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# SIMULATION ANALYSIS OF APPOINTMENT SCHEDULING IN AN OUTPATIENT DEPARTMENT OF INTERNAL MEDICINE

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## ABSTRACT

Long waiting times for treatment in the outpatient department of internal medicine, followed by short consultations has long been a complaint of patients. This issue is becoming increasingly important in Japan with the progressively aging society. In this context, a discrete event simulation model to examine various appointment schedules in a mixed-patient type environment in an outpatient department of a general hospital was developed. A special purpose data generator was designed to validate the model and to conduct experiments in bottleneck situations at consultation rooms in the existing system. Some efficient appointment schedules (ASs) were identified, which drastically reduced patient waiting time while keeping doctor idle time as low as possible without adding extra resources. The sensitivity of performance was examined under three realistic environmental factors: no show, variance of consultation time, and variation of walk-ins.

## 1 INTRODUCTION

At present, the challenges for improving healthcare organizations is stronger than ever. Issues such as expanded access to healthcare, a growing aging population, technological advancement and the rise of the price of health care have placed major pressures on these organizations. With increasing demand for improved healthcare, healthcare providers have had to reconsider the way of providing quality healthcare within their constrained resources. Efficient and effective management of healthcare is imperative due to the demands of an increasingly educated customer and to meet the intensive competitiveness in this sector. In such complicated circumstances, healthcare managers have a challenging task in balancing the needs of customers and employees, as the product of the organization could mean the difference between life and death.

With today's challenges to improve healthcare organizations, there is a continuing movement from inpatient services to outpatient services. Because of technological advancements and the establishment of a national insurance systems, inpatient services are now provided on an outpatient basis. In the outpatient department, long waiting times for treatment followed by short consultations have long been complaints of patients. In Japan it is often phrased as "waiting for three hours to be seen for three minutes". This disproportionately long waiting time in the consultation room has over the years been the focus of study among academicians and practitioners. Most have stressed the major cause to long waiting times as due to the poor patient appointment system in place.

Traditionally, the medical profession highlighted that a doctor's time was more valuable than a patient's so that the appointment schedule was designed to minimize a doctor's idle time overlooking patient waiting time. This is no longer valid in today's consumer oriented society. Today, customers use waiting time as a decisive factor in choosing a service provider. Therefore, the idle time of both parties must be considered in designing an AS although these two objectives are contradictory to each other. This study aims to develop such an appointment system in a real world healthcare organization: a mixed-patient outpatient department in a large general hospital located at Tajimi, Gifu prefecture, Japan.

## 2 LITERATURE REVIEW

The types of appointment systems range from single-block appointments on the one extreme to individual appointments on the other. Most of the appointment systems have concentrated on modifying and combining these two systems into different forms such as multiple-block, single-block/individual, single-block/multiple-block, and variable-sized/multiple-block.

The earliest work studying the appointment scheduling issue was made by Bailey (1952) and Welch (1964). Introducing a single-block/individual system, they proposed that the best scheduling policy was to place two patients at the start of the session and then schedule patients evenly over the period based on average service time. This rule focused on reducing waiting time of the patient and it remained one of the best over the past fifty years.

Following an analytical approach, Soriano (1966) compared a multiple-block system with an individual system and recommended that patients be scheduled two at a time with an interval of twice the consultation time. Ho and Lau (1992) evaluated nine scheduling rules that reduced client waiting time and server idle time, and they concluded that no single rule dominated in all environmental conditions. Ho and Lau (1999) extended their prior theoretical work by evaluating 50 scheduling rules via simulation and concluded that a variable-interval appointment-scheduling system designed to reduce patient waiting time performs well in most environmental conditions. Klassen and Rohleder (1996) proposed a rule in scheduling based on the client service time variance; for example, whether a client was "low variance" or "high variance." This empirical research showed that setting low variance clients at the beginning of the session and high variance clients at the end of the session would minimize both client waiting time and server idle time in most instances. Later they identified that this rule was still effective when the scheduler was unable to identify the low variance and high variance clients proportionately (Rohleder and Klassen 2000). In a more recent study, these scholars found that the above rule was still valid even in a multi-period environment (Klassen and Rohleder 2004).

Harper and Gamlin (2003) identified a schedule option that reduced patient waiting time unique to specific ENT outpatient department based on an algorithm. Worthington and Brahimi (1993) applied queuing theory to address this issue and proposed to place three patients at the start of the session and one every five minutes (average consultation time). Using dynamic programming approach, Fries and Marathe (1981) introduced the variable-sized multiple-block appointment system. Vissers and Wijngaard (1979) produced a general method for determining a suitable appointment system for an outpatient department lessening the number of variables involved in designing an appointment system. Chung (2002) adopted "modified–wave scheduling" by double booking at the start of each hour and leaving the end of each hour for catching-up. Isken, Ward, and McKee (1999) outlined a general framework for modeling outpatient obstetrical clinics for the purpose of exploring questions related to demand, appointment scheduling, examination room allocation, patient flow patterns and staffing. In a more recent study, Guo, Wagner, and West (2004) presented a simulation model to minimize the delays in appointments while simultaneously maximizing provider utilization and overall clinic efficiency.

## 3 MODEL

### 3.1 Description of the Outpatient Department

The outpatient department under this study operates from 8:30 am to 5.30 pm during weekdays with basically four different types of patient visits: appointed patients, same day appointment patients (walk-ins), patients who come for a medical test (exam patients) and new patients. Similar to widespread hospital outpatient departments in Japan, the largest percentage consists of patients with appointments. Figure 1 shows the generalized patient flow diagram.

