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SIMULATION MODELING AND ANALYSIS OF A MULTI-RESOURCE MEDICAL
CLINIC

By

Bo Sun

A thesis
Submitted to the Faculty of the
University of Louisville
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I also want to thank my dear friends. Their friendship makes my life sunny and colorful. They support me all the way

whatever in academic or in life. I want to thank my dear
parents for their love and understanding.

ABSTRACT

Simulation Modeling and Analyzing of a Multi-Resource
Modeling Clinic

Bo Sun

July, 6th, 2011

Healthy for Life is a relatively new University of Louisville medical clinic which attempts to stem the epidemic of childhood obesity. This program offers a range of face-to-face services for overweight children. The main problem addressed by this research is the no show rate (nearly 50%) of the clinic.

There are two goals of this thesis. One is to increase the staff utilization; the other is to decrease the waiting time. In this thesis, we study two potential methods to solve this problem. One involves using multiple resources for every visit; the other involves overbooking the patients.

Two simulation models were developed for studying the

system. One is an overbooking model in which the interarrival times are controlled for each type of patients. By increasing arrival rate of patients, the waiting time, the total number of served patients and the utilization of staff are increased. We need to trade off in order to choose the best arrival rate for the clinic

The second model involves using multiple resources for every visit. Each time a returning patient can visit one or two staff personnel depending on their willingness. We also change the interarrival time for patients in order to estimate the best values for these inputs.

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I. INTRODUCTION

In this thesis, we help the Healthy for Life Clinic in Louisville, Kentucky to solve the problem of scheduling patients in order to increase the staff utilization and decrease the patients' waiting time.

A. Background

The University of Louisville's Healthy for Life! Clinic serves the state of Kentucky's children. The University of Louisville Department of Pediatrics has partnered with Passport Health Plan, the Kentucky Chapter of the American Academy of Pediatrics (AAP), YMCA, Kosair Children's Hospital and other organizations to offer a solution. Healthy for life is a relatively new University of Louisville program which is attempting to stem the epidemic of childhood obesity (<https://louisville.edu/medschool/magazine/summer09/cover/healthy>). This program is a complete resource for

overweight children, offering a broad range of services from experts who can evaluate each child's individual needs and develop a customized treatment plan accordingly.

Body Mass Index (BMI) is a number calculated from a person's weight and height. BMI provides a reliable indicator of body fatness for most people and is used to screen for weight categories that may lead to health problems (<http://www.cdc.gov/healthyweight/assessing/bmi/>). Children with a Body Mass Index (BMI) in the 85th percentile or above are referred to this program. In addition, clinic services are free to children covered by Passport Health Plan. Services are also available to private-pay and privately-insured patients on a fee-for-service basis.

This program, which opened in June, 2009 in newly renovated space donated by Kosair Children's Hospital, features examination rooms, a counseling center, a group therapy space and a play center with treadmills, exercise bikes and other active gear. The clinic also includes a teaching kitchen where staff members offer cooking demonstrations, healthy-meal planning lessons and taste tests for parents and their children.

(<https://louisville.edu/medschool/magazine/summer09/cover/healthy>).

FIGURE 1 shows a layout of the clinic.

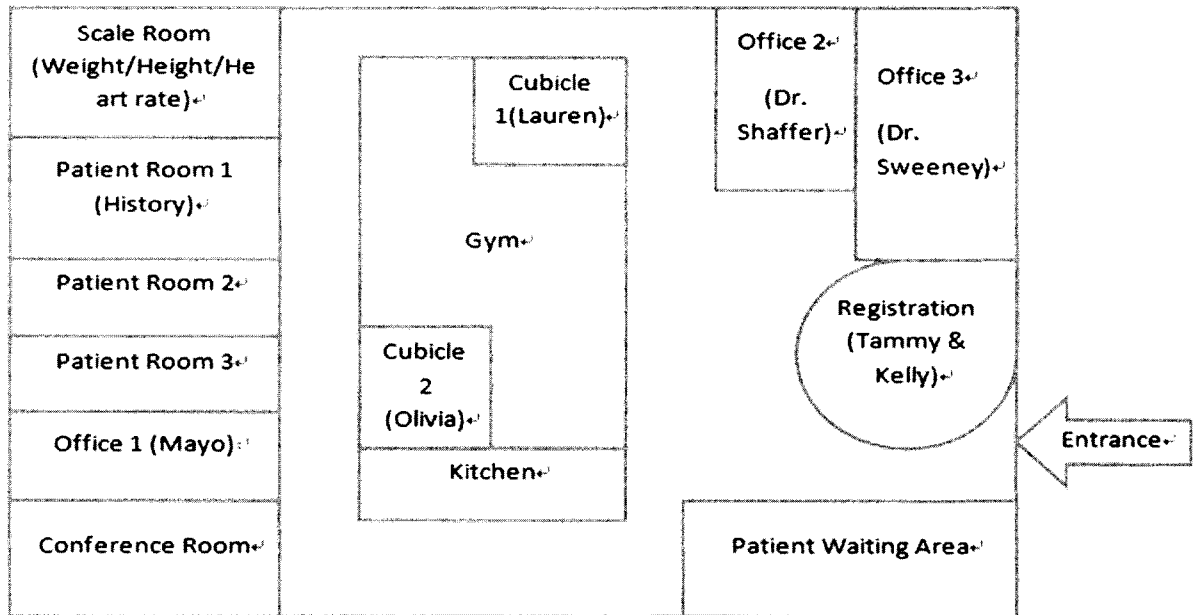


FIGURE 1 - Layout of clinic

B. Problem Statement

The basic problem addressed by this thesis involves the scheduling of the patients in order to improve the utilization of staff and decrease the waiting time for the patients. The director of the clinic found that patients who make appointments do not always show up, which means that staff in the clinic have to wait for them and cannot see other patients. The director wants to solve this problem and keep all the staff in this clinic busy. The director also wants

to decrease the waiting time for patients and keep the very sick patients "show up rate" high.

We collected data from July 2010 to August 2010, and analyzed this data to compare the show up rates between weekdays and different staff. We used this data to build a simulation model in order to estimate the utilization of staff, the waiting time for patients in the clinic, the number of patients served in one day, the total time stay in the clinic and the time when the clinic closed depending on the last patient leave clinic as a function of patient arrival rate.

C. Literature Review

C.1 Reasons for no show:

Currently, health care is a large industry that concerns everyone. The government also discusses the health care system. Most recently, President Obama signed the Patient Protection and Affordable Care Act (Stolberg, 2010). Many new medical treatments are being researched more intensely than ever. Many Industrial Engineers also do the research on health care, such as how to increase the utilization of staff and how to structure the patient's flow. Many people pay attention to how to keep

basic healthcare available to as many people as possible. Many hospitals emphasize short queue length in the waiting room and shift care from inpatient to outpatient facilities. This in turn is forcing outpatient clinical facilities to reassess their operation and capacities. (Muthurman and Lawley, 2008)

A patient no-show is a situation in which the patients make appointments with the staff in the clinic, but they do not show up for the appointment. In some clinics, up to 42% of scheduled patients fail to show up for pre-booked appointments. (Deyo and Inui, 1980). Rust and Gallups (1995) say that the problem of patient no-shows (patients who do not arrive for schedule appointments) is significant in many health care settings, where no show rates can vary from as little as 3% to as much as 80%. Vozenilek said the nationwide no-show rate is expected to be somewhere between 20% and 40% of all appointments made for medical clinic (2009).

In this thesis, the no show rate is nearly 50% which is high enough to effect the operation of the clinic. The most significant factor affecting no-show rates is the amount of time between scheduling the appointment and the appointment itself. Other statistically significant factors effecting

no-show rates are diagnosis, demographic data, geography, weather, and current financial situation of the patient (Vozenilek, 2009). Sometimes, the reason is the patients forget they have the appointment. According to the research, the longer time between the time of scheduling the appointment and the appointment itself, the more likely patients do not show up. A patient that is given an appointment that is less than a week away is more likely to show than a patient who books six months in advance (Vozenilek, 2009).

The other reason for a "no-show" is the patients' feelings and ideas. LaGanga and Lawrence (2007) says that in the clinic, almost 30% of adult patients failed to show up for their scheduled appointments with psychiatrists. In this thesis, the no show rate of the patients who are scheduled to see the psychologist is also the highest one. We need to find some methods to resolve this problem, especially for the patients who see the psychologist.

C.2 Effect of no show

No shows reduce provider productivity and clinic efficiency, increase health care costs and limit the ability

of a clinic to serve its client population by reducing its effective capacity (LaGanga and Lawrence, 2007). Muthuraman and Lawley (2006) says that patients who fail to show up for pre-booked appointments waste clinic resource, decreases the quality of care, escalates costs and impacts accessibility. The clinic also finds that the no show rate will negatively affect patients' satisfaction and quality of health care. (Chesanow, 1996; Murray and Berwick, 2003)

In one related study, only 74% of surveyed community mental health services consumers were satisfied with their access to services (Colorado Department of Human Services, 2005). In addition to community mental health centers, the no show problem may be particular severe for pediatric clinics, hospitals, and neighborhood medical and dental clinics (Bean and Talaga, 1995). In the manufacturing sector, we have learned that variation will lead to the deterioration of quality. Facing the problem of no shows, the staff in the clinic may wait for 10 to 15 minutes and begin to help others to increase the utilization. However, what if everyone shows up for a few hours? Though the waste of time will be well hidden, quality will suffer somewhere from the increase in variation

in patient arrival (Montgomery, 2009).

When patients do not show up for their appointment, they create a series of costs that they do not pay for themselves. For example, the clinic needs to pay the rent of the office and the salary for all the staff in the clinic. If the patients do not show up, the staff in the clinic need to wait for them and cannot earn the profit from other patients. The variation caused by no-shows will hurt quality and eventually tax the system further.

C.3 Scheduling Method

In traditional appointment scheduling, a patients seeking an appointment calls the clinic and is immediately booked for a future appointment time (Muthuraman and Lawley, 2008). Efficient use of clinic resources is critical in an era of rapidly escalating health care costs and calls for improved health care efficiency (Sweeney, 1996), so health care advisors need to face increasing pressure to control costs while delivering high- quality care (Wright and Kurt, 2006). In essence, there is little long-term pre-booking, clinics book only for a very short time horizon. Using short time horizon is to help more patients see their physician when they

have a need, not at some distant time in the future. The results show that the short-term no-show predictions are more reliable, and can play a more influential role in optimizing clinical patient scheduling. (Muthuraman and Lawley, 2008)

Some clinics overbook appointments by double-booking patients into common appointments times and relying on no-shows to allow the schedule to catch up (Chung, 2002). Others have experimented with "wave scheduling" policies that build extra appointments into a schedule to boost provider productivity and leave other appointment slots empty (LaGanga and Lawrence, 2007). Practitioners have reported success in managing appointment schedules with these and similar approaches, but their accounts have been anecdotal and do not analyze nor describe how schedule performance relates to no-show rates or other system characteristics. (Chesnow, 1996; Chung, 2002).

In this thesis, we use the overbooking method to schedule the patients' appointments. The practice of booking multiple appointments at the same appointment start time is intended to reduce the time that providers wait for patients to show up, thereby increasing productivity (Bailey, 1952). However,

to increase daily productivity, an increased number of patients must be booked and served in each clinic session.

(LaGanga and Lawrence, 2007)

In this thesis, the interarrival time for patients is changed, especially for the patients whose no show rate is high. An ideal overbooking model depends on four characteristics. The first is a valid patient no-show description that captures the actual pattern of patient behavior. The second is the underlying service model that reflects the operational dynamics of the clinic. The third is an objective function that reflects the performance concern of clinic managers. And the last is an efficient algorithm that can generate schedules of desired quality in a timely fashion (Zheng, 2009).

Overbooking does not mean double booking. Double booking is a specific case of block-booking, which is scheduling a multiple number of patients to show up at the same time and is not the only option for overbooking (LaGanga and Lawrence, 2007). Overbooking may schedule an appointment every 30 minutes when it can serve patients every 45minutes. The goal of the overbooking is to minimize the negative effect of

no-shows. According to the overbooking method, patient access and provider productivity are significantly improved, but the overbooking causes increases in both patient wait time and provider overtime. We need to tradeoff between these two measures and find a better solution to serve additional patients, minimize patient waiting time and increase the utilization of staff in the clinic. Furthermore, the overbooking method is the only one that directly compensates for no-show patients (LaGanga and Lawrence, 2007).

II. COLLECTION and ANALYSIS of DATA

A. Staffing and Scheduling Operations at Healthy for Life

There are seven staff members in the clinic. One receptionist, one nurse, one nurse practitioner, one physician, one exercise physiologist, one psychologist and one nutritionist.

