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OPTIMIZING STAFFING SCHEDULE IN LIGHT OF PATIENT SATISFACTION FOR THE WHOLE OUTPATIENT HOSPITAL WARD

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ABSTRACT

The waiting time for patients in outpatient departments of hospitals is a problem throughout the world. In this context, a discrete-event-simulation model was developed to examine congestions and doctor schedules in all departments of an outpatient hospital ward of the Nagoya University hospital. The method of gathering the required data on times for all outpatients and their routes is described in this paper as part of a performing simulation, especially by making use of electronic medical records. This study identified some of the best doctor schedule mixes by integrating the simulation model into an optimization program in order to reduce patient waiting time as well as doctor idle-time without adding a single additional resource.

1 INTRODUCTION

The accelerating inflation of health expenditures, aging population and greater emphasis on preventive medicine have compelled researchers to examine new ways to improve efficiency in outpatient services. Simulation analysts are in a more advantageous situation due to restrictions of applying analytical methods in complex interactions prevailing in healthcare. A simulation of hospital systems was conducted to provide the hospital administration with the tools that will give them the ability to predict performance under operational conditions in conjunction with hospital facilities (Austin and Boxerman 1995; Fetter and Thompson 1965).

A comprehensive literature can be found in Jun, Jacobson and Swisher (1999) for overall health care and Cayirli and Veral (2003) for outpatient scheduling.

In this study, a simulation model initially developed by Takakuwa and Katagiri (2007) for the entire departments of the outpatient hospital ward of a university hospital was redesigned considering actual working time of the doctors. Then, by incorporating a simulation model to an optimization algorithm, some optimum doctor schedule mixes (DSMs) were identified. The experimental data for the study 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 including: where the patients wait for the 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 the 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.

Most studies concerning scheduling simulations for healthcare clinics have been directed at patient scheduling (Wijewickrama and Takakuwa 2005). A number of studies have addressed scheduling staff in meeting patient demand while keeping patient arrivals unchanged. Alessandra et al. (1978) analyzed both staffing levels and patient arrivals to identify the bottleneck and improve patient throughput, which proposed to distribute current morning appointment patients to the afternoon shift. Another study identified an alternative which reduced average patient waiting time and average patient time in system simulating nurse workload in an emergency department (Draeger 1992). Kumar and Kapur (1989) examined ten nurse-scheduling alternatives and identified an alternative that yielded the highest nurse utilization. Tan, Gubaras, and Phojanamongkolkij (2002) suggested the addition of one or two extra doctors for each hour to reduce the bottleneck at doctor stations. A study related to patient flow and resource utilization for an individual physician showed that increased resource utilization does not necessarily imply longer waiting lines nor longer patient flow times (Côtè, 1999). Garcia et al. (1995), in an emergency department study, found that the total time in the system was reduced by 25% for low priority patient by adding a fast track line without affecting the times of patients with higher priority. Centeno et al. (2003) developed a tool that integrated a simulation model and an integer linear program (ILP) to establish the staffing requirements for each period in an emergency department. The simulation model used in the Centeno study established the staffing requirement for each period, and the ILP produced an optimum calendar schedule for the staff. Wijewickrama and Takakuwa (2004, 2006) developed simulation models by incorporating an optimization program to identify optimum DSMs in an internal medicine department of a hospital.

2 BASIC DESCRIPTION OF THE OUTPATIENT WARD

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. For the fiscal year of 2005, the average number of outpatients was 2061 and inpatients 844 persons per day. The hospital is presently planning to rebuild the hospital wards because the current building remains superannuated. The new hospital ward will consist of building with three stories above the ground and one below as shown in Figure 1. With the coming new buildings, the number of the patients is certainly expected to increase after completion of the new hospital wards.