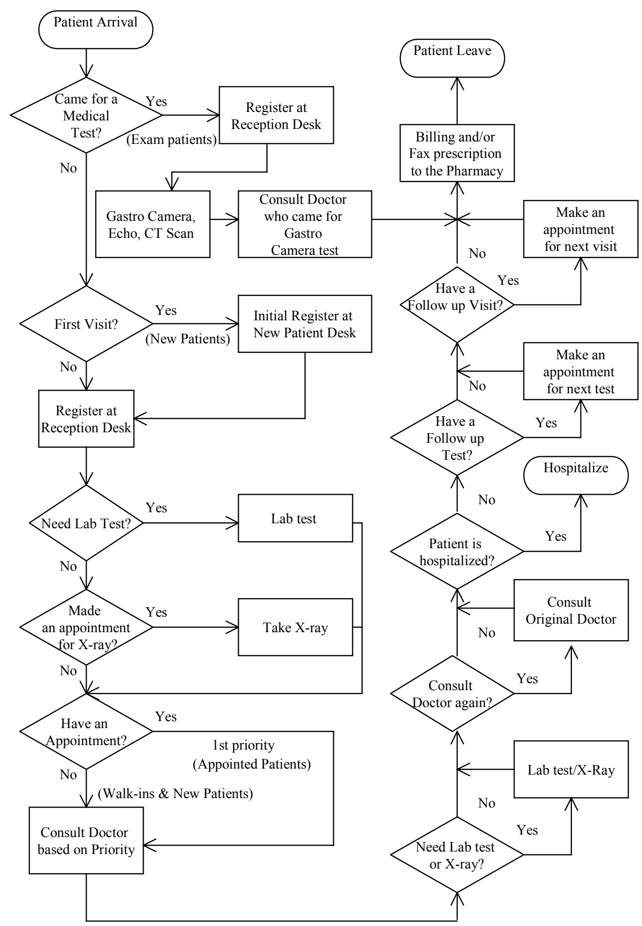



Figure 1: Patient Flow Diagram

All patients have to go to the reception desk for submission of their hospital card and required papers, and if necessary, for initial screening. New patients have to go to the new patient desk for filling-out applications, showing their health insurance certificate and obtaining the hospital card. Exam patients can go directly to the relevant test room after meeting the receptionist. Depending on the sickness or the availability of the pre-appointed test, the required patients have to do lab tests such as urine and blood tests or go to the X-ray room. Patients who make an appointment have priority over those who walk-in for a consultation. A separate doctor panel has been allocated to care for new patients. During the consultation with the doctor he decides whether the patient needs to be sent to a laboratory or X-ray. Patients who undergo a laboratory test or X-ray, have to consult the same doctor before leaving the hospital. After the second assessment, patients can leave the hospital after making appointments for follow-up tests and/or visits. Patients can order needed drugs from a pharmacy by faxing in the prescription after settling the bill at cashier. Based on the severity of the sickness, the doctor may decide to discharge or hospitalize the patient.

### 3.2 Performance Measures

This study employs a discrete event simulation technique and aims to identify the best scheduling rules under realistic environmental factors. Hence, our objectives are two fold:

1. Minimize patients' waiting time in the consultation room by keeping doctor idle time as low as possible and by evaluating the number of ASs.
2. Identify the degree of sensitivity of performance of ASs under selected environmental factors.

As there was an identical doctor panel employed in consulting appointed patients, walk-ins, and patients who came for medical tests, the performances were measured in combining these three categories. Although the category of new patient was left out in the measuring performances, in order to reflect the real situation of the model, new patients, and other patients who utilized facilities used by outpatients, were incorporated into the model. It is not necessary to argue that results generated by ignoring such interactions are misleading or a distortion. Therefore, the primary performance measures considered under this study were the weighted average patient waiting time (APWT) and the weighted average doctor idle time (ADIT) for three types of patients together.

Previous studies that have made use of ASs have ignored at least one of the following:

1. Walk-ins and other patients such as patients, who come for medical tests,
2. Inter-related subunits that use outpatients such as laboratories, receptionist, payment counters,
3. Other patients who utilized facilities also used by outpatients,
4. Second time consultation,
5. The idle time of doctors and realistic schedules that do not disrupt day-to-day activities of the hospital.

The present study emphasizes these issues to achieve the above-mentioned objectives.

Operational Research professionals have applied analytical techniques to improve health care processes. However these techniques ignore the interactions among sub systems, which is a common feature in health care systems. The use of a simulation technique further signifies the complexity of outpatient departments. Simulation is relatively easy compared to analytical techniques; scheduling appointments for regular patients, time allocating for walk-ins, and matching stochastic demand for resources with complex patient routines. Decision-makers are in a more advantageous situation when they are able to experiment with the existing system by altering it in diverse ways without disrupting day-to-day activities.

### 3.3 Data Collection

Data was collected via interviewing administrators, doctors, nurses and other clerical personnel, computer-recorded files, and by observation. Staff and appointment schedules, inter-arrival times of patients, steps involved in each sequence or route, the routine probabilities, process time, sub units and the relationships among sub units in each sequence for each patient category, and time taken to walk between two subunits represent the data collected from these sources. Accordingly, 31 distinct sequences were identified. Average process and delay time for each unit is summarized in the Table 1.