All staff have different responsibilities. The physician and the nurse practitioner have the same duty. In most situations, new patients see the physician and returning patients can see either the nurse practitioner or the physician. Both new and returning patients see the physician or nurse practitioner for one hour.

The receptionist is responsible for patients to check in and checkout, as well as some paper work. Additionally, one day before the appointment day, receptionist makes reminder phone calls to patients. At that time, patient either confirms with the appointment, or reschedules a new appointment, or leaves a message. The nurse is responsible

for taking in patients and recording the basic physical data, which takes nearly twenty minutes. Both new and returning patients see the nurse before they see the physician, or the nurse practitioner, or the nutritionist. When the nurse is busy, patients can see other staff first and see the nurse.

The responsibility of the exercise physiologist is offering children a range of physical activities and suggesting them some exercise options. The nutritionist helps patients with a healthy dietary habit. For new patients, nutritionist will spend half an hour in the teaching kitchen offering cooking demonstrations and healthy meal planning lessons for parents and their children. For returning patients, the nutritionist spends about half an hour in her office discussing patients concerns and their progress. Finally, the psychologist helps patients to have a good mood and attitude towards weight control. Seeing psychologist is considered an important element in this clinic because it deals with underlying psychological issues. The latter includes, eating habit, depression, academic underperformance, poor body image, psychosomatic complaints and dysfunctional family relations. If the patient's insurance does not cover this service,

patient needs to pay out of his or her own pocket. Usually, patients spend 30 to 40 minutes seeing the psychologist.

Table I

THE SCHEDULE OF STAFF

Staff	Total Number	Name	Available Time	Responsibility
Receptionist	1	Kelly	M-F(All day)	Patient check in/check out
Nurse	1	Tammy	M-F(All day)	Intake
Nurse Practitioner	1	Myra	M,T(All day)	By Appointment
Physician	1	Dr. Sweeney	M,T (Morning) Th.(All day)	By Appointment
Exercise Physiologist	1	Lauren	T.W (All day) Th. (All day)	By Appointment
Psychologist	1	Dr. Shaffer	T. Th.(All day) W(Afternoon)	By Appointment
Nutritionist	1	Olivia	M-F(All day)	Dietary Advice

From Table 1, we see that the physician, nurse practitioner, the exercise physiologist and the psychologist are not available for the whole week. Patients can make appointment with the physician on Monday, Tuesday mornings and Thursday; with the nurse practitioner on Monday and Tuesday; with the exercise physiologist on Tuesday, Wednesday and Thursday; with the psychologist on Tuesday, Thursday. One feature of the clinic is it is a multiple-resource center. For example, new patients should be seen by either physician or nurse practitioner at the first appointment. After that, patients could choose one from the exercise physiologist, psychologist, physician and nutritionist randomly for their subsequent visits.

B. Patients Flow at the Clinic

Patients need to make an appointment before visiting the clinic. For the new patients, they need to call the receptionist and fill some forms before going to the clinic. For the returning patients, they need to make next appointment before they leave the clinic. In general, patients come to

the clinic every month.

Figures 2 and 3 illustrate the process flow at the clinic for new and returning patients, respectively.

For the new patients, upon arrival they check in at the registration desk to fill the form out and then stay in the waiting room until being called in. This usually takes about 20 minutes. Before seeing the physician, they first see the nurse. However, if the nurse is busy, they can see the physician first, and then see the nurse to be taken in. If both the nurse and the physician are busy, new patients can see the nutritionist, and then wait until the nurse or physician become available. In a normal situation, it will take patients about 20 minutes to be taken in by the nurse, and about 1 hour to talk to the physician, and 30 minutes to see the nutritionist. After these, patients check out and schedule their next appointment in a month or so. This whole process usually takes new patients about two and half hours in the clinic.

For returning patients, as indicated in Figure 3, upon arrival, they first spend approximately 10 minutes checking in and then wait to be taken in by the nurse. After seeing the nurse, they see the staff whom they are scheduled to visit.

Usually they are the physician and the exercise physiologist. In addition, before patients see the physician and exercise physiologist, they need to see the nurse. Note that, returning patients can choose to see one or two staff during one visit. If the patient makes appointments with two staff at one visit, he/she can see any of them firstly, depending on availability. Lastly, when patients are finished with seeing the staff, they make the next appointment for next month before they leave, which takes about 5 minutes.

Usually it takes returning patients 20 minutes to be taken in, 1 hour to see the physician, 45 minutes to see the psychologist, 30 minutes to see the physiologist and 30 minutes to see the nutritionist. In normal situations, returning patients will stay in the clinic for two hours.

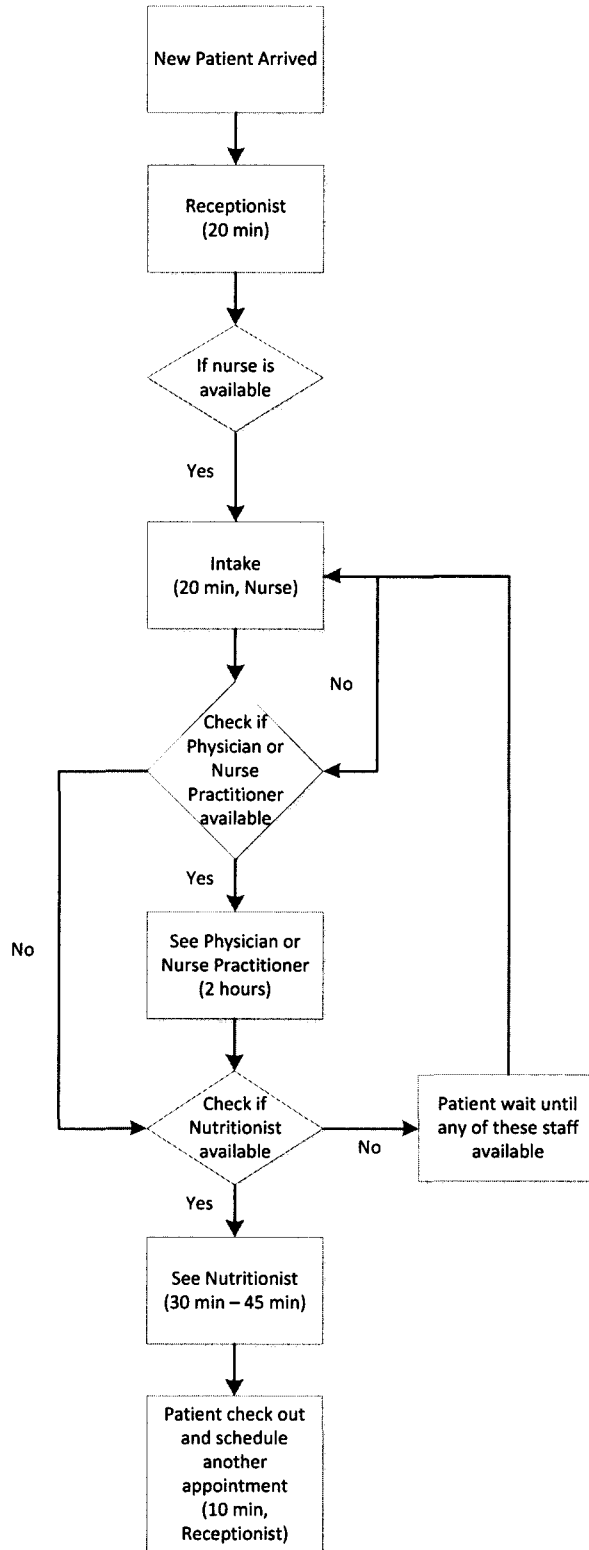


FIGURE 2 - New Patients Flow

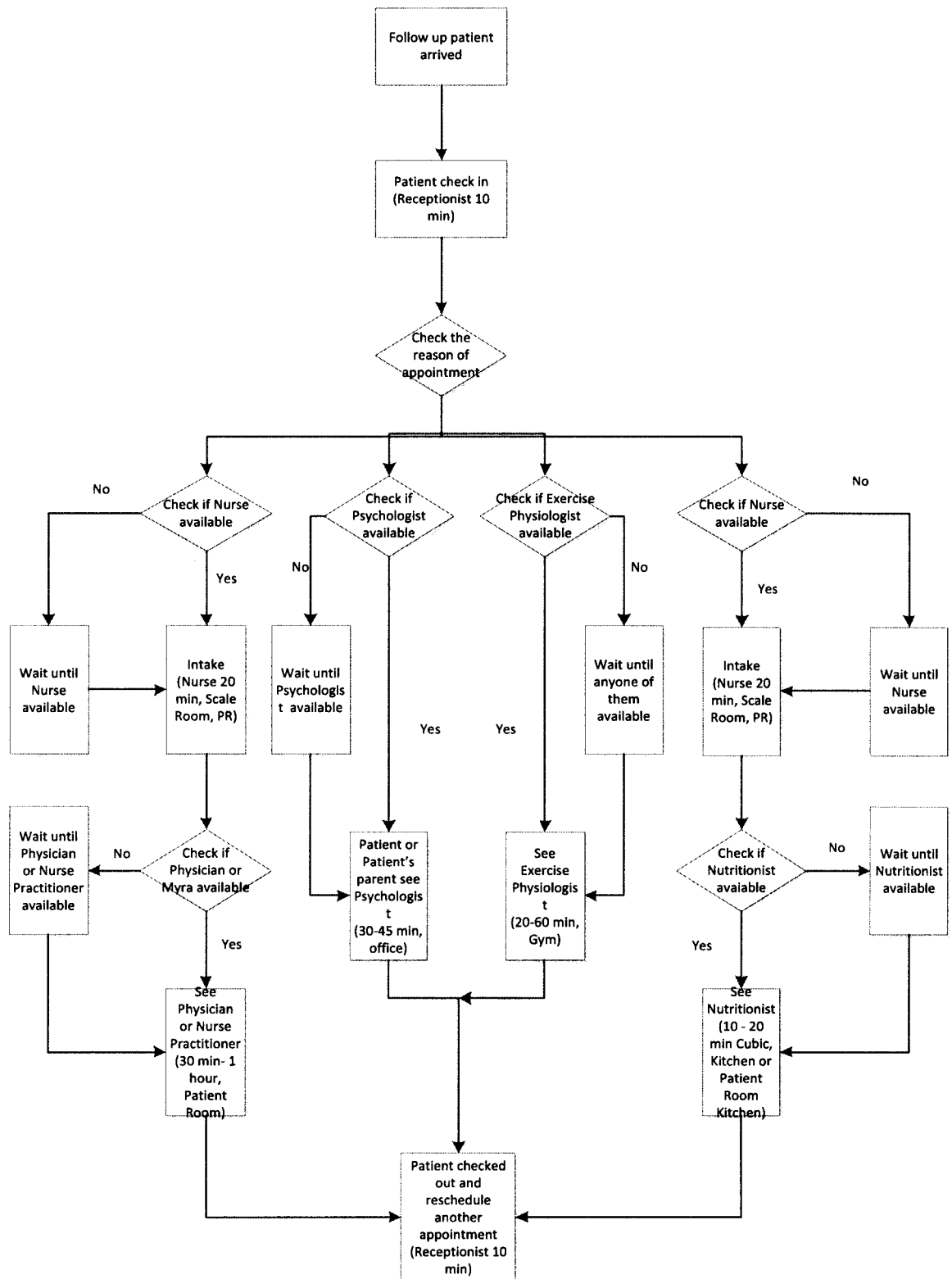


FIGURE 3 - Returning Patients Flow

C. Analysis of Data

C.1 Five Types of Patients

From the registration book, we learned that there are five types of patients. Type one is those patients who promise show up and they actually show up. Type two is those patients who promise show up but they do not actually show up. Type three is those patients who have missed the reminder call but actually show up. Type four is those patients who have missed the reminder call and do not actually show up. Type five is those patients who cancel or reschedule the appointment in response to the reminder call.

