北京

International Conference
on Industrial Engineering and Systems Management

IESM 2007
May 30 - June 2, 2007
BEIJING - CHINA

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Maximizing Utilization of Consultation Rooms at the Hospital Clinics *

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Abstract

This paper aims to find the optimal arrangement of consultation rooms in the specialist outpatient clinics of a hospital in Singapore to maximize the utilization factor. Doctors' utilization and waiting time of the patients were also optimized in this research. This was done by building and validating queuing and simulation models to predict and model the real life variance and uncertainty in the outpatient clinics. The results from the queuing theory served as a good gauge to compare the simulation results to confirm the validity of the model.

Key words: simulation, health services, optimal utilization.

1 Introduction

* With escalating healthcare costs, hospitals seek ways to contain costs, improve efficiency and provide quality healthcare services. Hospitals have traditionally emphasized breakthroughs in operating procedures and technology for surgical care to stay competitive. As competition among hospitals continues to intensify, however, patients may perceive little difference in the procedures and technology used by different hospitals. Consequently, hospitals are beginning to understand that process reengineering could be another strategy to achieve competitive advantage. In recent years, with a considerable increase in the movement of healthcare from in-patient cases to outpatient cases, specialist outpatient services have become an essential component in healthcare [32]. In specialist outpatient clinics of Singapore, the long waiting times in consultation rooms have been a major concern of patients.

Time is a scarce commodity to someone seeking treatment at the hospital, particularly those who are in critical conditions. Moreover, doctors also need to maximize their time, as they do not deal with inanimate objects but with the lives and well-beings of other human beings. This is especially so in a large hospital where doctors are involved with administrative work, reading reports, etc. and are constantly moving between departments. On the flip side of the value chain are the patients who are waiting for the doctors to attend to them. Waiting idly in the waiting room is certainly very unproductive as they could be back at home recuperating or even back at their jobs. Therefore, a delicate balance between the scheduling of patients' appointments and the availability of clinicians needs to be obtained for the optimum utilization of both the clinicians' and patients' time. Here, the consultation room utilization is defined as the percentage of total consultation rooms occupied by the clinicians per day. This study aims to find the optimal arrangement of consultation rooms in the specialist outpatient clinics of Tan Seng Hospital (TSH) of Singapore to maximize the utilization factor. Doctors' utilization and waiting time of the patients were optimized by building simulation models. The data was obtained thru the observation of patient flows, collection of arrival, consultation data and discussions with the clinic staff. The paper also describes the case study undertaken to validate the queuing and simulation models.

This research project was done in conjunction with the National Health Group (NHG) of Singapore. Under the group there are 4 hospitals, 1 National Center, 9 NHG Polyclinics and 3 Specialty Institutes. This paper is organized a follows. In section 2 a brief literature review is given. In section 3 a case study is described. Section 4 provides the data analysis and simulation, while results and discussion are given in section 5. Finally, section 6 draws conclusions.

2 Literature review

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Clinic scheduling problems are frequently encountered in the literature. Recently, a good bibliographic survey on medical staff rostering problems has appeared [12]. Several studies have utilized mathematical programming techniques to assist in finding efficient staff schedules [5],[8],[11]. Callahan [10] has highlighted the effects of problem-based scheduling on patient waiting and staff utilization of time in a pediatric clinic. Further, Hariharan et al [15] have evaluated the utilization of the clinics in a university teaching hospital. Numerous previous studies have been carried out to improve the efficiency of scheduling in health care systems [14],[19],[22],[26],[31]. Queuing theory and simulation strategies have been widely employed in many areas of healthcare such as emergency care center planning [23] waiting lists for transplants and surgery [34],[25],[30]. Staffing needs of whole hospitals [2] and even regional healthcare planning [13] have been modeled using queuing theory. However, in this paper we focus on the application of queuing models to an outpatient-appointment environment.

Previous research has sought to balance between the patient's waiting times with the clinicians in an outpatient environment. A large percentage of research in this area has assumed that a physician's time is more valuable compared to a patient's. Hence the main consideration in improving efficiency of the scheduling of appointments is to not keep the doctor waiting before the next patient arrives. Quite a number of papers have been based on the pioneer work of Bailey [7] using mathematical and operational techniques such as queuing theory [9],[17], simulation [1],[6],[16],[20],[28] and soft systems modeling. Recently, Wijewickrama [32] has addressed the problem from the points of staff scheduling and reducing queues in mixed patients' outpatient department.