Table 1: Process and Delay Time

| Items | Time (min.) |
|---|---|
| New patient receptionist | EXPO (5) |
| Patient receptionist | EXPO (1) |
| Consultation<br>Consultation New – 1st time<br>Consultation New – 2nd time | TRIA (2,3,8)<br>TRIA (2,3,8)<br>UNIF (2,3) |
| Blood test | EXPO (2) |
| Waiting for lab test report | TRIA (10,25,40) |
| X-ray | EXPO (3) |
| Payment | EXPO (0.50) |
| Prescription fax | EXPO (0.25) |
| Urine test | EXPO (3) |
| Follow up test appointment | TRIA (0.75) |
| Gastro Camera | UNIF (20,30) |
| Abdomen Echo | UNIF (20,30) |
| CT test | UNIF (30,55) |
| Treatment room | EXPO (2) |
| Rehabilitation | EXPO (30) |
| Fiber Room | EXPO (30) |
| Follow up appointment | EXPO (0.33) |
| Billing | EXPO (0.25) |

EXPO = Exponential, TRIA = Triangular, UNIF = Uniform

The total number of visits was over two thousand patients per week and the inter-arrival time of each patient category, except appointed patients, was estimated according to exponential distribution, as shown in Table 2. Patients who came outside of the clinic hours were simply removed from the model.

The existing AS was prepared based on the availability of specialist doctors in a specific time. For example, the existing AS for Tuesday is shown in the Table 3.

Table 2: Arrival Data of Non-appointed Patients

| Patient Category | Inter Arrival Time (min.) | Clinic hours |
|---|---|---|
| Walk-ins | EXPO (1.5) | 9.00 – 10.30 |
| Exam | EXPO (6.15) | 9.00 – 13.00 |
| New | EXPO (3) | 8.30 – 10.30 |

Table 3: Appointment Schedule on Tuesday

| Doctor | Periods of Time | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9-9.30 | 9.30-10 | 10-10.30 | 10.30-11 | 11-11.30 | 11.30-12 | 12-12.30 | 12.30-13 | 13-13.30 | 13.30-14 | 14-14.30 | 14.30-15 | 15-15.30 | 15.30-16 |
| **B** | 5 | 4 | 6 | 4 | 6 | 5 | 4 | 0 | 4 | 4 | 0 | 0 | 4 | 0 |
| **D** | 4 | 7 | 6 | 6 | 5 | 5 | 5 | 0 | 6 | 4 | 0 | 0 | 4 | 2 |
| **I** | 8 | 5 | 7 | 6 | 6 | 0 | 0 | 0 | 8 | 5 | 6 | 5 | 2 | 0 |
| **M** | 6 | 5 | 5 | 5 | 5 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Q** | 6 | 7 | 8 | 5 | 5 | 0 | 5 | 1 | 4 | 4 | 5 | 4 | 0 | 0 |
| **U** | 5 | 5 | 8 | 8 | 6 | 6 | 0 | 0 | 6 | 5 | 4 | 0 | 0 | 0 |
| **W** | 7 | 6 | 6 | 6 | 6 | 5 | 6 | 0 | 5 | 1 | 0 | 0 | 0 | 0 |

Seeing the schedule it becomes clear that there is not a systematic pattern. It should be pointed out that these doctors are involved in consulting other two categories of patients and patients who need second time consultation, in addition to the first time consultation of appointed patients shown in the Table 3. Moreover, the stochastic nature of the processing time of inter-related subunits restricts the design of a sound appointment schedule.

Among twenty-five doctors scheduled for a week, seven doctors engaged in consultation with these three categories of patients in a given day. Two doctors have been allocated to consult with new patients. Thirteen nurses are on duty and they work in the medical test appointment center, examination rooms, and consultation rooms. The working time of each doctor and nurse is based on schedules, including breaks. Description of the other resources available is list in Table 4 with the usage rate of outpatients compared to the total number of patients of the hospital.

### 3.4 Simulation Model

A simulation model for the outpatient department was created using the simulation package Arena (Kelton, Sadowski, and Sadowski 2003). The drawing was made to scale and considered all features pertinent to the study. A snapshot observation of part of the subject area is shown in the Figure 2.

Table 4: Resources other than Doctors and Nurses with Occupancy Rate of Outpatients

| Resource | Units | Occupancy rate (%) |
|---|---|---|
| Receptionist desk | 2 staff members | 100% |
| New patients reception desk | 2 staff members | 28% |
| Appointment center | 4 staff members | 28% |
| Billing | 2 staff members | 25% |
| Payment | 2 staff members | 28% |
| Prescription fax | 2 machines | 30% |
| X-ray | 2 staff members | 50% |
| Blood test | 5 staff members | 2% |
| Urine test | 3 staff members | 4% |
| Gastro camera | 2 machines | 100% |
| Abdomen Echo | 2 machines | 100% |
| CT test | 2 machines | 20% |