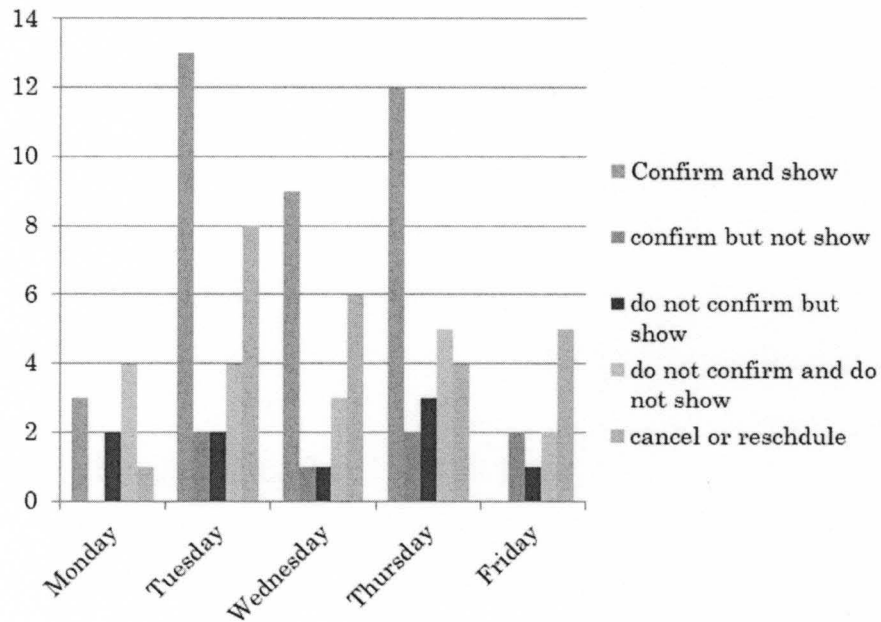


FIGURE 4 - Plot of five types of patients

From the plot we see that on Tuesdays and Thursdays the number of patients who confirm and show up is higher than other weekdays. On Fridays, most patients cancel their appointment or reschedule. This means on Fridays the clinic does not expect many patients even though the number of appointments may be large. Figure 4 also suggests that Tuesday, Wednesday and Thursday are preferred by patients. This may be attributed to the fact that all staff are available in the clinic, especially the physician and psychologist. Moreover, most patients prefer the time periods from 9am to 11am and from 1pm to 3pm.

C.2 No-show Rates for Patients

Table II is the data we collect from the clinic from July 1st to August 4th, 2010 (Sample ---24 days). In these 24 days, there are 486 scheduled appointments, among which 237 patients show up. Thus, the average no show rate is 48.77%, i.e., nearly half of the appointments are canceled or rescheduled. From Table II, we also see that: the exercise physiologist, the physician (Dr. Sweeney) and the psychologist (Dr. Shaffer) have more appointments than others. Another observation is that no-show rate (58.82%) for the psychologist is the highest. This implies that if we want to increase the average staff

utilization, we need to improve the no-show rate for the psychologist.

Table III
 No-SHOW RATES BY INDIVIDUALS AND BY WEEKDAYS

	Visits	Scheulded Appointments	No show rate
Total	237	486	48.77%
Physician	52	120	43.33%
Psychologist	80	136	58.82%
Nurse Practitioner	36	80	45%
Exercise physiologist	43	90	47.78%
Nutritionist	26	50	52%
Monday	25	62	40.32%
Tuesday	76	149	51.01%
Wednesday	38	84	45.24%
Thursday	73	145	50.34%
Friday	25	36	69.44%

From the table, we also see that, on Mondays the no-show rate is the lowest, and on Fridays the no-show rate is the highest. Other weekdays, the no show rate is similar. Therefore, if we adopt overbooking strategy, it should take place on Fridays to balance the workload during the week.

C.3 New and Returning Patients

Table III

NEW PATIENTS VS. RETURNING PATIENTS

Physician	New patient	Returning patient	New patient/ Returning patient
No show patient	31	21	1.47619
Total patient making appointment	73	47	
No show rate	0.42465	0.4468	1.5532
Nurse practitioner	New patient	Returning patient	New patient/ Returning patient
No show patient	12	24	0.5
Total patient making appointment	33	47	0.7021
No show rate	0.36363	0.51063	

We divide patients into two groups in our simulation model: new patients and returning patients. Table III suggests that compared to new patients, the no-show rate for returning patients is higher. In addition, Table III shows that the physician (Dr. Sweeney) has more new patients than returning patients. However, the nurse practitioner (Myra) sees more returning patients than new patients.

C.4 Classify the patients by factors

An individual's weight can be described as a percentage of the ideal or desirable weight based on his/her height. Consequently, this percentage can be used to categorize an individual as healthy, underweight, overweight, or obese. Among others, the Body Mass Index (BMI) is widely accepted to estimate body composition which correlates an individual's weight and height to lean body mass. The BMI is thus an index of weight adjusted for stature. The BMI is calculated by dividing weight in kilograms by height in meters squared and multiplying by 100. High values of BMI can indicate excessive fat, while low values can indicate reduced fat.

Table IV

BMI WEIGHT STATUS CATEGORY

Weight Status Category	Percentile Range
Underweight	Less than the 5 th percentile
Healthy weight	5 th percentile to less than the 85 th percentile
Overweight	85 th to less than the 95 th percentile
Obese	Equal to or greater than the 95 th percentile

The formula for children's BMI is different from that for adults. Below is a graph illustrating BMI's percentiles for

boys between two and twenty years old.

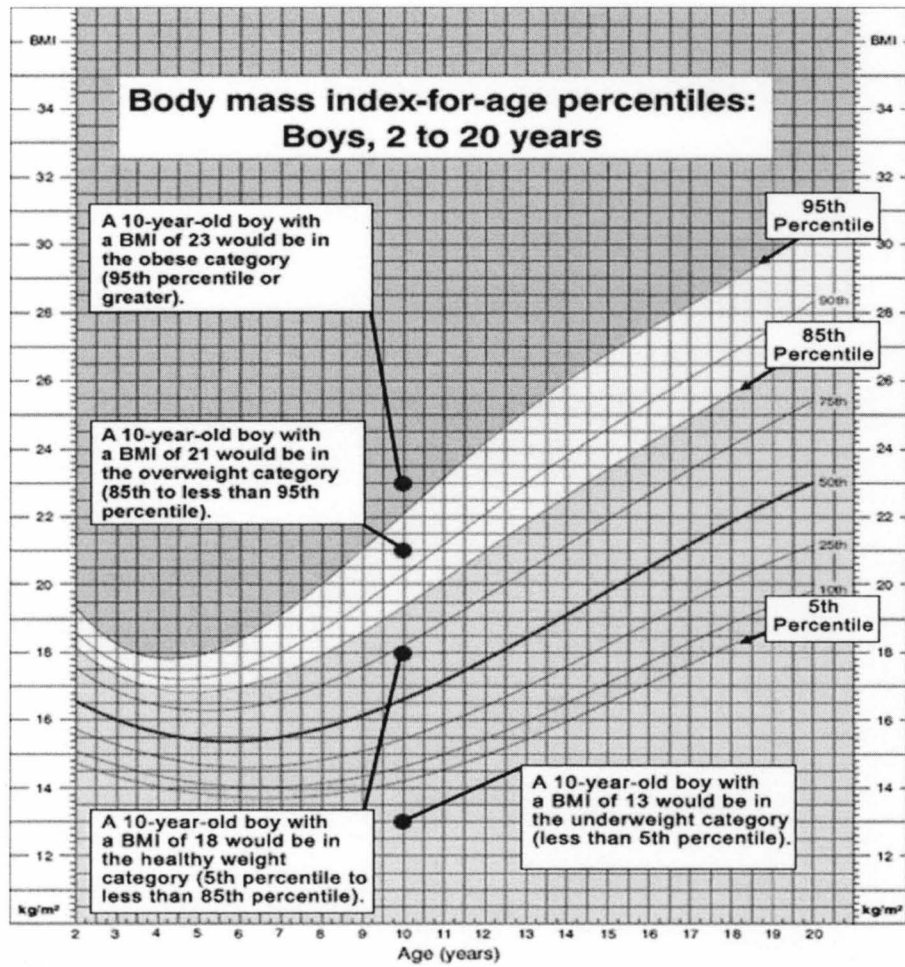


Figure 5 - BMI for Children

III. SIMULATION MODELS

A. The Overbooking Simulation Model

A.1 Overview

This simulation model is built in Arena Version 14th as a discrete-event, stochastic model. In the current setting the returning patients see one staff person on the visit. There are five parts to the model representing five types of patients, including new patients, returning patients who see the nutritionist only, returning patients who see the psychologist only, returning patients who see the physician only and returning patients who see the exercise physiologist only. The model runs for 8 hours (480mins) one day from 8am to 4 pm, or when all patients are finished whichever is later. The simulation is run for 30 replications. See Figure 6 for a representation of the model in terms of Arena modules.

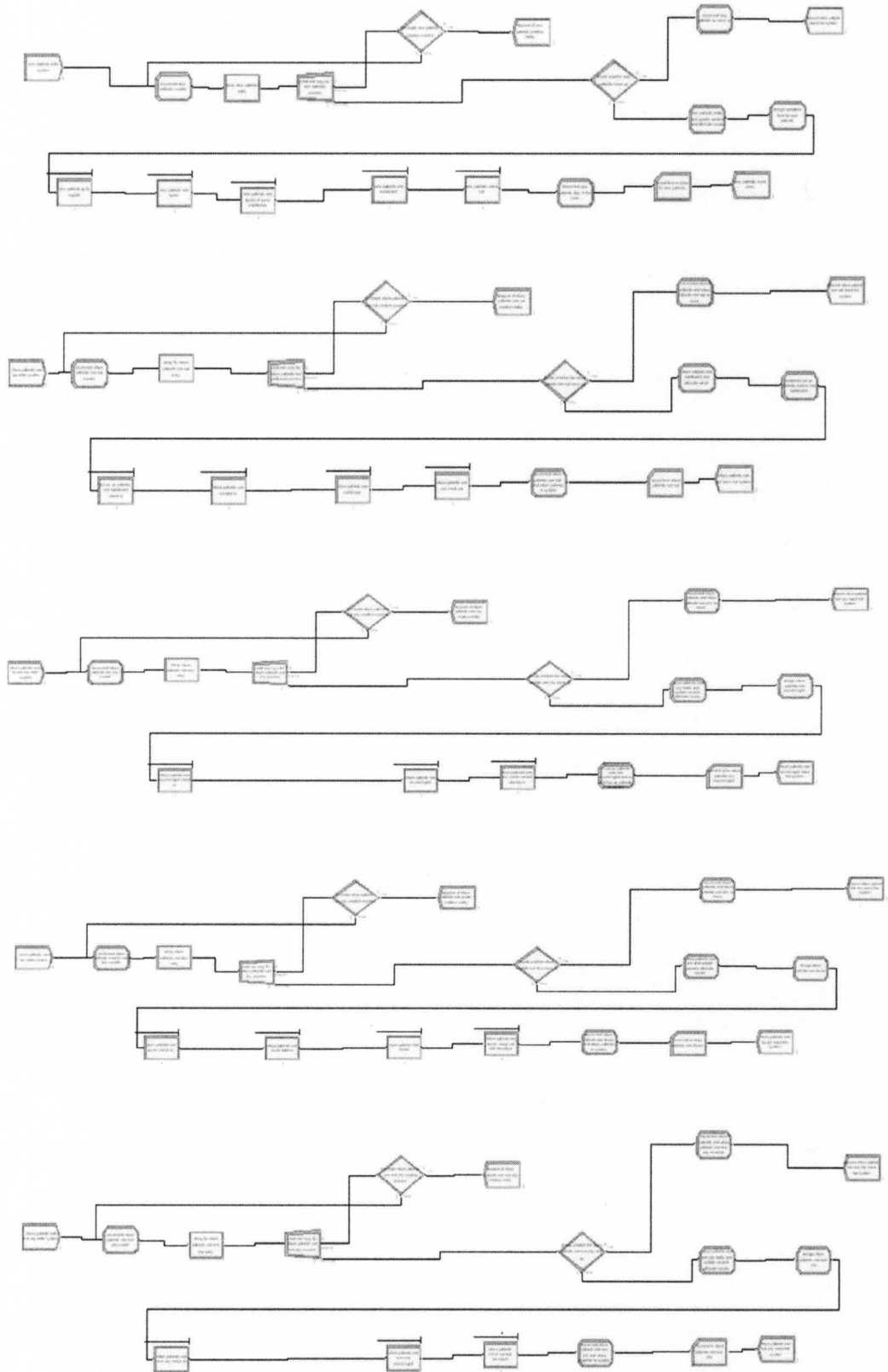


Figure 6- Overbooking Model

A.2 Modeling Assumption

The following assumptions are made in the simulation model

- Each of the staff works every day.
- The waiting room has unlimited capacity.
- Processing times follow the same distribution for the same type of patient.
- The clinic is closed when the last patient has been seen.
- Unlimited queue lengths are allowed at all processes.
- The order of processing is first-in-first-out (FIFO).

A.3 Model Construction and Approach

Features from the Basic and Advanced Process templates and the Blocks template of Arena are used. The following sections describe Model 1.

The model can be divided into two sections for each disjointed part in Figure 6. One section is for patients to make appointments with the clinic and the other section represents the process of the patients seeing staff in the clinic

Create Module: new patients make appointment

The Create Module generates new patients. This module creates only one entity each time. The time between arrivals in this module is given by the variable TBA NEW P. When we do the simulation, we can change the value of TBA NEW P and get alternative results. See Figure 7.