Due to the highly complex nature of medical clinics where the different patients require varying modes of treatment, it would be appropriate to utilize a flexible optimization method such as simulation which can represent each patient type's distinct needs and flows, at the same time taking into account the arrival patterns, the variance in length of treatment and consultations and exit patterns. Anderson et al [3], Levy et al [21], Rauner [27], Kumar et al [18] and Wijewickrama [32] illustrate the use of simulation for improving hospital facility design, staffing and scheduling and to reduce patient wait times and operating costs. Simulation can provide the opportunity to evaluate different alternatives at substantially lower costs with fewer risks. For example, Arvy and Morin [4] use simulation to study the effects of staffing adjustments on patient throughput within a clinic. Wilt et al [33] show that simulation can provide significant insight in a study of optimal staffing and facility design of an outpatient clinic.

Many variables are present in a real-life operation of medical clinics that needs to be considered, such as the varying activities carried out in the clinics. The developed models also need to be used by the clinic staff themselves as a scheduling and resource management tool. Therefore, this study proposed a better resource allocation arrangement by showing how a simulation model can be applied to outpatient medical clinics that handle both scheduled and walk-in patients, and recommends the most feasible solution to this particular situation.

2.1 Computer simulation with ARENA™ software

Arena™ simulation software is a powerful operations simulation tool. This software has a host of peripheral analysis tools such as the "Input Analyzer". It is able to assist users sort raw data collected from real-life situations and produce the best-fit distribution for the given values. The components of a simulation environment are: Entities, Attributes, Variables, Resources, Queues, and Statistical Accumulators. There are also non-essential components that can help users to best model a system.

3 Case study

The Tan Seng Hospital (TSH), established in 1844, is the second largest hospital in Singapore, with specialty centers dealing with Rehabilitation Medicine and Communicable Diseases. The hospital possesses state-of-the-art facilities and medical equipment, and also the latest communication and information technology tools. Within the hospital there are 18 Clinical Specialties ranging from Cardiology to Infectious diseases and 12 Allied Health Services [29]. To effectively optimize a real-life situation such as specialist outpatient clinics in TSH, an in-depth case study and analysis was carried out. The structure and characteristics within the two clinics of TSH were involved in this investigation. Staff of both clinics collected the data in September 2004. The different types of patients at the clinics were classified as described in Table 1.

3.1 General medicine (GM) specialist outpatient clinic

This outpatient clinic (SOC) of TSH focuses on Multi-system Illnesses, Undifferentiated Medical Problems, Hypertensions & Lipids Obstetric Medicine, Vascular Medicine, Haematology and Palliative Care. The Clinic is subdivided into subsections that deal with Critical Care & Respiratory Medicine and Digestive Diseases. The GM clinic has 2 registration counters: an automated one for repeat patients, and other one is manned by a counter staff. There are 16 consultation rooms and 2 subspecialty rooms used for Gastric Motility tests and the Breast Care Nurse. There are two payment counters located near the waiting area serviced by one cashier each. Further, there are 3 main queues within the clinic, the registration, the consultation and the payment queues. Only at the registration counter is there a physical queue where patients wait in line. The consultation queue is operated using queue numbers given at the registration counters and number displays outside the doctor's rooms. The payment queue number is different from the consultation queue. The patients awaiting payment wait at the main waiting area where they sit until they are serviced.

A total of 336 patients that attended the GM SOC were surveyed in a 5-day work-week during September 2004 by clinic staff. Out of these, a large percentage (78%) of them were Repeat cases, which had previously visited the clinic. The majority of patients was under the Subsidized payment scheme (86%) and did not require other procedures (81%) such as blood tests and X-rays. The detailed breakdown is shown in Table 2.

Table 1: Patient Classification

Type	Classification	Description
N	New	New cases that have no prior consultation in clinic(walk-in)
R	Repeat	Patients that have prior consultation in the clinic
S	Subsidized	Patients whose medical fees are subsidized by government funding
P	Private	Patients who pay the full fees incurred in for treatment
Walk-In Classifications		
1	Inpatient	Patient already warded in the hospital
2	Outpatient – Requested	Patient's request for consultation in clinic
3	Outpatient – Advised	Patient advised by Doctor for consultation in clinic
4	Emergency	Same day referral from Emergency Department

3.1.1 Appointments

As the patients were given appointment times before consultation, even for new cases, appointments were a good gauge of the usage of the facility. GM generally had peak hours from 0900 to 1200 hours and 1400 to 1600 hours where the patient appointments were the highest. The clinic was closed for lunch at 1300-1400 hours. There was a peak day on Monday (153 patients) and a sharp dip in appointments on Tuesday (53 patients). On Wednesday there was another up-swing of appointments (93 patients) and then Thursday (25 patients) and Friday (21 patients) were the 'off-peak' days.