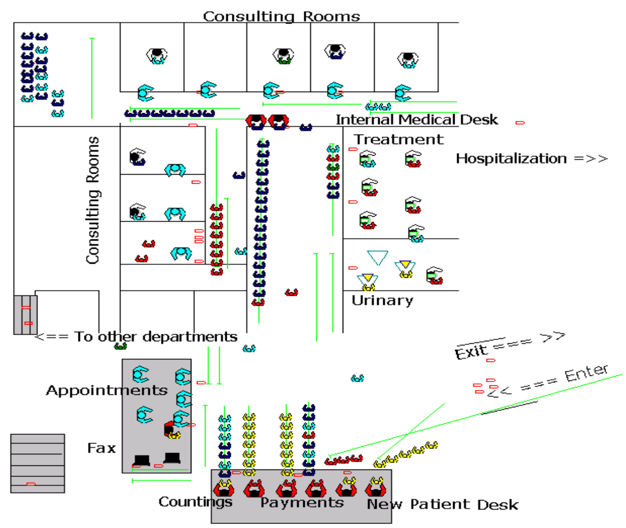



Figure 2: Layout of the Major Part of Outpatient Department of Internal Medicine

For the purpose of validating the model and conducting experiments in bottleneck situations in the consultation rooms of the existing system, a special-purpose data-generator was designed using Visual Basic for Application (VBA) in Arena. This automates the Arena model according to user request while generating experimental data. The initial VBA user form represents the existing state and the user is allowed to change the total number of patients and the patient mix. This kind of data generator has been used in previously two simulation studies. The first involved creating a flight schedule according to a specified number of flights and the boarding rate in a airport passenger terminal (Takakuwa and Oyama 2003), and the second, examined patient flows in an emergency department of a general hospital (Takakuwa and Shiozaki 2004).

According to a user's request, the program rearranges the appointment schedule, sets new inter-arrival time of other patients, and initializes variables such as doctors' capacities over the replications. In short, under any specified condition, the VBA code alters the modules of the model without touching the model.

## 4 VERIFICATION AND VALIDATION OF THE MODEL

A number of techniques were used to verify and validate the model. One technique known as functional testing and sensitivity analysis, was used to examine the accuracy and consistency of the model discussed under this section. Despite the impossibility of testing all input-output combinations in the model, some input parameters are selected, and a few illustrated in this section. (See Wijewickrama (2004) for more details on verification and validation techniques used in a different application of a hospital simulation model).

First, the varying behavior of some performance measures were examined by adjusting the patient arrivals with incremental percentages. Ten percent incremental arrivals from 10 to 40 percent were observed and the impact on APWT, the maximum queue level, and the number of patients who could not obtain the service before 5:30 pm (i.e. over time (OT) need patients) was examined, as shown in Figure 3.

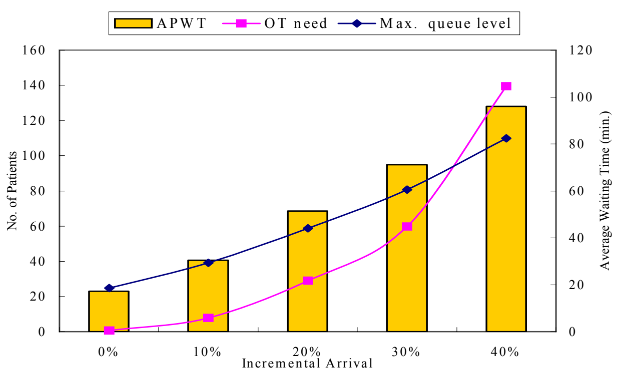



Figure 3: Impact of Incremental Arrival

Figure 3 shows that the APWT and the maximum number of patients in the queue are increasing with incremental arrival, complying with the consistency of the model. Moreover, this indicates a requirement for overtime work by doctors with the incremental arrivals. It is evidence that with 30% incremental arrivals, the required overtime work for doctors increases dramatically.

Second, sensitivity to patient mix in the consulting room was tested by increasing the appointment categories of patient and keeping others as they existed (Figure 4). The gaps between the APWT and ADIT were enlarged, as those objectives opposed each other. The average waiting time (AWT) of patients who used the same doctor panel also increased due to the bottlenecks in the consultation rooms while the AWT of the new patient category remained unchanged as anticipated.

Third, the impact on selected performances by changing the patient mix was measured. A step-by-step adjustment was made by increasing the appointment patients with the equally decreasing walk-ins without changing the total number of patients.

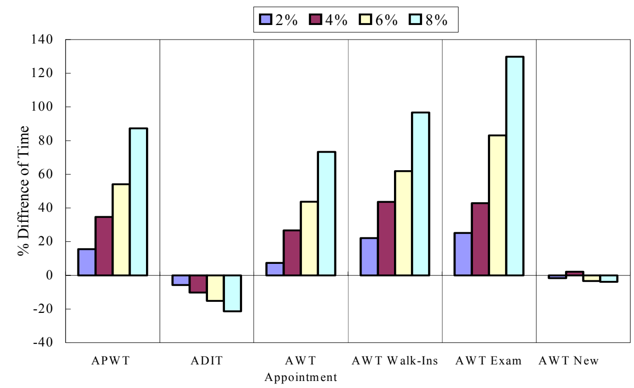



Figure 4: Impact on Performances by Increasing Appointed Patients

Figure 5 shows the impact on AWT on each patient type. As expected, increasing the change of transfer from 2.5% to 10%, the AWT of walk-ins and exam patients decrease drastically, compared to little increment of that appointment patients.