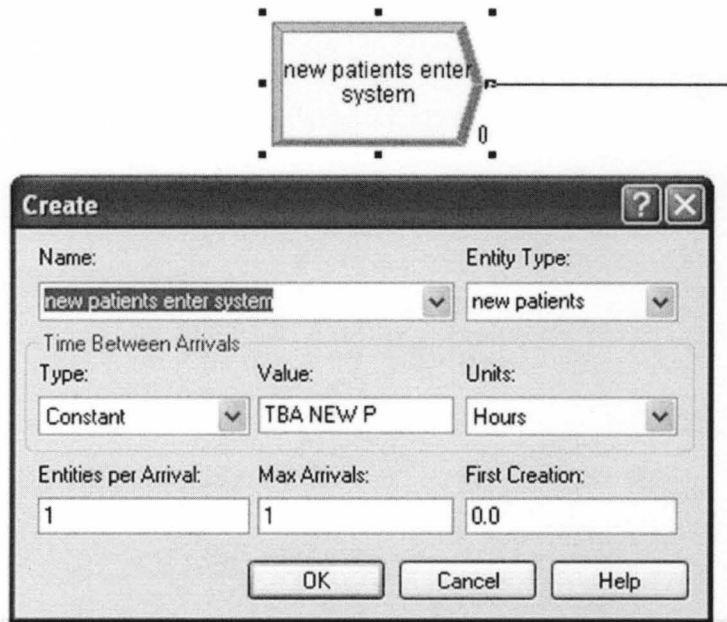


Figure 7 - Create New Patients Enter System

Assign Module and Delay Module: Assign new patient counter and Delay in the system

This portion of the model assigns the patients counter. Once one new patient appointment enters into the system, the counter for new patients will be increased by one. See Figure 8.

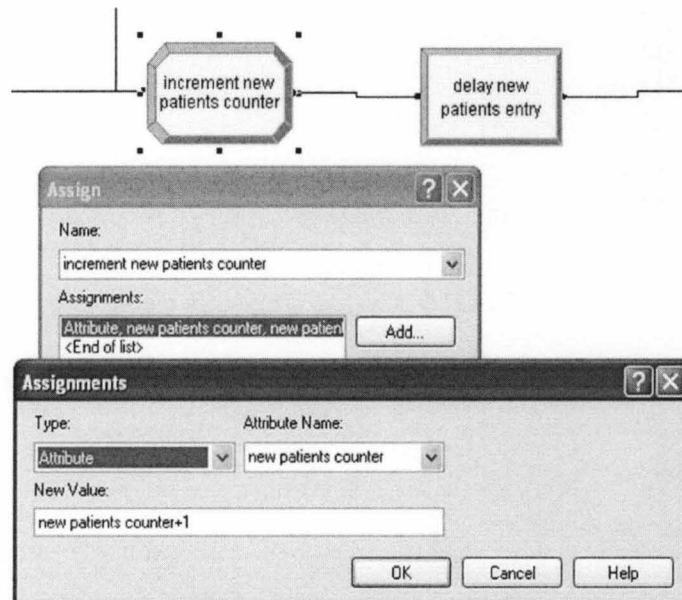


Figure 8 - Assign New Patients Counter and Delay in the System

Separate Module: Separating a single patient entity into multiple outgoing entities

The new patients making appointment will be separated in this module. One is to check whether it reaches the maximum appointment number in one day. If it is over the maximum number,

the patient entity will be disposed or scheduled in another day. However, if it is not over the maximum number, the Decide Module will be scheduled into this day. If the patient entity is scheduled, the determination is made as to whether this appointment will show up. This module is important in this model, because it is the same appointment, but it is separated in two ways. See Figure 9.

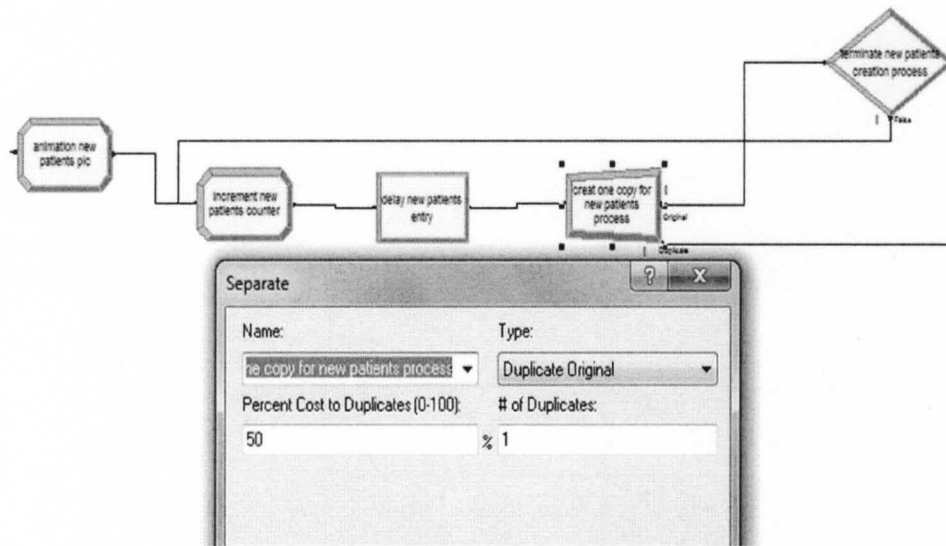


Figure 9 - Duplicate New Patients Making Appointment

Decide Module (1): decide whether the number of new patients counter is more than the maximum number of new patients' appointments.

The maximum number is changed as the interarrival time for the new patients. For example, if the new patients'

interarrival time is 30 minutes, and the work time in one day is 480minutes, the maximum appointment number in one day is 16. If this appointment is the 17th appointment this day, it will be disposed. If it is the 15th appointment this day, it will be scheduled. See Figure 10.

Decide module (2): Decide whether the appointment shows up. The no show rate is given by the data we have collected from the clinic. If the new patients who made appointments do not show up, we will use the Assign Module to calculate the number of the patients who did not show up and the number of new patients who did not show up. If the new patient shows up, the patient entity will continue the process in this model.

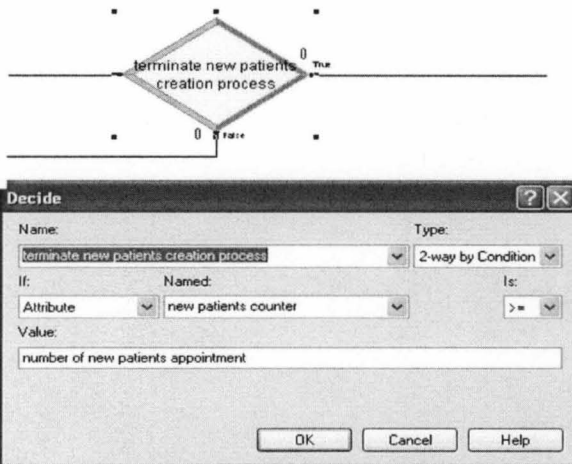


Figure 10 - Whether Appointment of New Patient is scheduled

Assign Module: Assign the new patient entity and update the variable and values.

First, add the entity type of patients and new patients. We not only want to know the numbers of new patients but also the total patient stay in the clinic. Therefore, the numbers of patients in the clinic and the numbers of new patients in the clinic need to be calculated. Once one new patient shows up, we need to add one to the number of total patients and the number of new patients. Last but most importantly is time. Total time for new patients staying in the clinic is an important datum for analysis. Therefore, we attribute the time from patients' arrival to when the patients leave the clinic. See Figure 11.

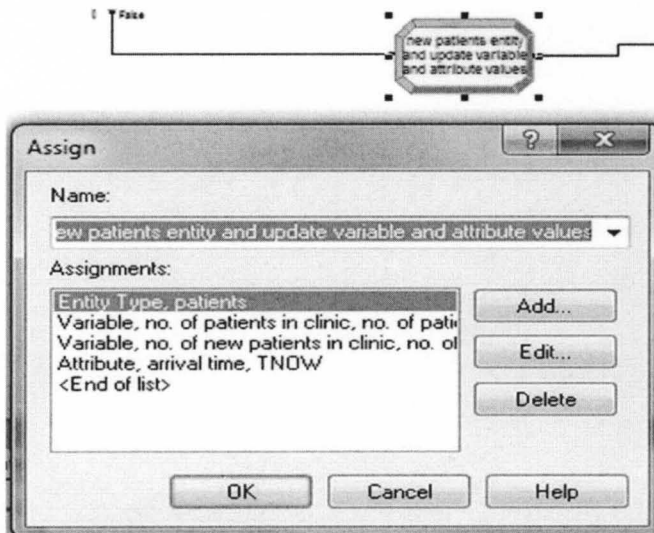


Figure 11 - Calculate the No. of Patients and Time

Process Module: Simulate the patient flow in the clinic

For example, when new patients come into the clinic, they will go to receptionist and then see the nurse. Then they will go to see the physician and nutritionist separately, depending on who is available. After that, they can go to registration to make another appointment. The delay time in the Process Model is the same as the real process time in the clinic so that we can know the total time of patients staying in the clinic and which staff takes the longest from the simulation result. When one patient sees the staff, he or she will seize this resource and other patients cannot share with him or her. Other patients have to wait until the staff is available again. The patients will follow the rule of first in and first out. See Figure 12.

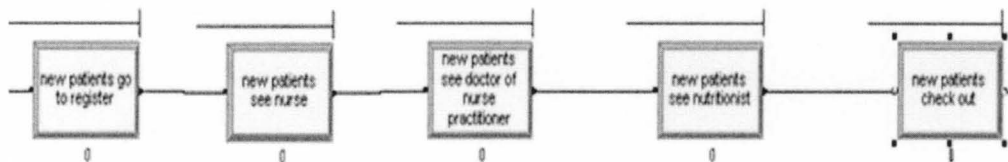


Figure 12 - Patients Flow in the Clinic

Special Process Module: patients see physician or nurse practitioner

In the clinic, there is one physician and one nurse

practitioner. They have the same duty. Here we use the Arena concept of 'set' with the value "preferred order". We design the order with physician in the first place, for patients will see the physician firstly if the physician is available. If both of them are available, the patients will see the physician. If the physician is busy, the patients will see the nurse practitioner. If both of physician and nurse practitioner are busy, patients will wait in the waiting room until either of them is available. See Figure 13.

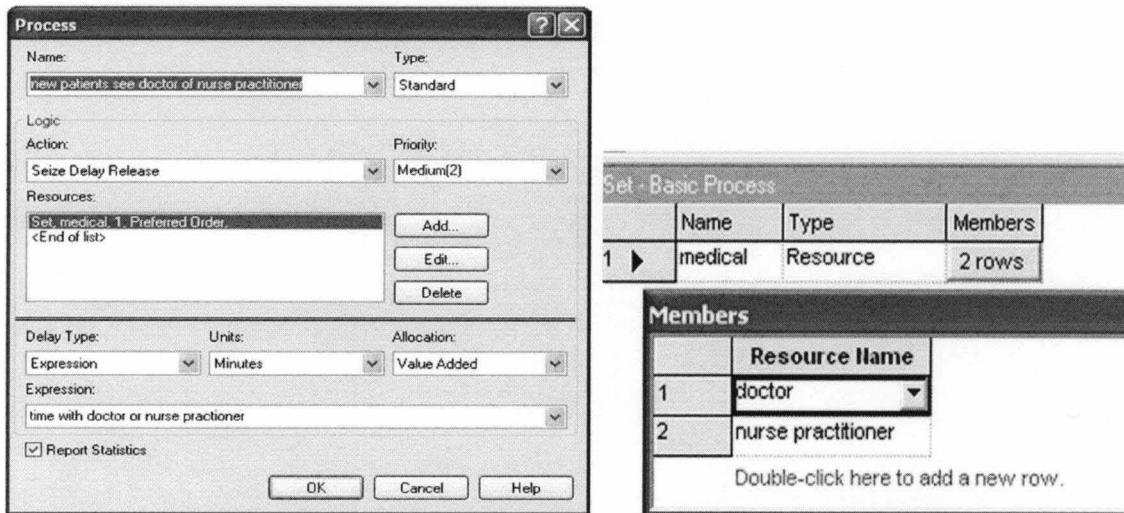


Figure 13 - Process for Patients to See Physician or Nurse Practitioner

Assign Module: Decrease the number of patients staying in the clinic.

We used the Assign Module to increase the number of patients when they came into the clinic. When they finish being seen, we will decrease the number of patients who are in the clinic and the number of new patients in the clinic. From the result, we can know the total number of patients served. We can also know the number of patients in the clinic over times. See Figure 14.