3.1.2 Specialist doctors available

The number of specialist doctors available reflects the number of appointments on that weekday, as seen from Figure 1. There is also a peak on Mondays (17 specialist doctors), then a dip on Tuesday (5 specialist doctors), slight increase on Wednesday (8 specialist doctors) and low period on Thursday and Friday (4 specialist doctors and 3 specialist doctors respectively).

3.1.3 Consultation rooms utilization (CRU)

The Consultation Room Utilization (CRU) is calculated from the number of consultation rooms occupied by the specialist doctors per day over the total number of consultation rooms. Though this method has its inaccuracies, it is hard to quantify strictly how much of the consultation room is utilized down to the minute. This is due to specialist doctor's involvement in administrative work, pre-consultation preparation (i.e. reading of medical reports, X-rays) and other related work in the room. As seen from the data (Figure 2) the CRU is 100% on Monday and rather low on the other days (53% and below).

Table 2: GM Patient Types

GM Patient Types (SEP)			
Type	Number	Percent	Description
N	74	22%	New
R	262	78%	Repeat
Payment Scheme			
P	46	14%	Private
S	290	86%	Subsidized
Procedure			
Y	65	19%	Required
N	271	81%	Not Required

3.2 Rheumatology, allergy & immunology (RAI) specialist outpatient clinic

The RAI Clinic of the TSH mainly has two areas of focus: Rheumatology, and Clinical Immunology/Allergy. Rheumatology deals in the diagnosis and management of the following disorders: Arthropathies, Connective Tissue Diseases, Soft Tissue Rheumatism, and Rheumatic Diseases. Clinical Immunology/Allergy handles the diagnosis and management of the following problems: Drug, Food, and Insect Venom Allergies, Anaphylaxis, Urticaria & Angioedema, Allergic Rhinitis & Asthma, Atopic Eczema, and Investigations. Only 2 registration counters are in operation due to lower number of patients. There are 2 payment counters and 9 consultation rooms. Similar to the GM clinic, there are 3 main queues within the clinic. Although the overall operation of the clinic varies with GM, the main flow of patients is similar. The data reflects the high proportion of patients that do not require procedures within the clinic. Therefore, a similar simulation model is built for the two clinics with differing input conditions.

3.2.1 Patient types

A total of 212 patients that attended the RAI clinic were surveyed in a 5-day work-week in September 2004 by clinic staff. Out of these, almost all (97%) of them were Repeat cases, which have previously visited the clinic. The majority of patients were under the Subsidized payment scheme (67%) and did not require other procedures (70%) such as blood tests and X-rays. The detailed breakdown is shown in Table 3.

3.2.2 Appointments

The peak hours for RAI in September were generally 0900-1200 and 1400-1600, especially for the high volume days. However, on some days (Wed and Thu) the clinic does not have patients after 1300 hours, and on Friday there were no patients. Mondays (74 Patients) are the peak days and the patient volume decreases as the days progress. The low day is on Friday with no patients at all.

Table 3 : RAI Patient Types

RAI Patient Types (SEP)			
Type	Number	Percent	Description
N	7	3%	New
R	205	97%	Repeat
Payment Scheme			
P	69	33%	Private
S	143	67%	Subsidized
Procedure			
Y	63	30%	Required
N	149	70%	Not Required

3.2.3 Doctors available

The daily availability of doctors in RAI also reflects the patient volumes in the week. As seen from Figure 3, the peak day on Monday corresponds with the peak of appointments on Mondays, and number of doctors progressively drops. Similarly, the RAI Doctors available also reflects the patient volumes with Mondays not having any doctors and peaking on Tuesdays.

3.2.4 Consultation rooms utilization (CRU)

The CRU for the RAI clinic is rather low on most days, and even on the peak days, the utilization only reaches 67%. The average utilization is only 33% (Figure 4). A patient enters the consultation room only when a clinician is available.