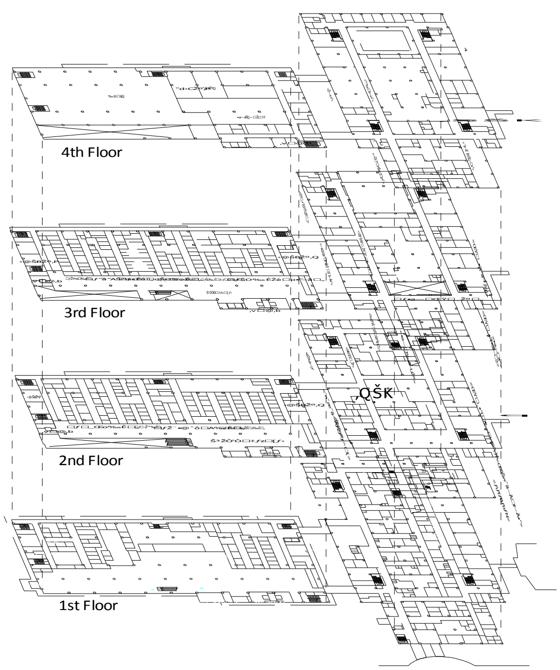


Figure 1: Planned Outpatient Hospital Ward at Nagoya University Hospital

The data in this study comes from the current hospital wards and was used as an average to evaluate the performance on the anticipated hospital wards to be completed in the near future. The outline of the patient flows and the associated processes in the clinical departments are shown in Figure 2. Basically, the outpatient arrives at the reception, has a test, and consults a doctor. After this processing, the patient pays expenses and returns home. The electronic medical record was employed for recording the history of medical treatment for the patient, but in this study it is utilized to prepare input data to perform simulation. A layout plan and the precise work shift of the staff were required for the input data, and a time study on the test, inspection and treatment activities performed as necessary.

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

- Acquire a series of raw data, including reception/payment data, electronic medical record, terminal-unit data, and test/inspection data;
- Process the series of raw data;
- Prepare input data for simulation, using the data generator;
- Perform the simulation;
- Performance measures generated by simulation are used by optimization program to search an optimum doctor mix for the outpatient department; and
- Obtain the optimum doctor mix/es.

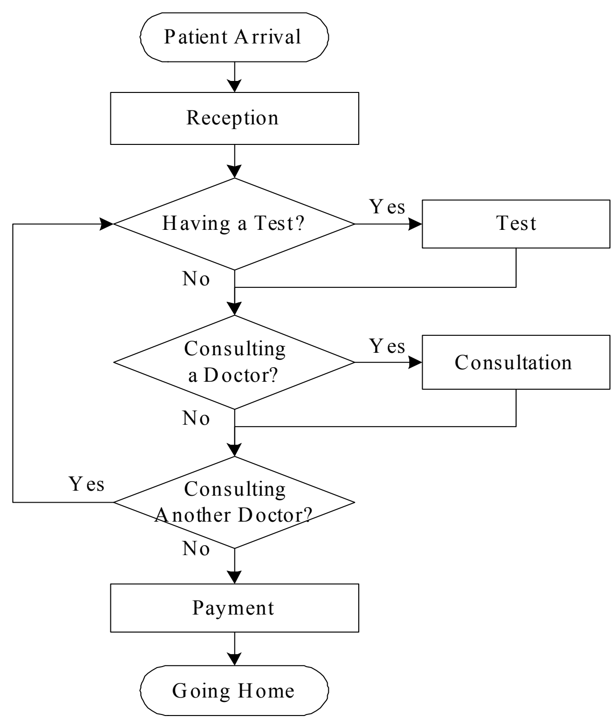


Figure 2: Outline of Outpatient Flow and Processes

First, a series of typical sequencing for the routing of approximately eight thousand outpatients was investigated through the electronic medical records for the specified five days. Our team 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 the frequency and their routings in Table 1. For example, Sequence Number 90257991 appeared 103 times in the electronic medical records of outpatients in five days of observation, with the routing comprised of the reception, the gastroenterology department, the orthopedic surgery department, and finally the payment area. The clinical departments considered in this study were summarized in Table 2 in which the frequency stood for the average number that appeared in the sequences of outpatients in the electronic medical records.