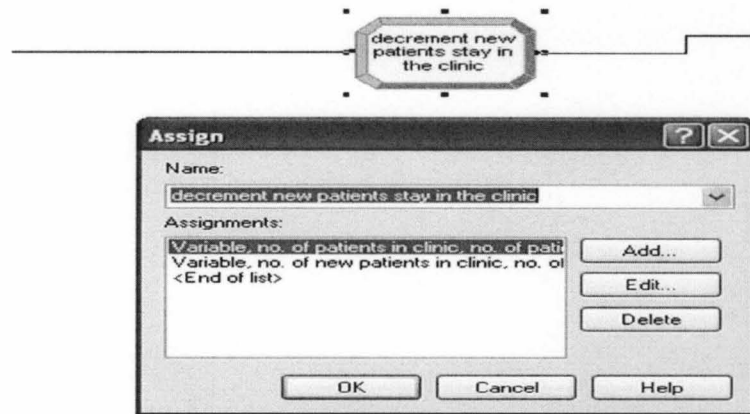


Figure 14 - Assign Patients Leave the Clinic

Record Module: Record time patients stay in the clinic.

When the patients leave the clinic, we can record the interval time for patients, so we can know the total time of patients

staying in the clinic. See Figure 15.

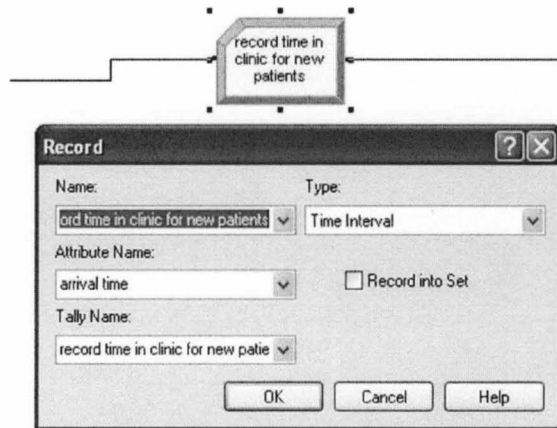


Figure 15 - Record Total Staying In the Clinic

B. Simulation for Multiple-Resource Model

B.1 Overview

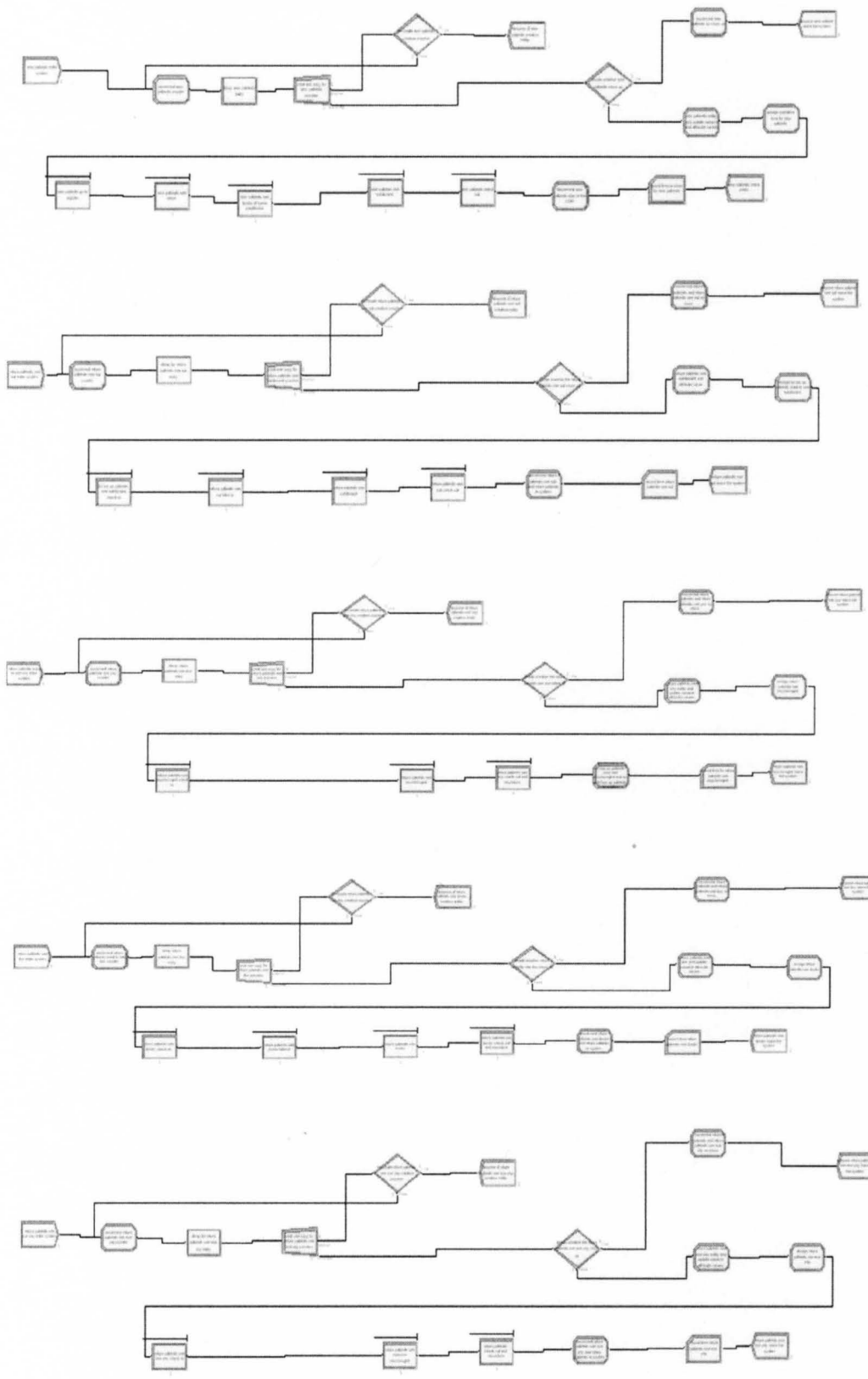
In the overbooking model, the first five sections are the same as the overbooking model. In this model we consider that the returning patients could choose to see one or two staff persons in one appointment.

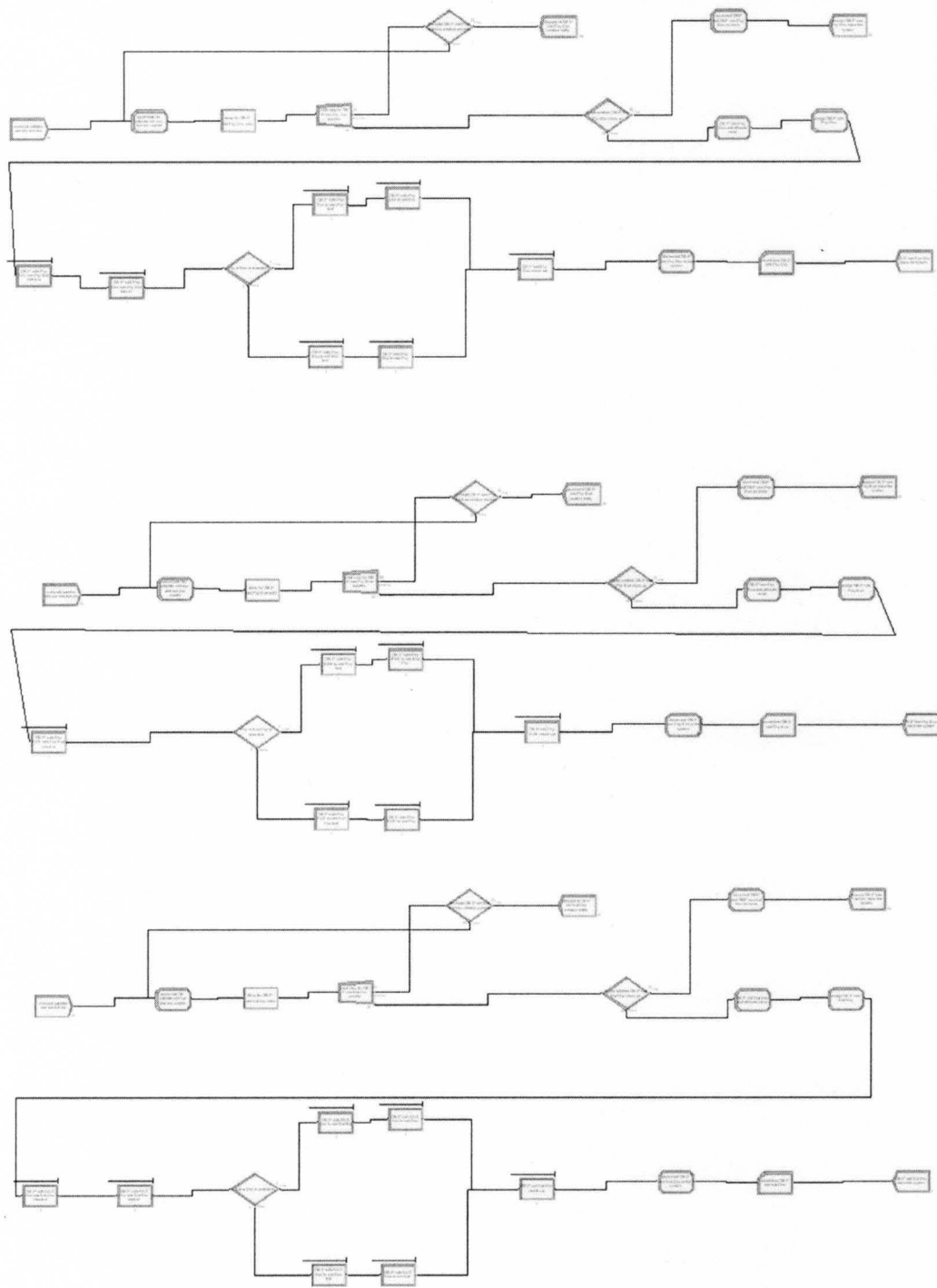
We can divide returning patients into 10 types. Four of them are returning patients who see the physician, the nutritionist, the psychologist and the exercise physiologist, respectively. The other patients are returning patients who see two staff every time. They can see the physician and the nutritionist, the physician and the psychologist, the

physician and the exercise physiologist, the nutritionist and the psychologist, the nutritionist and the exercise physiologist, or the psychologist and the exercise physiologist each time. If they want to make an appointment with two staff the next time, they can choose which staff they want to see.

One thing we need to pay attention to is that before the patient sees the physician and the nutritionist, they need to see the nurse for take-in. If they want to see the exercise physiologist and the psychologist, they do not need to see the nurse.

If the patients make appointments with two staff members, they can see any of them first, depending on who is available. The model runs for 8 hours (480mins) one day from 8am to 4 pm, or when all patients are finished, whichever is later. See Figure 16.





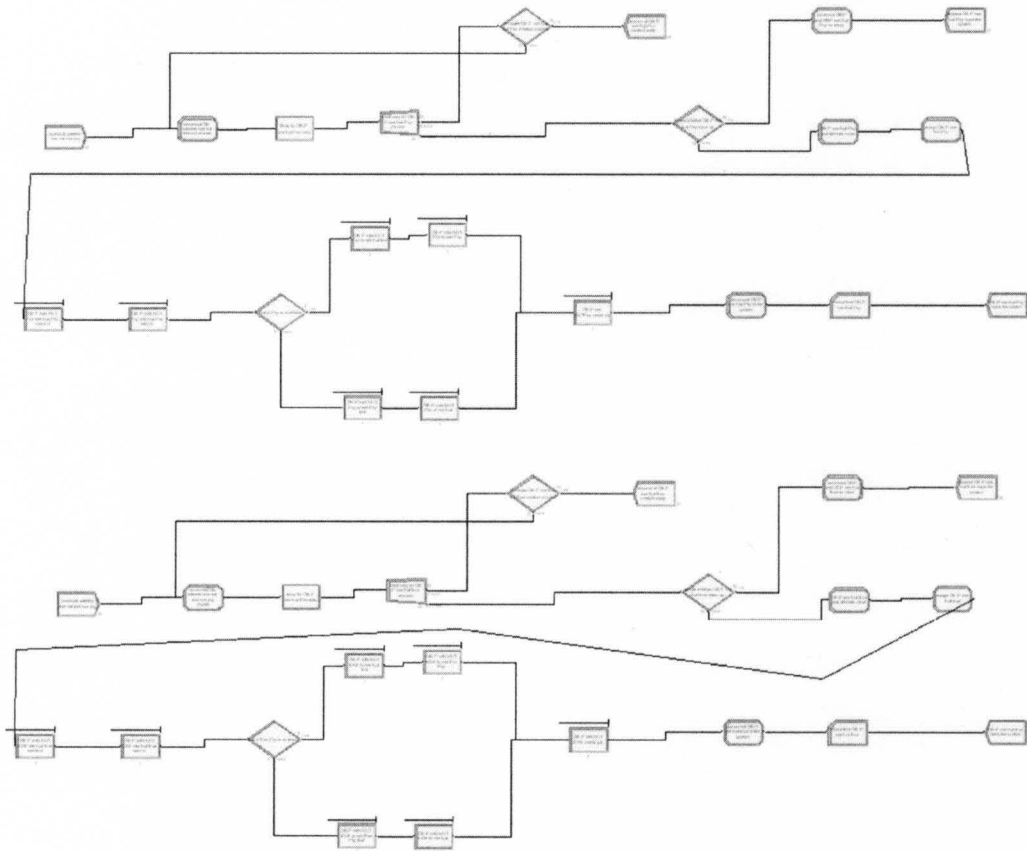


Figure 16 - Overview the Multiple Resource Model

B.2 Modeling Assumptions

The following assumptions are made in the simulation model

- Each of the staff works every day.
- The waiting room has unlimited capacity.
- Processing times follow the same distribution for the same type of patient.