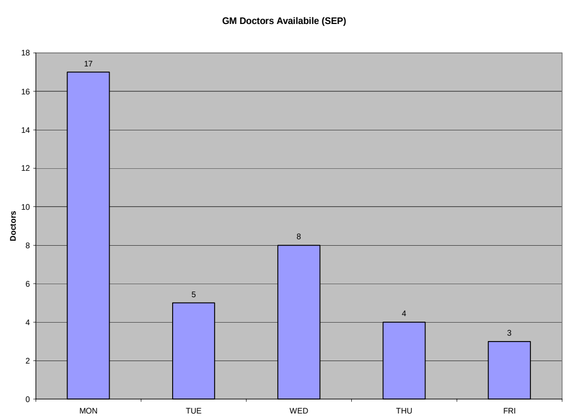


Figure 1: GM Specialist Doctors Available

4 Data analysis and simulation

The individual patient's data were analyzed through the Input Analyzer in the Arena™ Simulation software. The program then produced the best-fit distribution of the data. With the best-fit distribution, the multi-server situation in the outpatient clinics was modeled and simulated.

GM Inter-arrival Time Data

The GM Inter-arrival time is exponentially distributed with a mean of 4.6 minutes. The curve fit from the Input Analyzer (Figure 5) is shown below.

GM Service Time Data

The GM service time is Erlang distributed. The curve fit from the Input Analyzer (Figure 6) is shown below. The service time distribution is Erlang and has a mean of 11.7 minutes, with standard deviation of 6.64. The square error value is 0.0661 and χ^2 goodness of fit p-value is greater than 0.005. The distribution has a square error of 0.0828 when fit into an exponential distribution.

RAI Inter-arrival Time Data.

The RAI Inter-arrival time is also exponentially distributed with a mean of 7 minutes. The curve fit shape is very similar to Figure 5.

RAI Service Time Data.

The RAI service time is Erlang distributed with a mean of 13 minutes and std. dev. of 5.73.. The service time curve fit shape is very similar to Figure 6.

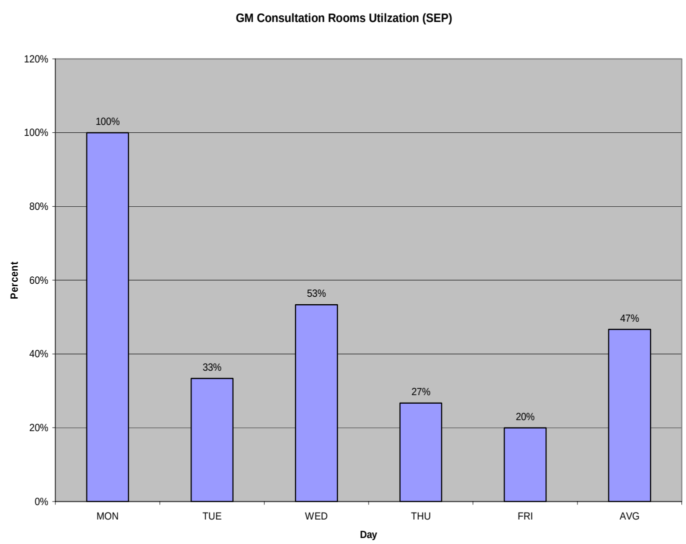


Figure 2: GM Consultation Rooms Utilization

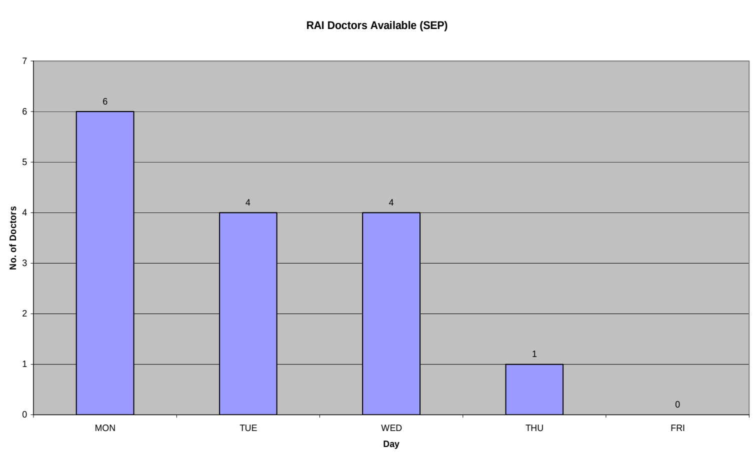


Figure 3: RAI Doctors Available (SEP)