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

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 Doctors	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
Respiroligy	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. od 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 Physiatrics	85	3	1.97%	TRIA(1, 14.5, 136)	0.0

In addition, the number of the resource units for the clinical departments were summarized in Table 2. Similarly, the parameters of the receptions of the clinical departments were placed in Table 3, and those of the test/inspection departments developed into Table 4.

For the purpose of validating the model and to conduct experiments of bottleneck situations in clinical departments of the existing system, a special-purpose data generator was designed using Excel VBA used previously in a number of healthcare simulations (Wijewickrama 2006; Takakuwa and Shiozaki 2004), flight scheduling simulation (Takakuwa and Oyama 2003) and warehousing distribution centers (Takakuwa et al. 2000). The generated data included the arrival time of each patient and the sequence of the routing. By making use of the generated data as an external file input for the simulation model, experiments were conducted under specified conditions.

3 EXPERIMENTS

3.1 Waiting Time

The above-mentioned procedure for preparing the simulation data is further explained in this section as the process of obtaining the patient waiting and consultation times considering the case of two thousand patients or the typical congestion in a hospital. In the case of Nagoya university hospital, all associated areas of the outpatient hospital ward were included in the simulation model 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).

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 order to investigate the waiting and the consultation times, as well as the degree of congestion inside the hospital ward, ten replications of the simulation were executed. The 95% confidence interval on the average percentage of the waiting time for some selected clinical departments is shown in Figure 3.

As expected with the simulation, Figure 3 shows that the waiting time at many of clinical departments remains too long. The waiting times for consultation in the urology and the psychiatry departments were especially longer compared to those of all other clinical departments.

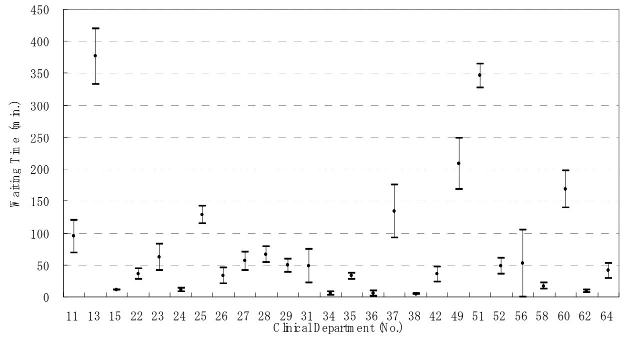


Figure 3: Simulation Results on Waiting Time

3.2 Doctor Schedule Mix (DSM)

As a simulation is unable to uncover the best solution, identifying and evaluating the best or near best options for the solution has been impossible to achieve. A simulation can only provide estimates of performance measures and it is not an optimization tool. Therefore, this study combined the simulation model with a deterministic operational research technique that capitalized on the advantages of both techniques simultaneously. In order to reduce the long waiting time of the clinical departments we employed an optimum DSM using an optimization program in Arena, called OptQuest.

OptQuest is an optimization program in Arena that uses a special search algorithm to search for the best solution or a near best solution. OptQuest combines the *metaheuristics* of Tabu Search, Neural Networks, and Scatter Search into a single search heuristic (Kleijnen and Wan 2007) in order to find the best value for one or multiple objective functions.

One major advantage with integrating the simulation model with an optimization program is that the decision variables of the objective functions are not necessarily in the constraints. Based on performance measures like the weighted average patient waiting time (WAPWT), which was generated by the simulation model, the OptQuest can evaluate alternative staffing schedules by altering number of doctors in each clinic subject to given constraints.