- The clinic is closed when the last patient has been seen.
- Unlimited queue lengths are allowed at all processes.
- The order of processing is first-in-first-out (FIFO).

B.3 Model Construction and Approach

Features from the Basic and Advanced Process Templates and the Blocks Template are used. The following sections describe the construction of Model 2. Because we previously introduced the patients who just see one staff, here we just introduce the part corresponding to returning patients who see two staff each time.

The model can be divided into two parts for every separate section; one is for patients to make appointments with the clinic and the other is the process having of the patients seeing staff in the clinic, if they show up.

The part of the model involving patients making appointments in this model is the same as the overbooking model. The difference is the maximum numbers of patients, for there are more patients coming into the clinic. We need to reduce the maximum numbers of patients.

We use the Assign Module after patients have shown up in

the clinic. (We use the returning patients who want to see physician and nutritionist as an example).

Assign Module: Assign the returning patients who see two staff every time entity and update the variable and values.

First, assign the entity type for patients, returning patients and returning patients who see the physician and the nutritionist. We not only want to know the numbers of returning patients who see the physician and the nutritionist (OB P see Nut Doc) but also the total number of patients who stay in the clinic. Therefore, the numbers of patients in the clinic and the numbers of returning patients who see the physician and the nutritionist in the clinic need to be calculated. Once one returning patients who see the physician and the nutritionist shows up, the total number of patients and the number of returning patients who see the physician and the nutritionist will be increased by one.

Last but most importantly is time. The total time for returning patients who see the physician and the nutritionist staying in the clinic is an important datum for analyzing. Therefore, we assign the time from patients' arrival to when

the patients leave the clinic. See Figure 17.

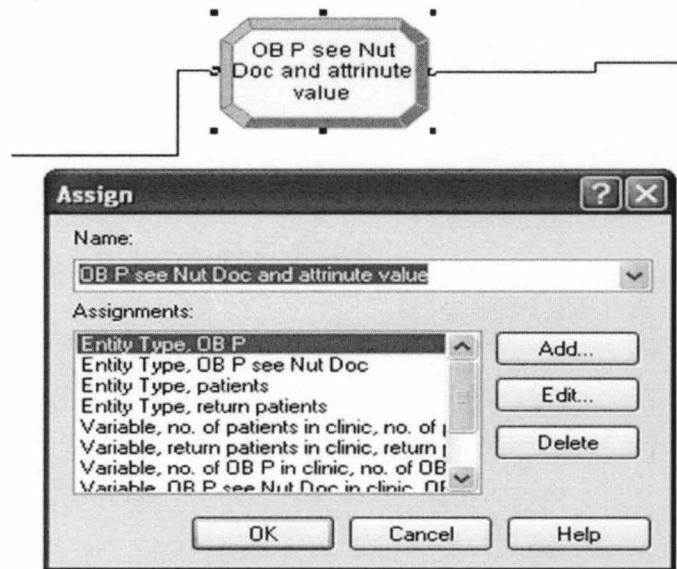


Figure 17 - Assign Module for Patients
See Two Staff Once

Process Module: Simulate the patients flow in the clinic

For example, when patients who see the physician and the nutritionist come into the clinic, they will go to receptionist and then see the nurse for take-in. After that, the patient will go to see the physician or nutritionist, depending on who is available. If both of them are available, the patients will go to see the nutritionist first then go to see the physician. If both of them are busy, they have to go to the waiting room to wait. After seeing both of them,

they can go to the receptionist to make another appointment.

The delay for the Process Model is the same as the real process time in the clinic so that we can know the total time of patients staying in the clinic and which staff requires the longest from the simulation result. When one patient sees the staff, he or she will seize this resource and other patients cannot share with him or her. Other patients have to wait until the staff is available again. The patient will follow the rule of first in and first out. See Figure 18.

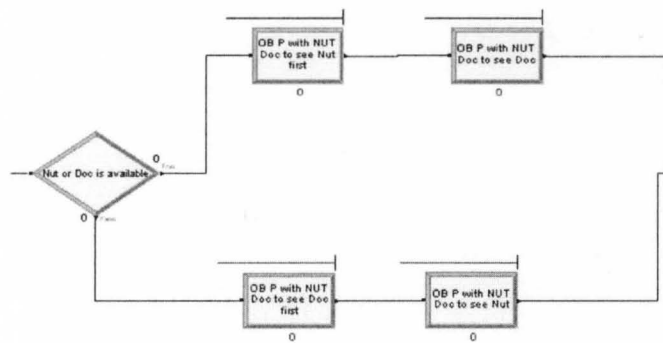


Figure 18 - The Process of Seeing Multiple Resources

We use the Decide Module to decide which staff person is available. We use an expression to determine if they are available. If the waiting queue of patient who wants to see the nutritionist is shorter than the queue of patients who

want to see the physician, the patient will go to see the nutritionist firstly then to see the physician. Otherwise, the patient will go to see the physician first.

After that, the patients will go to make the next appointment and then leave the clinic. See Figure 19.

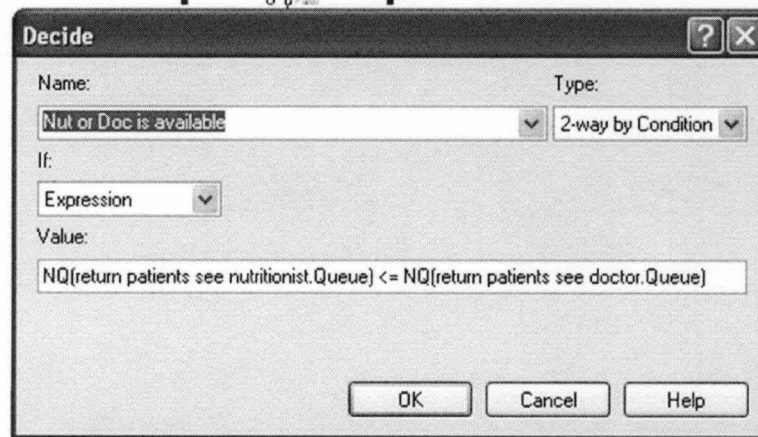


Figure 19 - Decide to See Which Staff

Assign Module: Decrease patients' stay in the clinic.

We used the Assign Module to increase the number of patients when they came into the clinic. When they finish being seen, we will decrease the number of patients who are in the clinic and the numbers of returning patients who see physician and nutritionist in the clinic. From the result, we can know the total number of patients who are reserved. We can also know the number of patients in the clinic at different times.

Record Module: Record time patients stay in the clinic.

When the patients leave the clinic, we can record the interval time for patients, so we can know the total time of patients staying in the clinic.

IV. SIMULATION RESULTS

In this chapter we present the simulate experiments and their results. We first introduce an overbooking model and then a multiple resource model.

In the overbooking model, all patients see only one staff at each visit. Because the no-show rate of the returning patients who sees the psychologist is the highest, we focus on changing parameters for the returning patients who see the psychologist. In particular, we vary the interarrival time for these patients as 15, 30, 45, 60, 75, 90 and 120 minutes. For each of the above interarrival time for patients seeing the psychologist, we again vary the interarrival time for patients seeing other staff as 30, 45, 60, 75, 90 and 120 minutes. While varying interarrival times for these two groups of patients, we also keep track of new patients and returning patients. Similarly, we vary the interarrival time for new and returning patients as 15, 30, 45, 60, 75, 90 and 120 minutes.

In the multiple resource model, we assume returning patients either visit one staff or two staff at a visit. The no-show rate of returning patients who see two staff is the average of the two staff's no show rate. We adjust the interarrival time for all patients in respect to the maximum number for patients that can be seen at the clinic during a day. Detailed results are provided in subsequent sections.

A. The Overbooking Model

A.1 Changing the Interarrival Time for Returning Patients who

See the Psychologist

Let T_1 = The interarrival time for returning patients seeing the psychologist

Let T_0 = The interarrival time for patients seeing other staff

- $T_1 = 15$ minutes

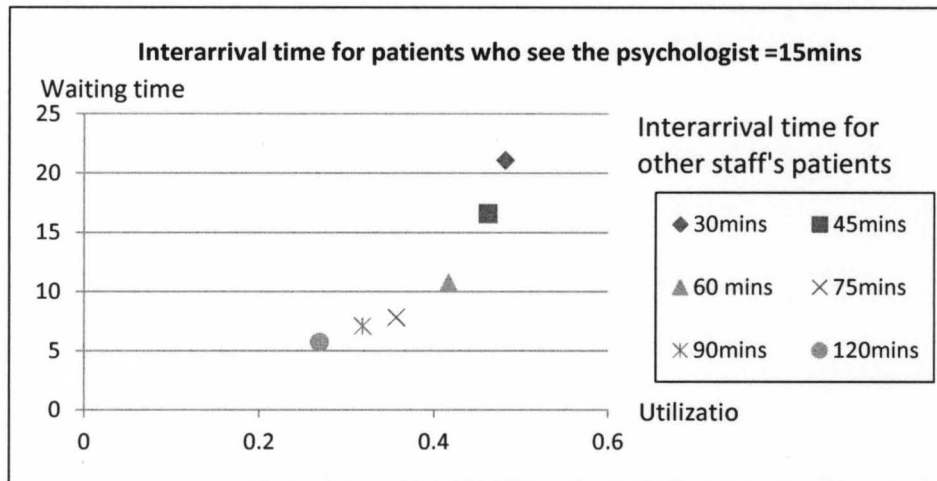


Figure 20 - Interarrival Time for Patients Who See the Psychologist = 15 minutes

Figure 20 plots the average patient waiting time against the average system utilization when the interarrival time for returning patients seeing psychologist is set to be 15 minutes. Six situations are considered, when the interarrival time for other patients are set to be 30, 45, 60, 75, 90 and 120 minutes, respectively. Also note that the average waiting time and utilization are computed based on 30 replications. The reason we do not consider the interarrival time for other patients to be 15 minutes is that the no-show rate for those patients is lower than the one for patients who see the psychologist.

From the plot we can find that utilization is not significantly improved with overbooking (25% VS. 50%), but the latter has caused significant increase in patients waiting time (5 minutes vs. 20 minutes). We need to tradeoff between the utilization and the waiting time. We study two points from the plot. One has the highest utilization when T_1 and T_0 are 15 and 30 minutes, respectively. In this case, the average utilization of the staff is 0.482, the waiting time for patients is 21.109 minutes, the total time for patients staying in the clinic is 108.53 minutes (1.81 hours), the number of patients through the system is 84, and the duration

of the clinic open hours is 984.7 minutes (16.41 hours). The other point has the median utilization when T1 and T0 are 15 and 60 minutes, respectively. In this case, the average utilization of the staff is 0.417, the waiting time for patients is 10.716 minutes, the total time for patients staying in the clinic is 93.347 minutes (1.56 hours), the number of patients served is 47, and the duration of the clinic workday is 592.5 minutes (9.875 hours).

- T1 = 30 minutes

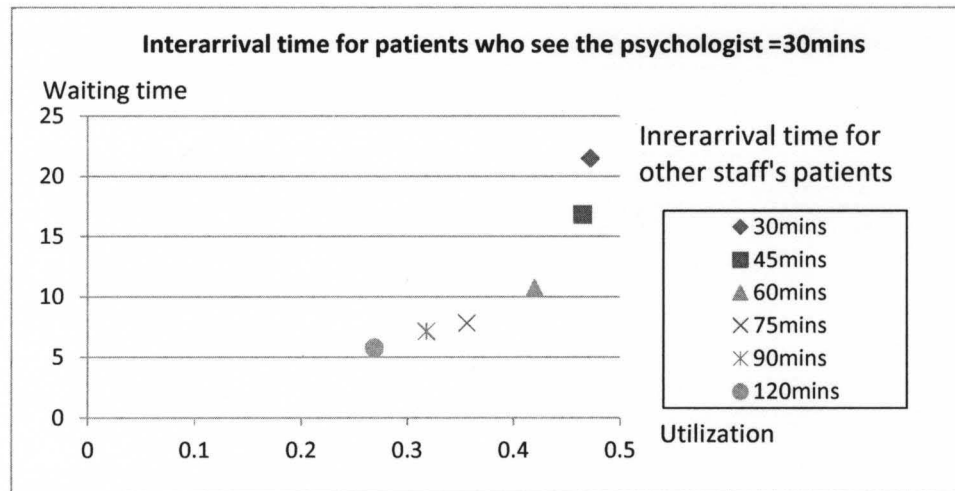


Figure 21 - Interarrival Time for Patients Who See the Psychologist = 30 minutes

In Figure 21, the point with the highest utilization occurs when T1 and T0 are both 30 minutes. In this case, the average utilization of the staff is 0.472, the waiting time

for patients is 21.469 minutes, the total time for patients staying in the clinic is 109.18 minutes (1.82 hours), the number of patients served is 75, and the duration of the clinic workday is 944 minutes (15.73 hours). On the other hand, the point with the median utilization occurs T1 and T0 are 30 and 60 minutes, respectively. In this case, the average utilization of the staff is 0.42, the waiting time for patients is 10.7 minutes, the total time for patients staying in the clinic is 93.393 minutes (1.57 hours), the number of patients served is 47, and duration of the clinic workday is 584.6 minutes (9.74 hours).