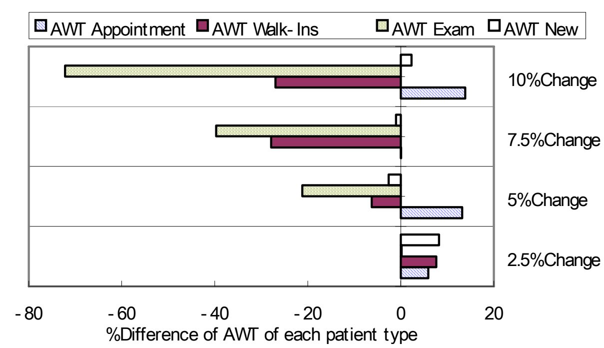



Figure 5: Patient Mix Change of Transferring Walk-Ins to Appointment Category

Another change was made to the model by a slight decrement (2%) to number of patients to one appointment patient sequence which has the second time consultation, and transferring those patients to one time consultation sequence (Case 1) and vice versa (Case 2). Performance measures in Figure 6 show that the outpatient department is highly sensitive to such little changes in the patient mix.

This information is useful in validating the model as well as for healthcare managers in formulating policies.

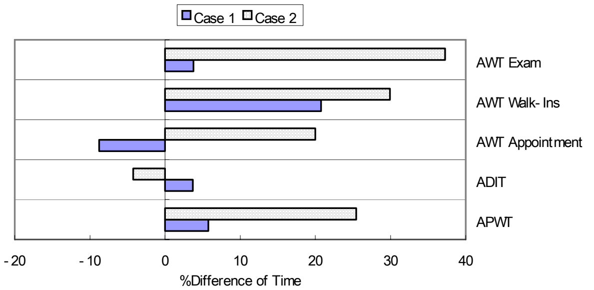



Figure 6: Patient Mix Change within the Appointment Patients

Based upon on the results from verification and validation techniques applied in testing, the model provided realistic predictions for the system behavior under the various experimentations illustrated in the next part of this paper.

## 5 EXPERIMENTATION

Results from the simulation model reveal that patients have to wait a long time to consult a doctor even though it may take only a few minutes to examine a patient. Consequently, as in Figure 7, over one third of total waiting time (excluding process time) was recorded in front of consultation rooms. The experimental process concentrated on the issues of excessive waiting time at the consultation room, aiming to shorten the patients' waiting time, and not complementing the idle time of the doctors.

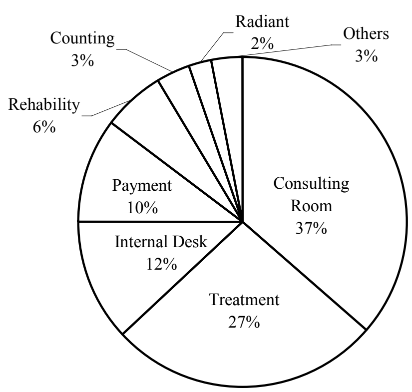



Figure 7: Breakdown of Waiting Time

### 5.1 Evaluation of Appointment Schedules

This study evaluated number of ASs for appointment patient category after placing the one-an-half-hour walk-ins slot in an appropriate time-block. The reason for this was that among those waiting at peak time in each patient type, the highest numbers corresponded to walk-ins. A proper placement of this slot is essential to gaining the advantages in the appointment schedule. Among the number of placements, it was revealed that the best placement was set between 1:00 and 2:30 pm. As more appointed patients come in the morning session, the congestion can be decreased by making this slot in the afternoon. Nevertheless, such a placement allows appointment patients to obtain a real benefit in the appointment system because most of them are coming in the morning session. The arrival block of the exam patient category was not changed as their waiting time was not as high as with walk-ins and their impact on overall performances was minimal.

The ASs considered in this study is summarized in Figure 8, and the formulation is based on Ho and Lau's (1999) recommended format.

The AS 1 below illustrates the existing schedule system as it depends on the first-come-first serve basis. A number of patients $b$, varying from 1 to 12, arrives at the beginning of each $T$ minutes slot. The first set appointment time of the day is zero ($A_1 = 0$) and other times at $A_i$ th time. The second schedule is similar to the first but priority is given to the patients who take shorter times for consultation with doctors. Set patients takes shorter processing time in the first part of the session, then the patients take average processing time and finally the patients take longer processing time. The third schedule includes a buffer period of one hour to the existing system where no patients have appointed times. The fourth schedule sets the walk-ins slot at 1:00 to 2:30 pm to the existing system.

The fifth AS is the Baily-Welch rule as $k$ of the $A_i = A_{i-1} + \mu_t + k\sigma_t$ set to zero and $A_1=A_2=0$. The next two schedules set $k$ to 0.1 and 0.2 by delaying the appointment time of the third patient to rest of the patients. Schedules 8, 9 and 10 are assigned four patients at the beginning of the session to the previous schedules 5, 6, and 7. In schedule 11, two patients are appointed at a time with an interval of twice the average consultation time. Schedules 12 and 13 modify the individual appointment system by setting the schedule time slightly early for patients after the first patient using $k > 0$. The individual appointment system is introduced at schedule 14. Schedules 15 and 16 set $k$ to 0.1 and 0.2 by delaying the arrival from the second patient to rest of the patients. AS 17 calls patients individually and it delays arrivals after the first patient, assigning two different $k$ times for a pair alternatively. $B$ is the number of patients set as a pair. Schedules 18, 19, and 20 delay the arrival time of the second, third, and fourth patients as set in schedules 8 and 10 from 0 to $k_2$, $k_3$, and $k_4$ times respectively.

The user can enter the variables unique to each schedule such as $\sigma$, $k$, $B$, and no-show rates via the user form designed in VBA. The VBA updates the variables in the Arena model accordingly. For an example, Figure 9 shows such a form designed in use for schedule 17.