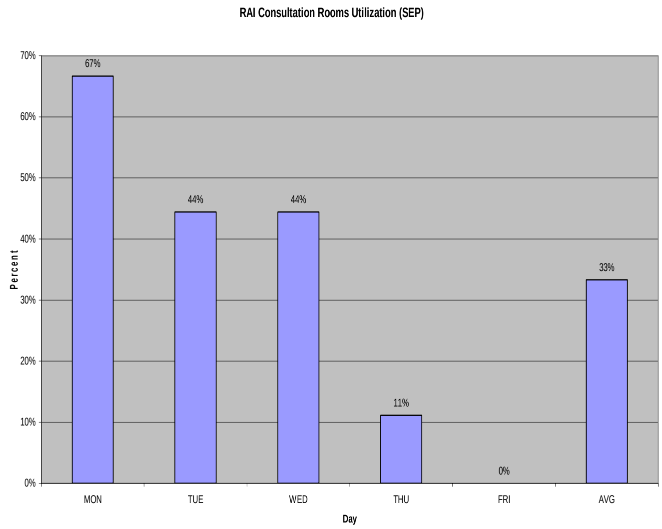
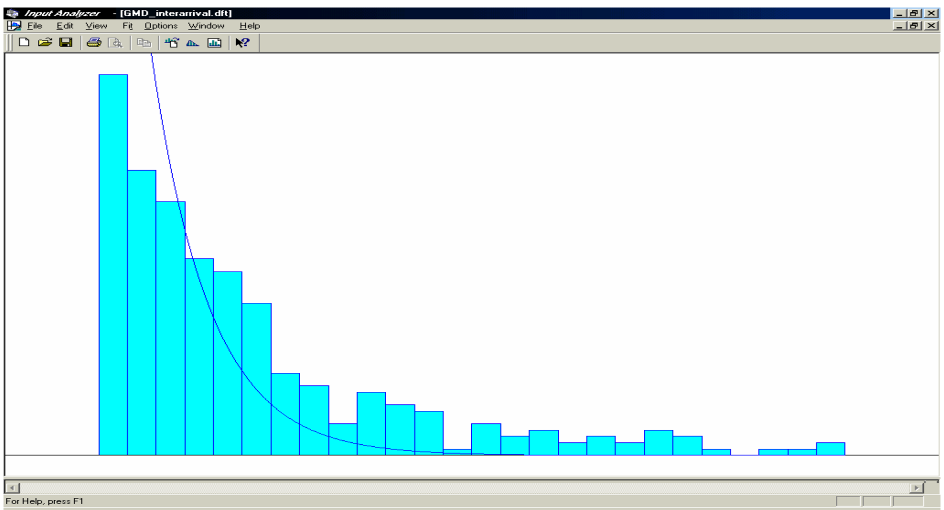
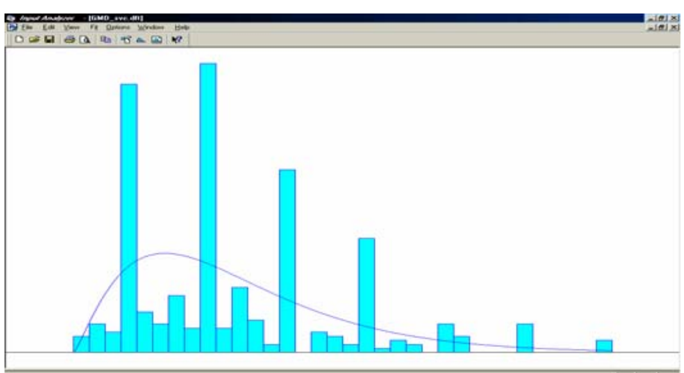


Figure 4: RAI Consultation Rooms Utilization



Inter-arrival Time (in minutes)

Figure 5: GM Inter-arrival Time Curve Fit



Service Time (in minutes)

Figure 6: GM Service Time Curve Fit

4.1 Simulation

After obtaining the Interarrival and the Service times, the simulation model was developed on the *main* patient flow where the patients *arrive*, *register*, *queue* for consultation, *sees the doctor*, *pays* and *exits*. The arrival rates and other data are entered into the model to mimic actual operations in the clinics. The number of doctors is varied for different runs and the results are compared with queuing theory results.

5 Results and discussion

The results from queuing models and the values obtained from the simulation are compared. The queuing theory results and the actual data serve mainly to confirm the validity of the simulation. The simulation, once verified, was used to compare the utilizations of the doctors and the consultation rooms with the time patients spend waiting in the queue. Thus, with this information, the resources in the clinic were optimized to reach the optimum operation point. The number of servers was varied to obtain the different indicator values as the doctors in the clinic changed (3 to 8 doctors). The range of 3 to 8 doctors is chosen because from the case study data, this is the range, which both clinics are most often operating in.