- T1 = 45 minutes

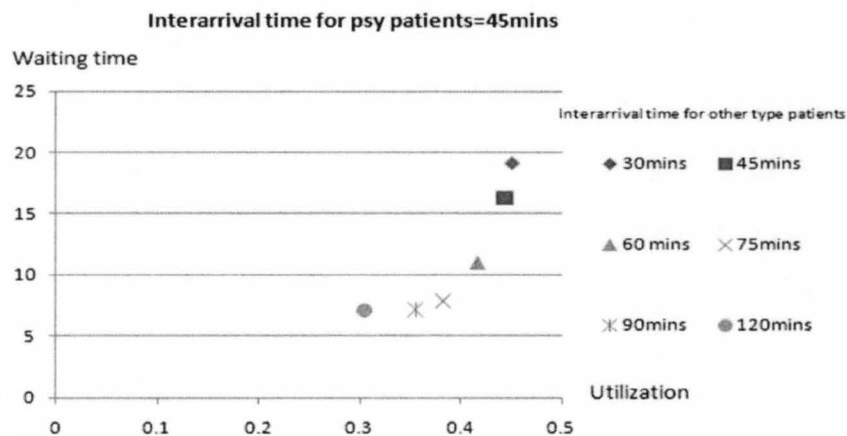


Figure 22 - Interarrival Time for Patients Who See the Psychologist = 45 minutes

From Figure 22, the point with the highest utilization occurs when T1 and T0 are 45 and 30 minutes, respectively. The average utilization of the staff is 0.416, the waiting time for patients is 10.995 minutes, the total time for patients staying in the clinic is 93.862 minutes (1.56 hours), the number of patients served is 44, and the duration of the clinic workday is 568.4 minutes (9.47 hours). On the other hand, the point with the median utilization occurs when T1 and T0 are 45 and 60 minutes, respectively. In this case, the average utilization of the staff is 0.453, the waiting time for patients is 16.528 minutes, the total time for patients staying in the clinic is 101.009 minutes (1.68 hours), the number of patients served is 67 and the duration of the clinic workday is 924 minutes (15.4 hours).

- T1 = 60 minutes

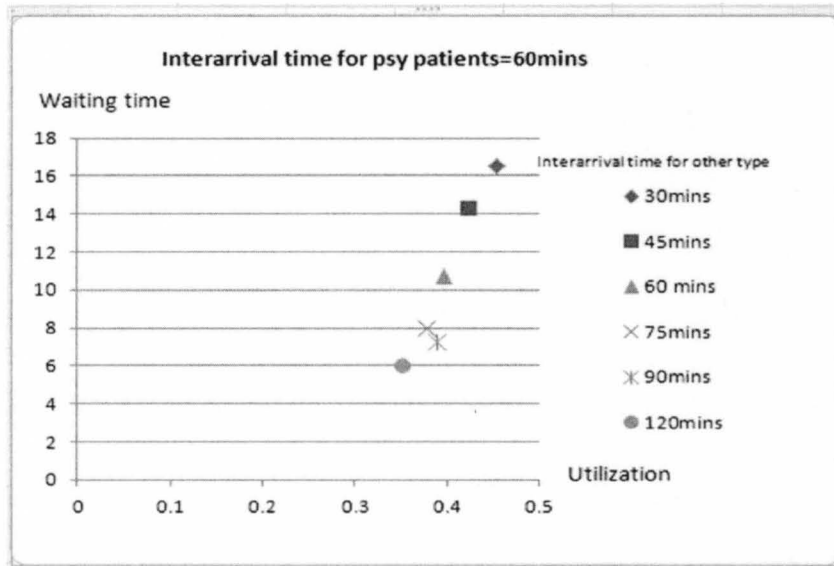


Figure 23 - Interarrival Time for Patients Who See the Psychologist = 60 minutes

From Figure 23, when T1 = 60 minutes, as the interarrival time for other patient increase from 30 to 120 minutes, the utilization increases only marginally. But the increase in waiting time is rather drastic (6 VS.18 minutes). We study two points from the plot, one has the highest utilization when T1 and T0 are 60 and 30 minutes, respectively. In this case, the average utilization of the staff is 0.453, the waiting time for patients is 16.528 minutes, the total time for patients staying in the clinic is 101.009 minutes (1.68 hours), the number of patients served is 67, and the duration of clinic workday is 924 minutes (15.4 hours). On the other hand, the

point with the median utilization occurs when T1 and T0 are both 60 minutes. In this case, the average utilization of the staff is 0.396, the waiting time for patients is 10.689 minutes, the total time for patients staying in the clinic is 93.776 minutes (1.56 hours), the number of patients served is 41 and the duration of clinic workday is 546.5 minutes (9.1 hours).

- T1 = 75 minutes

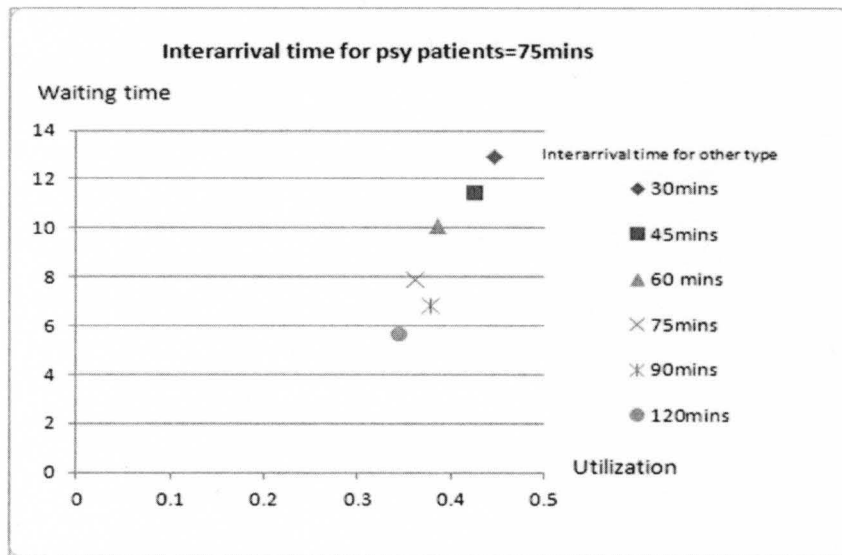


Figure 24 - Interarrival Time for Patients Who See the Psychologist = 75 minutes

From Figure 24, the point with the highest utilization occurs when T1 and T0 are = 75 and 30 minutes, respectively. The average utilization of the staff is 0.448, the waiting time for patients is 12.892 minutes, the total time for

patients staying in the clinic is 95.761 minutes (1.59 hours), the number of patients served is 64, and the duration of clinic workday is 914 minutes (15.23 hours). On the other hand, the point with the median utilization occurs when T1 and T0 are 75 and 60 minutes, respectively. In this case, the average utilization of the staff is 0.386, the waiting time for patients is 10.064 minutes, the total time for patients staying in the clinic is 92.747 minutes (1.54 hours), the number of patients served is 39, and the duration of clinic workday is 556.1 minutes (9.27 hours)

- T1 = 90 minutes

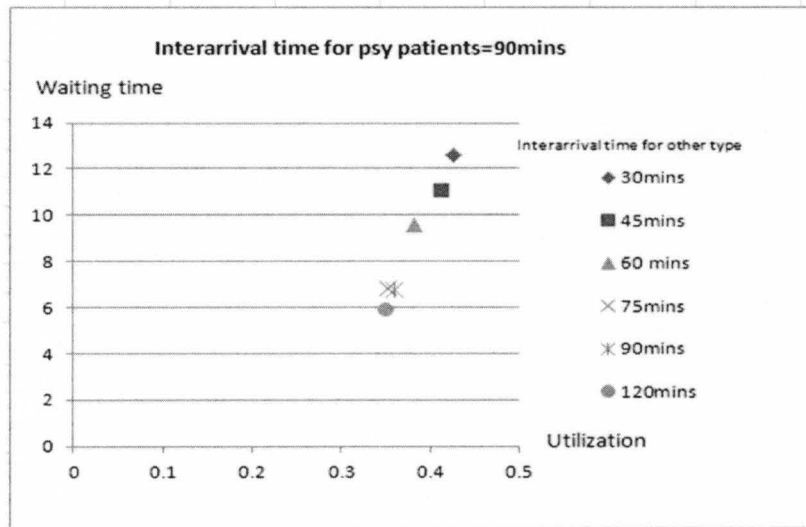


Figure 25 - Interarrival Time for Patients Who See the Psychologist = 90 minutes

The plot is designed similarly to the one in Figure 23. From Figure 25, the point with the highest utilization occurs when T_1 and T_0 are 90 and 30 minutes, respectively. The average utilization of the staff is 0.427, the waiting time for patients is 12.614 minutes, the total time for patients staying in the clinic is 94.56 minutes (1.58 hours), the number of patients served is 64, and the duration of clinic workday is 923.1 minutes (15.39 hours). On the other hand, the point with the median utilization occurs when T_1 and T_0 are 90 and 60 minutes, respectively. In this case, the average utilization of the staff is 0.382, the waiting time for patients is 9.598 minutes, the total time for patients staying in the clinic is 91.428 minutes (1.5238 hours), the number of patients served is 38 and the duration of clinic workday is 553.1 minutes (9.21 hours).

- T1 = 120 minutes

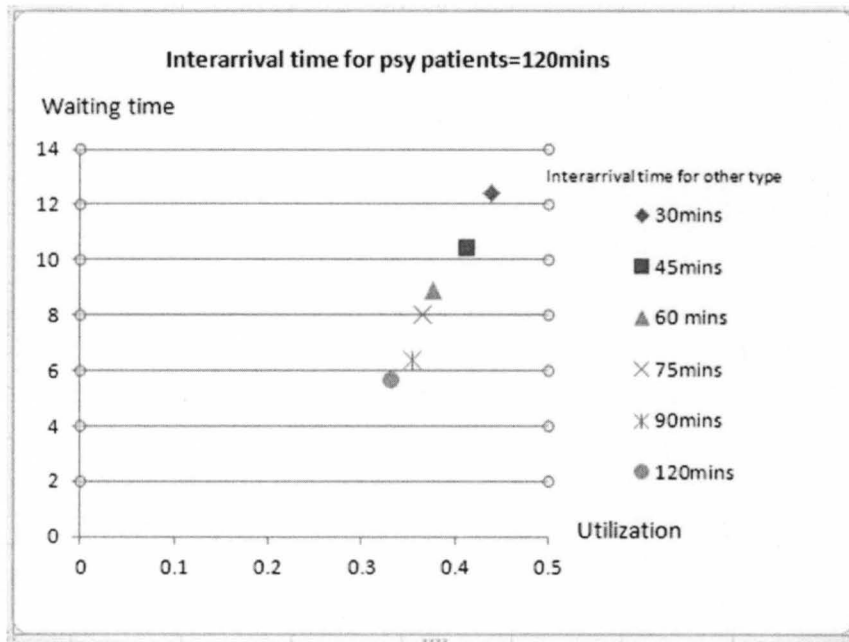


Figure 26 - Interarrival Time for Patients Who See the Psychologist = 120 minutes

Finally, Figure 26 shows that the point with the highest utilization occurs when T1 and T0 are 120 and 30 minutes, respectively. The average utilization of the staff is 0.439, the waiting time for patients is 12.382 minutes, the total time for patients staying in the clinic is 92.394 minutes (1.54 hours), the number of patients served is 62, and the duration of clinic workday is 901 minutes (15 hours). On the other hand, the point with the median utilization occurs when T1 and T0 are 120 and 60 minutes, respectively. In this case, the average utilization of the staff is 0.376, the waiting time for patients is 8.889 minutes, the total time

for patients staying in the clinic is 88.95 minutes (1.48 hours), the number of patients served is 37, and the duration of clinic workday is 553.7minutes (9.23 hours).