The objective of the optimization program is to minimize WAPWT for all clinical departments. The existing total number of doctors was hundred-and-ten (summation of No. of doctors in Table 2). Due to resource limitation and hospital policies, there are some upper and lower limits in the number of doctors allocated to each department. The optimization model is as follows;

Minimize:

Weighted Average Patient Waiting Time (WAPWT)

$$WAPWT = \frac{1}{n}\sum_{i=1}^{n} x_i$$

where x_i = ith patient waiting time (min.).

Subject to:

(1) Total Number of Doctors:

$$\sum d_j \leq 110$$

where d_j = number of doctors allocated for jth consultation clinic (persons).

(2) Maximum and minimum number of doctors, respectively, in each consultation clinic:

$d_{10} \geq 4,\ d_{10} \leq 8\ ;\ d_{11} \geq 1,\ d_{11} \leq 4;\ d_{13} \geq 2,\ d_{13} \leq 5;$
$d_{15} \geq 1,\ d_{15} \leq 4\ ;\ d_{17} \geq 1,\ d_{17} \leq 4;\ d_{20} \geq 1,\ d_{20} \leq 2;$
$d_{22} \geq 3,\ d_{22} \leq 7\ ;\ d_{23} \geq 1,\ d_{23} \leq 3;\ d_{24} \geq 3,\ d_{24} \leq 7;$
$d_{25} \geq 3,\ d_{25} \leq 7\ ;\ d_{26} \geq 2,\ d_{26} \leq 4;\ d_{27} \geq 1,\ d_{27} \leq 4;$
$d_{28} \geq 1,\ d_{28} \leq 4\ ;\ d_{29} \geq 1,\ d_{29} \leq 4;\ d_{30} \geq 1,\ d_{30} \leq 3;$
$d_{31} \geq 1,\ d_{31} \leq 3\ ;\ d_{33} \geq 1,\ d_{33} \leq 2;\ d_{34} \geq 1,\ d_{34} \leq 3;$
$d_{35} \geq 3,\ d_{35} \leq 5\ ;\ d_{36} \geq 1,\ d_{36} \leq 3;\ d_{37} \geq 1,\ d_{37} \leq 2;$
$d_{38} \geq 1,\ d_{38} \leq 3\ ;\ d_{39} \geq 1,\ d_{39} \leq 2;\ d_{40} \geq 1,\ d_{40} \leq 2;$
$d_{42} \geq 1,\ d_{42} \leq 4\ ;\ d_{47} \geq 2,\ d_{47} \leq 6;\ d_{49} \geq 3,\ d_{49} \leq 7;$
$d_{51} \geq 1,\ d_{51} \leq 5\ ;\ d_{52} \geq 1,\ d_{52} \leq 3;\ d_{54} \geq 4,\ d_{54} \leq 8;$
$d_{56} \geq 1,\ d_{56} \leq 3\ ;\ d_{58} \geq 3,\ d_{58} \leq 6;\ d_{60} \geq 3,\ d_{60} \leq 6;$
$d_{62} \geq 1,\ d_{62} \leq 4\ ;\ d_{64} \geq 3,\ d_{64} \leq 7$

$d_j \geq 0$ and integer for all j appeared in Table 2

Initial optimization program was executed one thousand times, and the Figure 4 shows the graph of the above model when the time lapsed after seven hours. Within this timeframe eight hundred and thirty simulations were executed and this graph established the best result found so far as a function of the simulation number run. After running one thousand different scenarios, the best scenario was discovered by the 954th, where the WAPWT was 73.58 minutes, which was achieved with 110 doctors. A myriad of DSMs were identified which reduced the WAPWT compared to the base case, and Table 5 shows few of these mixes.

The optimum solution cut the WAPWT by 40.34%, which represented a reduction of approximately half of waiting time per patient compared to the existing system at the hospital. Interestingly, reducing the total number of doctors up to 105 also improved the solution by a 17.31% drop in patient waiting time. In other words, 21.35 minutes of waiting time *per* patient was saved by employing 105 doctors; which represented a large reduction of idle time of both patients and doctors.