The model was run for a simulation period of 120 hours to model an 8 hours, 5-day work- week with an additional 8 hours for and to make sure that the simulation reaches steady-state. The number of doctors was varied for each run, a total of 5 runs were carried out (also 3 to 8 doctors). There are three main indicators that were used in the verification between the queuing theory and simulation; they are *Waiting time in queue, Number in queue and Average Server Utilization.*

5.1 GM Clinic results

The GM Clinic results were calculated using exponential Inter-arrival distribution and exponential service for the M/M/s model and Erlang service time in the simulation.

Average Waiting Time in Queue

The average waiting time trend of the consultation room queue can be seen from Table 4. The waiting time results from the queuing theory and simulation are very close to each other, with a maximum difference of only 3.98 minutes (3 doctors).

Table 4: GM Average Waiting Time

GM Waiting Time Results (minutes)			
Doctors	Queuing Theory	Simulation	Difference
3	18.54	14.56	3.98
4	2.64	1.82	0.82
5	0.66	0.54	0.12
6	0.18	0.12	0.06
7	0.04	0.03	0.01
8	0.012	0.01	0.002

Average Number in the Queue

Looking at the average number of patients waiting in the consultation queue, Table 5 shows results for the average number in queue. Once again the difference is slight, with only the 3 doctors' case where the number of patients in queue differs by 1.06 patients the other cases differ by 0.32 or less patients.

Table 5: GM Average Number in Queue

GM Number in queue (patients)			
Doctors	Queuing Theory	Simulation	difference
3	4.027	2.961	1.066
4	0.582	0.262	0.32
5	0.142	0.134	0.008
6	0.037	0.032	0.005
7	0.009	0.007	0.002
8	0.0002	0.0003	-0.0001

Average Server Utilization

The difference between queuing theory and simulation in average server utilization is even lower. As seen from Table 6, the values from queuing theory and the simulation are almost identical, with maximum difference of only 0.0282 (6 doctors).

Table 6: GM Average Server Utilization

	Average Server Utilization			**Consultation Room Utilization (CRU)**
Doctors	Queuing Theory	Simulation	difference	Simulation
3	0.847	0.854	0.007	0.160
4	0.635	0.629	-0.006	0.157
5	0.508	0.519	0.011	0.162
6	0.423	0.451	0.028	0.169
7	0.363	0.350	-0.013	0.153
8	0.317	0.303	-0.014	0.151

Average Consultation Room Utilization (CRU)

For the average CRU of GM consultation rooms when all rooms are available, the results from the simulation show that the maximum CRU occurs when 6 doctors (0.169) are on duty, followed by 5 doctors (0.162) and 3 doctors (0.160). The trend of the CRU is not generally decreasing, with CRU hitting a peak at 6 doctors. This can be seen from last column of Table 6.

5.2 RAI Clinic results

Similar to the GM Clinic, RAI Clinic results were calculated using exponential Inter-arrival distribution and exponential service for the M/M/s model and Erlang service time in the simulation. However, the results were obtained with varying sample mean and standard deviation.

Average Waiting Time

As seen from Table 7, the average waiting time results from Queuing theory and Simulation (columns 2 to 4) are generally close to each other, with only the 3 doctors' case showing significant variation in data (0.018).

Average Number in queue.

When looking at the average number of patients waiting in the consultation queue, Table 7 also shows results for the average number in queue for RAI (columns 5 to 7). Once again the difference is small, with only the 3 doctors' case where the number of patients in queue differs by 0.157 patients the other cases differ by 0.023 or less patients.

Table 7: RAI Waiting Time Results

	RAI Waiting Time Results (hours)			**RAI Number in queue (patients)**		
Doctors	Queuing Theory	Simulation	Difference	Queuing Theory	Simulation	Difference
3	0.071	0.053	0.018	0.613	0.456	0.157
4	0.014	0.010	0.004	0.121	0.098	0.023
5	0.010	0.008	0.002	0.026	0.019	0.007
6	0.002	0.001	0.001	0.005	0.004	0.001
7	0.0007	0.0006	0.0001	0.0011	0.0008	0.0003
8	0.0001	0.0001	0.000	0.0002	0.0002	0.000

Average Server Utilization.

The average server utilization also has closely matching results as seen from the first four columns of Table 8. The maximum difference is only 0.015 (6 doctors).

Average Consultation Room Utilization (CRU)

For the average CRU of RAI consultation rooms when all rooms are available, the results from the simulation show that the maximum CRU occurs when 3 doctors (0.215) are on duty, followed by 7 doctors (0.196) and 8 doctors (0.196). This is shown in the last column of Table 8.