$T = 30$ minutes
$A_1 = 0$
$12 \geqq b \geqq 1$
$A_i = A_{i-1} + T, I > 1$
1. First come, first serve
2. Shorter processing time patients at the beginning
3. Setting a buffer slot
4. Setting walk-ins slot at 1:00 to 2:.30 pm

$A_1 = A_2 = 0$
$A_i = A_{i-1} + \mu_t + k\sigma_t, I > 2$
5. $k = 0$
6. $k = 0.1$
7. $k = 0.2$

$A_1 = A_2 = A_3 = A_4 = 0$
$A_i = A_{i-1} + \mu_t + k\sigma_t, I > 4$
8. $k = 0$
9. $k = 0.1$
10. $k = 0.2$

11. $A_i = A_{i+1} = (i - 1)\mu_t$, $i = 1, 3, 5, \ldots$

$A_1 = 0$
$A_i = A_{i-1} + \mu_t - k\sigma_t, I > 1$
12. $k = 0.1$
13. $k = 0.2$

$A_1 = 0$
$A_i = A_{i-1} + \mu_t + k\sigma_t, I > 1$
14. $k = 0$
15. $k = 0.1$
16. $k = 0.2$

$A_1 = 0$
$A_i = A_{i-1} + \mu_t + k_1\sigma_t, I > 1$ ....*(1)*
$A_i = A_{i-1} + \mu_t + k_2\sigma_t, I > 1$ ....*(2)*
17. $k_1 = 0.1$, $k_2 = 0.5$, $B = 5$

$A_1 = 0, A_2 = k_2, A_3 = k_3, A_4 = k_4$
$A_i = A_{i-1} + \mu_t + k\sigma_t, I > 4$
18. $k_2 = 2, k_3 = 2.5, k_4 = 3, k = 0$
19. $k_2 = 0.5, k_3 = 1, k_4 = 1.5, k = 0$
20. $k_2 = 2, k_3 = 2.5, k_4 = 3, k = 0.2$

$\mu_t$ : Average Consultation Time, $\sigma_t$ : Standard Deviation of Consultation Time

Figure 8: Appointment Schedules

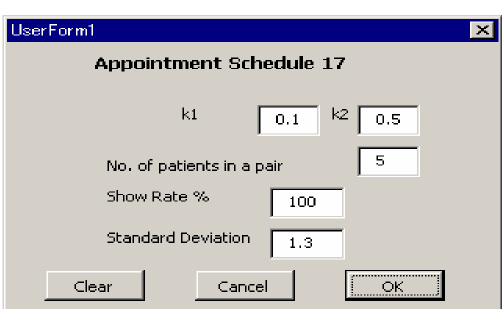



Figure 9: User Form of Schedule 17

The scatter diagram in Figure 10 displays the results after integrating APWT and ADIT in each schedule. Accordingly, schedule 4, which had walk-ins as the slot, reduces both APWT and ADIT drastically.

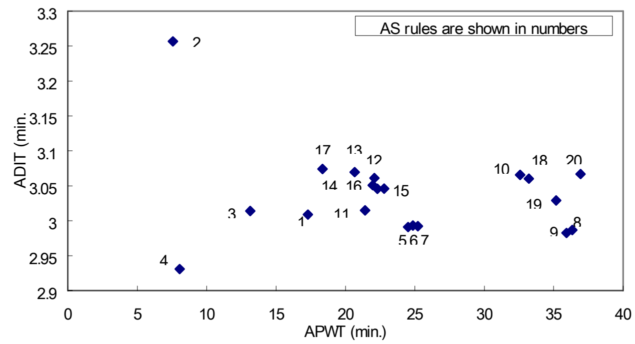



Figure 10: Scatter Diagram for APWT and ADIT

By incorporating the walk-ins at the time slot of 1:00-2:30 pm, these new schedules (from 5 to 20 in the Figure 8) were run and the results of all schedules shown in Figure 11.

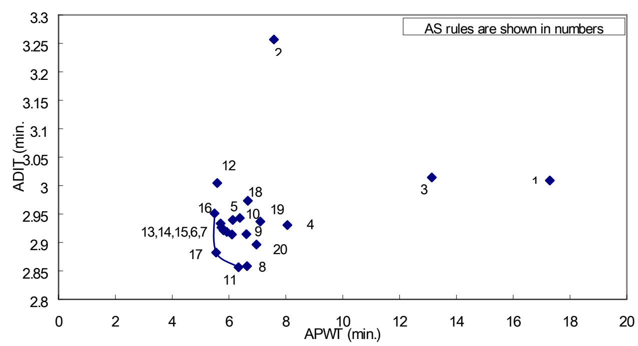



Figure 11: Efficient Frontier

An efficient frontier is derived by integrating APWT and ADIT in each case as depicted in Figure 11. This "efficient frontier" moves from the upper left to the lower right. Points on upper left raise ADIT and those on the lower right raise APWT. Accordingly, AS 11, AS 17, and AS 16 are efficient, as they lie on the frontier due to the proper placement of walk-ins arrival. Interestingly, AS 2, which recorded a remarkable reduction of APWT, shows up far from the origin due to increased ADIT. Again, the results of the existing system (AS 1) display the highest APWT, which is a common feature in many outpatient departments.

The next step is to plot a graph of waiting patients in consultation rooms via the best schedules identified in the study. Figure 12 illustrates the number of waiting patients in consultation rooms in relation to the time of day that compares the best schedules with existing schedule.