The graph constructed for the existing system in Figure 3 was reproduced for scenario 1 as followed in, Figure 5. Except for department number 27, the waiting time was reduced considerably with lowering the risk of variability.

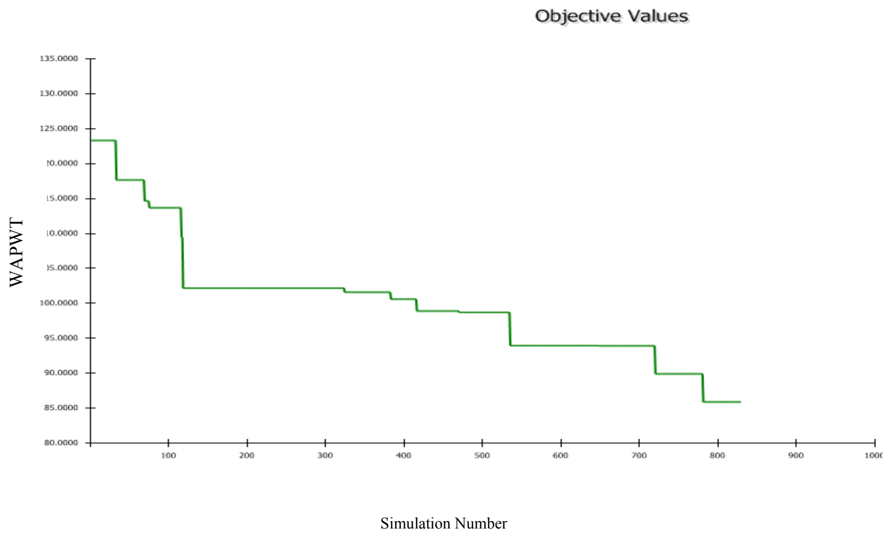


Figure 4: Optimization Graph after Seven Hours

Table 5: Optimization Results

Scenario	Base	1	2	3	4
% of waiting time reduction	-	40.34%	38.78%	17.31%	0.45%
Minutes of waiting time reduction	-	49.75	47.83	21.35	0.55
WAPWT	123.33	73.58	75.5	101.98	122.78
Orthopedic Surgery	7	6	6	6	5
Hand Surgery	2	3	2	2	2
Urology	2	3	3	2	3
Radiology	3	1	1	2	2
Dept. of Emergency Medicine	3	4	4	3	4
Internal Medicine (Pre-Examination)	1	2	2	3	2
Cardiology	5	5	5	4	4
Nephrology	2	2	2	1	1
Diabetology and Endocrinology	5	3	3	2	2
Gastroenterology	5	5	5	5	5
Hematology	3	3	3	3	2
Respiroligy	3	1	1	2	2
Neurology	3	2	2	3	2
Dept. of General Medicine	3	2	2	3	2
Geriatrics	2	2	2	1	1
Dept. of Outpatient and Home Medicine	2	2	2	3	1
Surgery Treatment	1	2	2	3	1
Cardiac Surgery	2	2	1	1	1
Gastroenterological Surgery	4	3	4	4	3
Breast and Endocrine Surgery	2	1	1	2	2
Pediatric Surgery	1	2	2	1	3
Vascular Surgery	2	1	1	2	2
Thoracic Surgery	1	2	2	2	1
Transplantation Surgery	1	2	2	1	1
Neurosurgery	3	2	2	1	2
Obstetrics and Gynecology	4	6	6	5	5
Ophthalmology	5	5	5	5	5
Psychiatry	3	5	5	5	5
Dept. od Psychiatry for Parents and Children	2	3	3	2	2
Otorhinolaryngology	6	7	6	6	6
Anesthesiology	1	2	2	1	1
Pediatrics	5	4	4	3	4
Dermatology	4	5	5	5	6
Plastic and Reconstructive Surgery	2	1	1	2	2
Oral and Maxillofacial Surgery	6	6	6	5	5
Dept. of Surgical Center	1	2	2	2	1
Dept. of Physiatrics	3	1	1	2	2
No. of Doctors	110	110	108	105	100

