Reception	1	3.4	TRIA(1, 3.28, 33)
Orthopedic S.	7	16.9	TRIA(1, 8.8, 391)
Hand Surgery	2	13.4	TRIA(1, 5.36, 97)

(i) DataGenerator

(l) InputData

Patient ID	Arrival Time		Sequence
140	470.3320007	1	904991
118	472.821991	1	905191

Table 6: Distances between Selected Clinical Departments

	Entrance	R. R.	O. R.	O.	P. R.	Payment	N. R.	N.	O. S. R.	O. S.	H. S.	1F. E. LB	1F. LB	Exit
Entrance	-	20	61	71	36	36	38	58	50	66	74	58	17	6
Reexamination R. (*)	20	-	48	59	32	32	33	51	41	60	69	58	18	23
Ophthalmology R.	61	48	-	27	63	67	67	88	78	95	104	99	58	68
Ophthalmology	71	59	27	-	76	80	80	98	93	108	117	115	72	82
Payment R.	36	32	63	76	-	6	26	40	36	53	62	69	36	33
Payment	36	32	67	80	6	-	23	39	33	51	60	62	41	38
Neurosurgery R.	38	33	67	80	26	23	-	24	15	32	41	44	36	32
Neurosurgery	58	51	88	98	40	39	24	-	26	44	50	57	56	54
Orthopedic Surgery R.	50	41	78	93	36	33	15	26	-	21	30	35	49	43
Orthopedic Surgery	66	60	95	108	53	51	32	44	21	-	20	40	63	58
Hand Surgery	74	69	104	117	62	60	41	50	30	20	-	52	74	71
1st Fl. East LB	58	58	99	115	69	62	44	57	35	40	52	-	56	50
1st Fl. LB	17	18	58	72	36	41	36	56	49	63	74	56	-	23
Exit	6	23	68	82	33	38	32	54	43	58	71	50	23	-

(*)R.: Reception

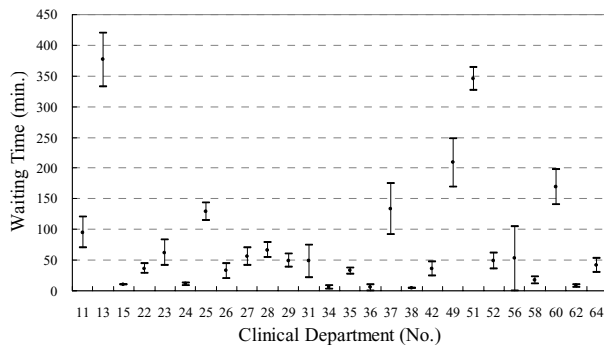


Figure 7: Simulation Results on Waiting Time

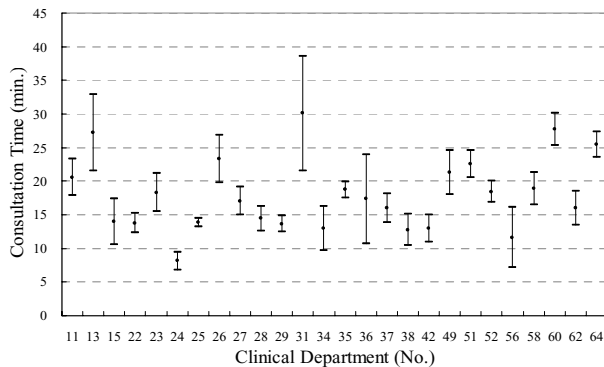


Figure 8: Simulation Results on Consultation Time

5 SUMMARY

- (1) A simulation model of the planned outpatient ward of a university hospital was constructed and used especially to examine the patient waiting time and congestion.
- (2) The method of gathering required data on times for all outpatients and their routes was proposed

to perform a simulation, especially by making use of electronic medical records.

- (3) The proposed procedure was presented using an actual case to demonstrate the applicability to a large-scale university hospital.

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