For GM, the 3 main indicators *Waiting Time, Number in queue* and *Average Server Utilization* all have closely matching results. This shows that the simulated result is validated by the queuing theory, also implying that the other results for the simulation are accurate and can be used for further analysis. When all rooms are available, the 6 doctors' case, the CRU (17%) is the highest and waiting time short (0.14 minutes); however, the average server utilization is low (45%). If the clinic changes its operation model and reassigns the unutilized rooms for other purposes (e.g. treatment, storage) then the CRU would equal the average doctor utilization. Therefore the number of consultation rooms used will be the same as the number of doctors. In this case, utilizing 4 doctors will be the best, with CRU and server utilization (both 63%) and waiting time (1.2 minutes).

As for RAI, the 3 main indicators *Waiting Time, Number in queue* and *Average Server Utilization* also have closely matching results. In the 3 doctors' case the CRU (22%) is the highest with the waiting time (3.15 minutes) still under acceptable limits, at the same time, the average utilization rate for doctors (60%) is the highest. This is the optimum resource allocation point for the RAI clinic when all consultation rooms are open, as it maximizes all three main indicators the CRU, waiting time and doctors' utilization. The overall CRU is slightly higher for RAI than GM due to less consultation rooms available in the former. Once again if the number of doctors equals the number of available Consultation Rooms, then the CRU would be equal to the average server utilization. The 3 doctors case will still be the best with CRU and server utilization of 60% and waiting time of 3.15 minutes.

Table 8: RAI Average Server Utilization

RAI Average Server Utilization				**Consultation Room Utilization (CRU)**
Doctors	Queuing Theory	Simulation	Difference	Simulation
3	0.618	0.604	0.014	0.215
4	0.463	0.460	0.003	0.192
5	0.370	0.365	0.005	0.187
6	0.309	0.294	0.015	0.187
7	0.264	0.257	0.007	0.196
8	0.231	0.227	0.004	0.196

6 Conclusions

The current situation in the RAI and GM clinics at TSH is that of under-utilization of resources, especially the consultation rooms. Hence, this research sought to optimize and reach a balance between the consultation room utilization (CRU), patients' waiting time and doctors' utilization. Both the queuing models and the simulation were run under a varying number of servers (Doctors) and the results tabulated for comparison. It was found that the simulation model was consistent with the queuing theory assessment for both clinics. The results from the simulation were then compared and the optimal resource allocation point for both clinics was found.

Therefore, for a significant increase in the CRU of both clinics, it is recommended for the clinic to reduce the number of consultation rooms to equal the number of doctors at any one time. This is to free up the consultation rooms for other purposes so that they can be better utilized (i.e. for treatment or additional storage). However, the use of the consultation rooms must be flexible to accommodate future increases in patient volumes, so that when there are higher volumes than usual, the clinic can adapt appropriately. Hence, the GM and RAI clinics need 4 and 3 doctors, respectively. This would increase the CRU from 47% to 63% for GM and 33% to 60% for RAI. Therefore this solution provides a significant increase in server utilization, and CRU.

7 References

[1] Aharonson-Daniel L., Paul R.J. and Hedley A.J. (1996). "Management of queues in out-patient departments: the use of computer simulation", *Journal of Management in Medicine 10,* 50-58.

[2] Agnihothri S.R. and Taylor P.F. (1991). "Staffing a centralized appointment scheduling department in Lourdes Hospital", *Interfaces 21,* 1-11.

[3] Anderson J.G., Harshbarger W., Weng H.C., Jay S.J. and Anderson M.M. (2002). "Modeling the costs and outcomes of cardiovascular surgery", *Health Care Management Science 5(2),* 103-111.

[4] Arvy C. and Morin J. (1979). "Improving patient access and service in regional OB/GYN out-patient clinics", *Proceedings of the HIMSS 1997 Winter Simulation Conference*, 7-9.

[5] Azaiez M.N. and Al-Sharif S.S. (2005). "A 0-1 goal programming model for nurse scheduling", *Computers and Operations Research 32*, 491-507.