A more flattened line depicts the number of waiting patients in consultation rooms for the best cases identified in this study. Considering the total number of patients waiting for a day, all three types of patients show a great reduction. Based on AS 11, the percentage of reduction of the number of waiting patients in consultation rooms for each type was 32%, 74% and 97% for appointed, walk-ins and exam patients respectively. As a result of this, the total number of patients waiting for consultation for a day was reduced from a hundred and fifteen to fifty five, a 52 percent reduction compared to the existing system. This AS could reduce the total number of patients waiting for consultation at a peak time, from twenty-five to six, a 74 percent reduction compared to the existing system.

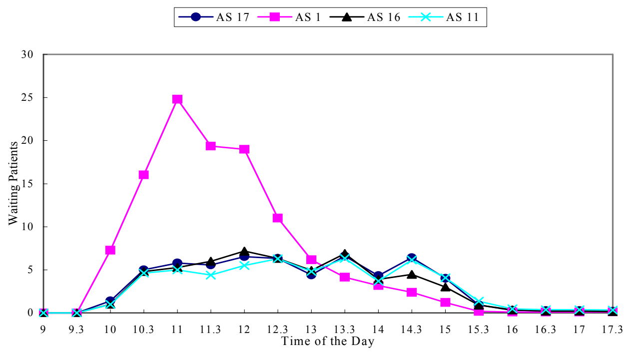


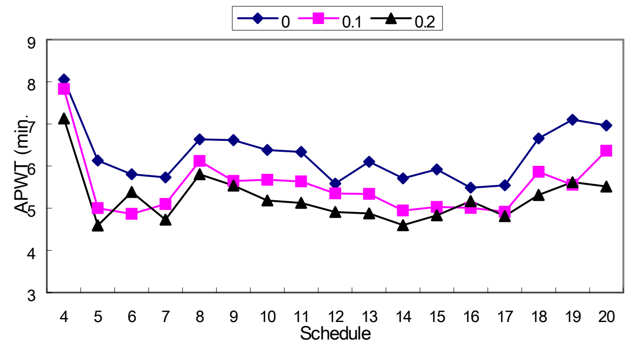

Figure 12: Best Schedules vs. Existing Schedule

## 5.2 Effects of Environmental Factors

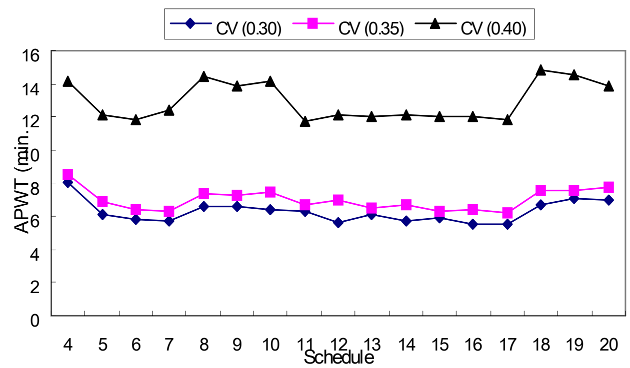
One of major objectives of this study is to identify the degree of sensitivity of performance of ASs under realistic environmental factors. A number of environmental factors have been explored in the literature of appointment scheduling but in this study only a few factors such as no-show, variance of consultation time, and variation of walk-ins, were considered as shown in Figure 13. ASs 1, 2, and 3 are not taken into consideration in this study here due to inferior results obtained in the previous analysis.

One of the factors taken into consideration, no-show, does not directly relate to the schedule, yet, it keeps doctor from being idle. On the other hand, features such as "inventory effect" of the schedule, walk-ins, and second time consulting patients can utilize idle time effectively. According to the literature, no-show rate deviates from 5% to 20% and Brahimi and Worthington (1991) found empirically that about 10 percent of patients do not show up. The impact of no-show in each schedule on APWT is illustrated in Figure 13 (a).

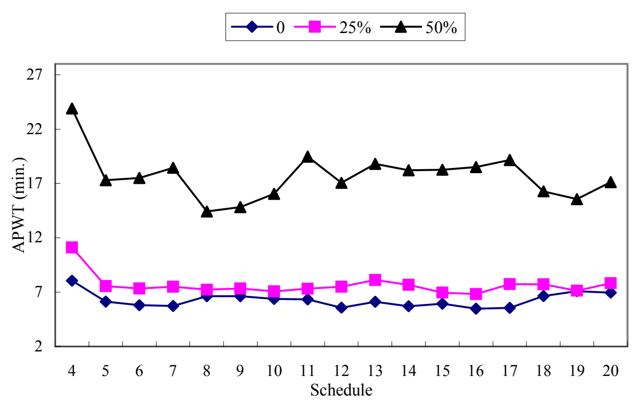
It is observed that ASs 5 and 7, which places 2 patients at the beginning have the lowest APWT with more no-shows. AS 6 outperforms at 0.1 rather than at 0.2 no-show rates. On the other hand, the variability of APWT is minimal for AS 16. As expected, the general patient-waiting time has been lightened with more no-shows because of the availability of open sessions for almost all schedules.




(a) Effect of No-show on ASs




(b) Effect of CV on ASs




(c) Effect of Walk-ins on ASs

Figure 13: Effect of Environmental Factors

Second, the service time variability was measured using coefficient of variation (CV). Generally speaking, high service variability creates excessive waiting time. The results are provided in Figure 13 (b).