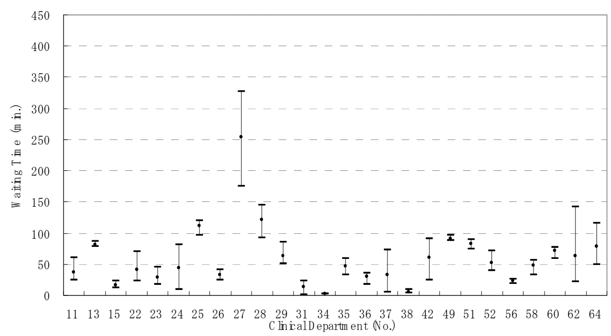
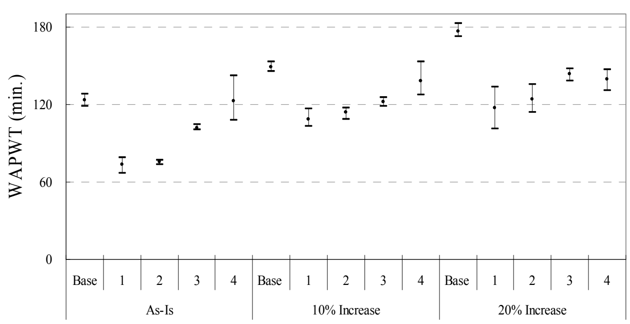


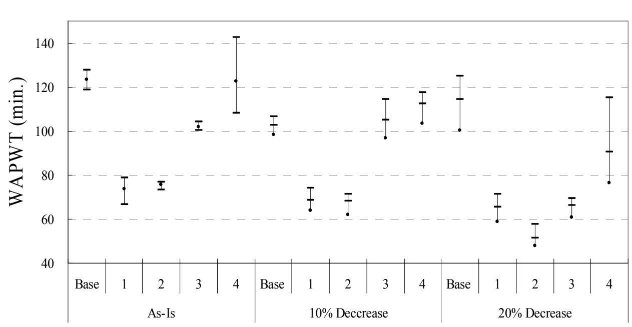
Figure 5: Scenario 1 Results on Waiting Time

3.3 Sensitivity Analysis

A sensitivity analysis was made to explore the validity of the optimum doctor mix scenarios due to the changing arrival pattern of the outpatient department. This issue is particularly important with the coming new buildings, the number of patients is certainly expected to increase after completion of the new hospital wards.



(a) Impact of Increasing Arrival on WAPWT



(b) Impact of Decreasing Arrival on WAPWT

Figure 6: Impact of Changing Arrival on Waiting Time

The impact of increasing and decreasing arrivals on the WAPWT was investigated for Base and other four scenarios as shown in Figure 6.

Interestingly, all scenarios performed well compared to the base of the section of *As-Is* and in 10% to 20% incremental situations. Moreover, variability in the WAPWT of first two scenarios was negligible compared to the base except for the 20% incremental situation

In the case of decreasing arrivals, surprisingly, the WAPWT for all scenarios were also outperformed compared to the base in any situation, although the variability was much higher for the fourth scenario.

4 SUMMARY

1. A simulation model of the planned outpatient ward of a university hospital was constructed and used to examine patient waiting time and congestion.
2. The method of gathering the required data on times for all outpatients and their routes was proposed by performing a simulation and by making use of electronic medical records.
3. Finally, the impact on the WAPWT was analyzed by identifying an optimum DSM using an optimization program. The program identified scenarios which could reduce the idle time of patients and doctors without an additional single resource both in the current arrival and in differing arrival situations.

It is interesting to observe the results of this study enhancing two aspects of the model. One incorporated appointment scheduling rules in addition to staff scheduling while the second widen the scope of the study by adding emergency patients to the outpatient model.

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