[6] Babes M. and Sarma G. (1991). "Outpatient queues at the Ibn-Rochd health center", *Journal of the Operational Research Society 42,* 845-855.
[7] Bailey N.T.J. (1952). "A study of queues and appointment systems in hospital out-patient departments, with special reference to waiting times", *Journal Royal Statistical Society 42,* 845-855.
[8] Bard J.F., Binici C. and deSilva A.H. (2003). "Staff scheduling at the United States postal service", *Computers and Operations Research 30,* 745-771.
[9] Brahimi M. and Worthington D.J. (1991). "Queuing models for outpatient appointment systems: a case study", *Journal of the Operational Research Society 42,* 733-746.
[10] Callahan N.M. and Redmon W.K. (1987). "Effects of problem-based scheduling on patient waiting and staff utilization of time in a pediatric clinic", *Journal of Applied Behavior Analysis 20(2),* 193-199.
[11] Caprara A., Monaci M. and Toth P. (2003). "Models and algorithms for a staff scheduling problem", *Mathematical Programming 98,* 445-476.
[12] Cheang B., Li H., Lim A. and Rodrigues B. (2003). "Nurse rostering problems- a bibliographic survey", *European Journal of Operational Research 151,* 447-460.
[13] De Vries T. and Beekman R.E. (1998). "Applying simple dynamic modeling for decision support in planning regional health care", *European Journal of Operational Research 105,* 277-284.
[14] Grumbach K., Keane D. and Bindman A. (1993). "Primary care and public emergency department overcrowding", *American Journal of public Health 83(3),* 372-378.
[15] Hariharan S., Chen D. and Merritt-Charles L. (2006). "Evaluation of the utilization of the preanaesthetic clinics in a university teaching hospital", *BMC health Services Research 6,* 59.
[16] Harper P.R. and Gamlin H.M. (2003). "Reduced outpatient waiting times with improved appointment scheduling: a simulation modeling approach", *OR Spectrum 25,* 207-222.
[17] Hsieh P.J, Tan B. and Lin C. (2003). "An integrated approach to determine hospital outpatient staffing needs", *International Journal of Healthcare Technology and Management 5,* 96-122.
[18] Kumar A. and Shim S.J. (2006). "Simulating staffing needs for surgical instrument distribution in hospitals", *Journal of Medical System 30,* 363-369.
[19] Lacy N.L., Paulman A. and Reuter M.D. (2004). "Why we don't come: patient perceptions on no-shows", *Annals of Family Medicine 2(6),* 541-545.
[20] Lehaney B., Clarke S.A. and Paul R.J. (1999). "A case of an intervention in an outpatients department", *Journal of the Operational Research Society 50,* 877-891.
[21] Levy D.T., Chaloupka F., Gitchell J., Mendez D. and Warner K.E. (2002). "The use of simulation models for the surveillance, justification and understanding of tobacco control policies", *Health Care Management Science 5(2),* 113-120.
[22] Lipscomb J., Kilpatrick K.E., Lee K.L. and Pieper K. (1995). "Determining VA physician requirements through empirically based models", *Health Service Research 29(6),* 697-717.
[23] Liyanage L. and Gale M. (1995). "Quality improvement for the Campbelltown hospital emergency service", *1995 IEEE International Conference on Systems, Man and Cybernetics. Intelligent Systems for the 21st Century 3,* 1997-2002.
[24] National Health Group (NHG) (2005). *[Online]: http://www.nhg.com.sg (December, 2005),*
[25] Naylor C.D., Levington C.M., Wheeler M. and Hunter L. Queuing for coronary surgery during severe supply-demand mismatch in a Canadian referral centre: A case study of implicit rationing Social Science & Medicine 37:61-67.
[26] Parkerton P.H., Wagner E.H. and Smith D.G. (2003). "Effect of part-time practice on patient outcomes", *Journal of General Internal Medicine 18(9),* 717-724.
[27] Rauner M.S. (2002). "Using simulation for AIDS policy modeling: benefits for HIV/AIDS prevention policy makers in Vienna, Austria", *Health Care Management Science 5(2),* 121-134.
[28] Su S. and Shih C.L. (2002). "Managing a mixed-registration-type appointment system in outpatient clinic", *International Journal of Medical Informatics 70,* 31-40.
[29] Tan Seng Hospital (TSH) (2005). *[Online] Available: http://www.ttsh.com.sg.*
[30] Wang Q. (2004). "Modeling and analysis of high risk patient queues", *European Journal of Operations Research 155*, 502-515.
[31] Welch H.G., Chapko M.K., James K.E. and Schwartz L.M. (1999). "The role of patients and providers in the timing of follow-up visits", *Journal of General Internal Medicine 14(4),* 223-229.
[32] Wijewickrama A.K.A. (2006). "Simulation analysis for reducing queues in mixed patients' outpatient department", *International journal of Simulation Modeling 5(2),* 56-68.
[33] Wilt A. and Goddin D. (1989). "Health care case study: simulating staffing needs and work flow in an outpatient diagnostic center", *Industrial Engineering 21(5),* 22-29.
[34] Zenios S.A. (1999). "Modeling the transplant waiting list:a queuing model with reneging" *Queueing Systems 31,* 239-251.