Figure 13 (b) does not show a significant difference among each schedule except one minor exception. ASs 11 and 15 work well in both CV of 0.3 and 0.35. Surprisingly, a small fractional increment of CV from 0.35 to 0.4 worsens the performance for almost all schedules, which occurs over 5-time increments compare to the changed CV.

The last part of the experimentation was devoted to exploring the impact of walk-ins on APWT that have not been a subject in the studies of appointment scheduling. In servicing a walk-in, it directly has an effect on the waiting time of subsequent appointment patients. This is an important issue in outpatient departments, as seasonal fluctuations occurred due to seasonal deceases.

As in Figure 13 (c), ASs 8, 9, and 10 perform well with growing walk-ins. This may be due to the fact of "inventory effect" of the schedules that appoint four patients at the beginning of the session. According to this figure, more frequent walk-ins keep patients in queues for excessive time periods.

## 6 CONCLUSIONS

A simulation model was developed to examine a number of different appointment schedules on mixed-patients types in the outpatient department of internal medicine in a general hospital. Results show that under the existing system, patients have to wait for a long time for consultations that only last for a few minutes. The experimentation processes concentrated on this issue aiming to shorten waiting time of patients by keeping the idle time of doctors as low as possible.

For the purpose of validating the model and conducting experiments in bottleneck situations at a consultation rooms of the existing system, a special-purpose data-generator is designed. It can be observed that the changes of patient mix is highly sensitive to performances of the consultation rooms.

First, three efficient ASs were identified in terms of idle time of both patients and doctors among twenty ASs. Second, the impact of three realistic environment factors such as no-shows, variance of consultation time, and variation of walk-ins on different ASs were examined. In conclusion, though there is no single dominant AS, it appears that most of the ASs are specific to the three environments.

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## REFERENCES

Baily, N. T. J. 1952. A study of queues and appointment systems in hospital out-patient departments, with special reference to waiting-times. *Journal of the Royal Statistical Society* 14 (2): 185-199.

Brahimi, M. and D. Worthington. 1991. Queuing models for out-patient appointment systems – a case study. *Journal of the Operational Research Society* 5 (1): 91-102.

Chung, M. K. 2002. Tuning up your patient schedule. *Family Practice Management* 41-45. Available via <www.aafp.org/fpm/20020100/41tuni.html> [accessed January 4, 2005].

Fries, B. E. and V. P. Marathe. 1981. Determination of optimal variable-sized multiple-block appointment systems. *Operations Research* 29 (2): 324-345.

Guo, M., M. Wagner, and C. West. 2004. Outpatient clinic scheduling – a simulation approach. In *Proceedings of the Winter Simulation Conference*, ed. R.G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters, 1981-1987. Washington, D.C. Available via <www.informs-cs.org/wsc04papers/265.pdf> [accessed February 4, 2005].

Harper, P. R. and H. M. Gamlin. 2003. Reduced outpatient waiting times with improved appointment scheduling: a simulation modelling approach. *OR Spectrum* 25: 207-222.

Ho, C. and H. Lau. 1992. Minimizing total cost in scheduling outpatient appointments. *Management Science* 38 (2): 1750-1764.

Ho, C. and H. Lau. 1999. Evaluating the impact of operating conditions on the performance of appointment scheduling rules in service systems. *European Journal of Operational Research* 112: 542-553.

Isken, M. W., T. J. Ward, and T. C. McKee. 1999. Simulating outpatient obstetrical clinics. In *Proceedings of the Winter Simulation Conference*, ed. P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 1557-1563. Piscataway, New Jersey. Available via <www.informs-cs.org/wsc99papers/225.PDF>[accessed January 12, 2005].

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

Klassen, K. J. and T. R. Rohleder. 1996. Scheduling outpatient appointments in a dynamic environment. *Journal of Operations Management* 14 (2): 83-101.

Klassen, K. J. and T. R. Rohleder. 2004. Outpatient appointment scheduling with urgent clients in a dynamic, multi-period environment. *International Journal of Service Industry Management* 15 (2): 167-186.

Rohleder, T. R. and K. J. Klassen. 2000. Using client-variance information to improve dynamic appointment scheduling performance. *Omega* 28: 293-302.

Soriano, A. 1966. Comparison of two scheduling systems. *Operations Research* 14 (3): 388-397.

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. Available via <www.informs-cs.org/wsc03papers/207.pdf> [accessed January 12, 2005].

Takakuwa, S. and H. Shiozaki. 2004. Functional analysis for operating emergency department of a general hospital. In *Proceedings of the 2004 Winter Simulation Conference*, ed. R. G. Ingals, M. D. Rossetti, J. S. Smith, and B. A. Peters, 2003-2011. Washington, D.C. Available via <www.informs-cs.org/wsc04papers/268.pdf> [accessed January 12, 2005].

Vissers, J. and J. Wijngaard. 1979. The outpatient appointment system: design of a simulation study. *European Journal of Operational Research* 3: 459-463.

Welch, J. D. 1964. Appointment systems in hospital outpatient departments. *Operational Research Quarterly* 15 (3): 224-237.

Wijewickrama, A. K. A. 2004. Optimum number of parking spaces in a hospital: a simulation analysis. *International Journal of Simulation Modelling* 3 (4): 132-141.

Worthington, D. and M. Brahimi. 1993. Improving outpatient appointment systems. *International Journal of Health Care Quality Assurance* 6 (1): 18-23.

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