A.2 Conclusions on the Interarrival Time for Patients who See the Psychologist:

From Figures 20 through 26, we find that the number of patients served and utilization of staff are significantly improved when overbooking takes place. But the latter also causes increase in both patient waiting time and clinic opening time (system throughput time). We compile the following Table V, consisting of selected data points from figures 20 through 26, to study the tradeoff between the utilization and the waiting time. Our goal is to choose a set of parameter settings that yields higher utilization and shorter waiting time. In addition, we target the duration of clinic open hours to be near 8 hours (8am to 4 pm) or 480 minutes.

Table V

DATA OF HIGH AND MEDIAN UTILIZAION POINT

Interarrival time for psychologist patients	Interarrival time for other patients	Utilization	Waiting time for patients (minutes)	Total time in clinic for patients (minutes)	# of patients	Duration of Clinic Workday (minutes)
15mins	30mins	0.482	21.109	108.54	84	984.7
15mins	60mins	0.417	10.716	93.347	47	592.5
30mins	30mins	0.472	21.469	109.18	75	944
30mins	60mins	0.42	10.7	93.393	47	584.6
45mins	30mins	0.451	19.08	104.657	70	950
45mins	60mins	0.416	10.995	93.862	44	568.4
60mins	30mins	0.453	16.528	101.009	67	924
60mins	60mins	0.396	10.689	93.776	41	546.5
75mins	30mins	0.448	12.892	95.761	64	914
75mins	60mins	0.386	10.064	92.747	39	556.1
90mins	30mins	0.427	12.614	94.56	64	923.1
90mins	60mins	0.382	9.598	91.428	38	553.1
120mins	30mins	0.439	12.382	92.394	62	901
120mins	60mins	0.376	8.889	88.95	37	553.7
150mins	30mins	0.418	9.962	88.3158	62	906.69
150mins	60mins	0.362	6.769	83.6984	36	536.31

Table V suggest that the combination of the interarrival time for returning patients who see psychologist being 30 minutes and the interarrival time for other patients being 60 minutes meets our criteria. Particularly, for this setting, the average utilization is 42%, the average waiting time is 10.7 minutes, the average total time for patients in clinic is 93.393 minutes (1.56 hours), the number of patients served per day is 47, and duration of the clinic workday is 584.6 minutes (9.74 hours).

A.3 Changing the interarrival time for all returning patients

The purpose for this experimental run is to calibrate the interarrival times between new and returning patients.

Let T_r = The interarrival time for returning patients

Let T_n = The interarrival time for new patients

- $T_r = 15$ minutes

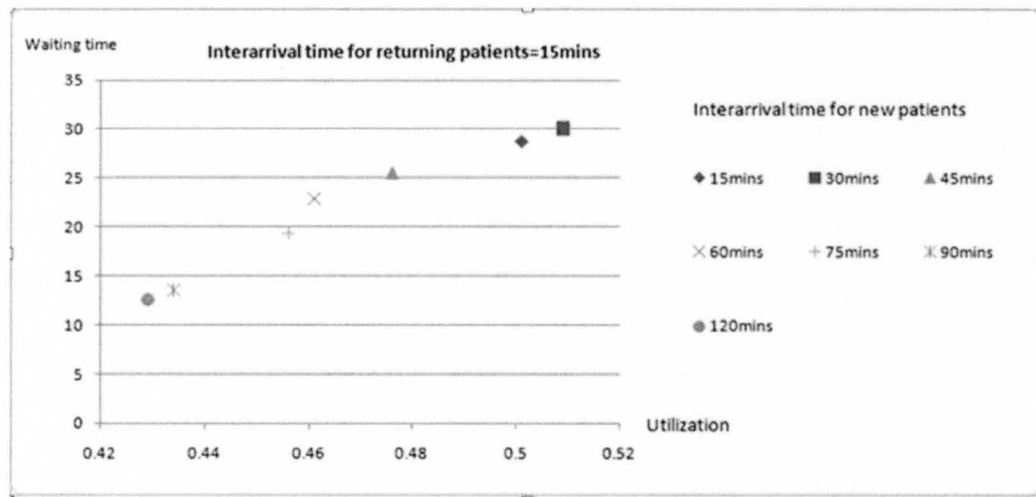


Figure 27 - Interarrival Time for Returning Patients = 15 minutes

Figure 27 plots the average patients waiting time against the average system utilization when the interarrival time for returning patients is set to be 15 minutes. Seven situations are considered, when the interarrival time for new patients are set to be 15, 30, 45, 60, 75, 90 and 120 minutes, respectively. Also note that the average waiting time and utilization are computed based on 30 replications.

Again, as in section A.1, overbooking causes not only

increase in the staff utilization, but unfortunately, increase in the patients' waiting time. Similar to the techniques we employ in section A.1, we study two points from the plot. One has the highest utilization when T_r and T_n are 15 and 30 minutes, respectively. In this case, the average utilization of the staff is 0.509, the waiting time for patients is 30.08 minutes, the total time for patients staying in the clinic is 122.9 minutes (2 hours), the number of patients though the system is 121, and the duration of clinic open hours is 1299.33 minutes (21 hours). The other point has the median utilization when T_r and T_n are 15 and 60 minutes, respectively. In this case, the average utilization of the staff is 0.461, the waiting time for patients is 22.897 minutes, the total time for patients staying in the clinic is 111.703 minutes (1.86 hours), the number of patients served is 105, and the duration of the clinic workday is 1202.54 minutes (20.03 hours).

- $T_r = 30$ minutes

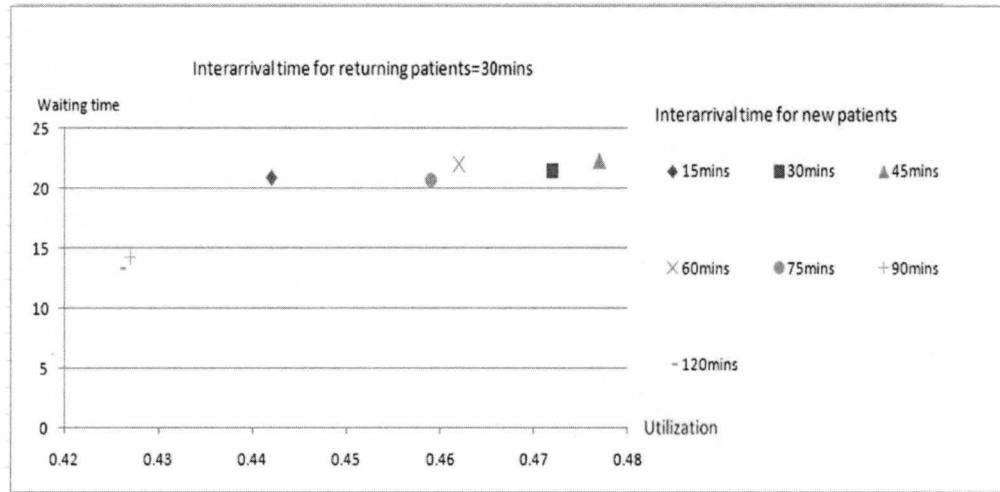


Figure 28 - Interarrival Time for Returning Patients = 30 minutes

From Figure 28, we find that the system utilization and the patient's total waiting time are not very sensitive to the change in T_r and T_n . We also can see that the waiting time are almost same when T_r is 30 minutes. So, we study one point from the plot which is the highest utilization point when T_r and T_n are 30 and 45 minutes, respectively. In this case, the average utilization of the staff is 0.477, the waiting time for patients is 22.276 minutes, the total time for patients staying in the clinic is 111.127 minutes (1.85 hours), the number of patients reserved is 69, and the duration of the clinic open hours is 822.64 minutes (13.7 hours).

- $T_r = 45$ minutes

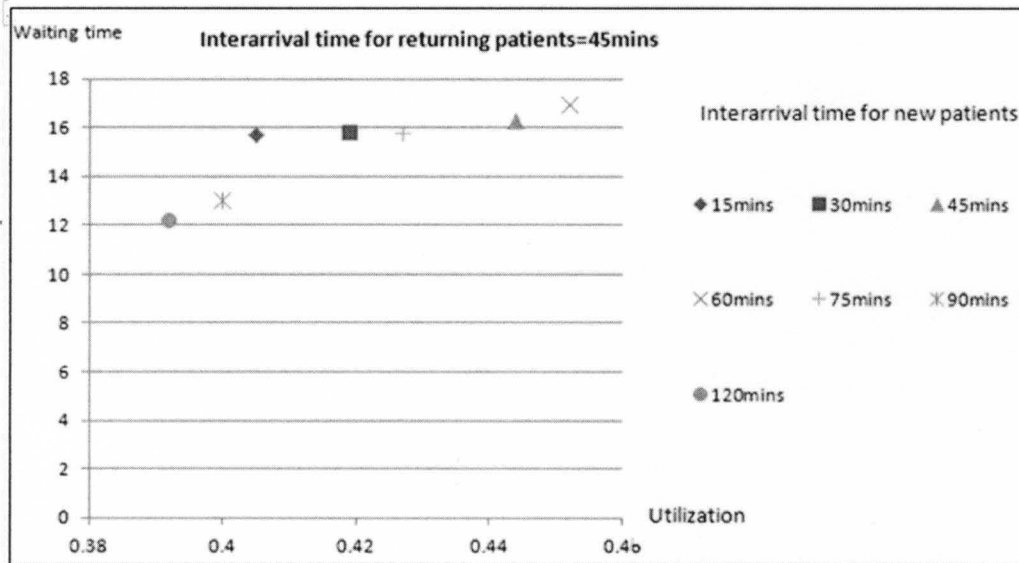


Figure 29 - Interarrival Time for Returning Patients = 45 minutes

From Figure 29, we find that the patient's total waiting time are not very sensitive to the change in T_r and T_n . We do not need to compare the highest utilization point and the median utilization point, for the patient's waiting time are similar. The point with the highest utilization occurs when T_r and T_n are 45 and 60 minutes, respectively. In this case, the average utilization of the staff is 0.452, the waiting time for patients is 16.954 minutes, the total time for patients staying in the clinic is 103.265 minutes (1.72 hours), the number of patients be reserved is 51, and the duration of clinic workday is 635.49 minutes (10.59 hours).

- $T_r = 60$ minutes

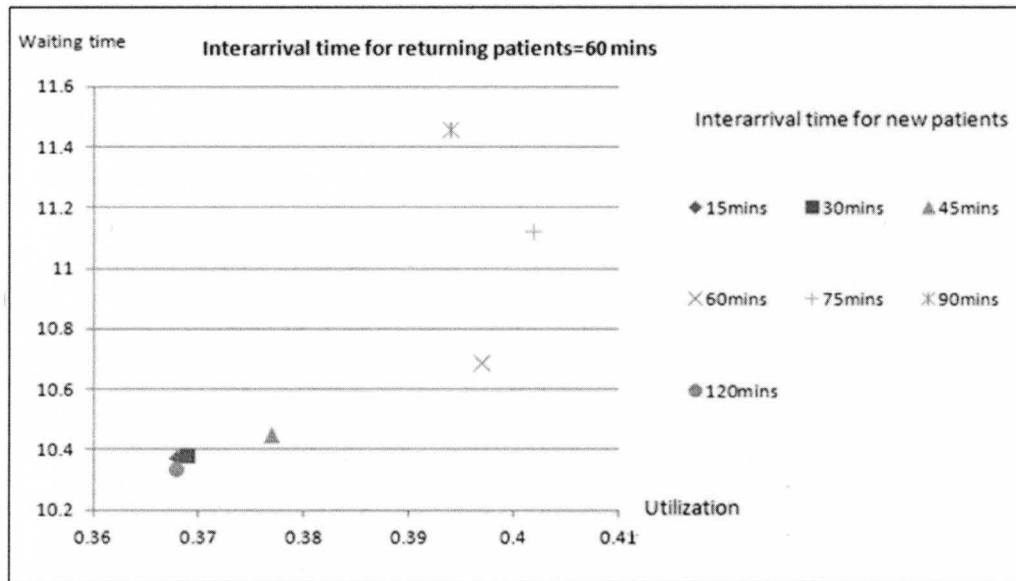


Figure 30 - Interarrival Time for Returning Patients = 60 minutes

From Figure 30, we find that the system utilization and the patient's total waiting time are not very sensitive to the change in T_r and T_n . Nevertheless, we study the highest utilization point when T_r and T_n are 60 and 75 minutes, respectively. In this case, the average utilization of the staff is 0.402, the waiting time for patients is 11.118 minutes, the total time for patients staying in the clinic is 94.403 minutes (1.57 hours), the number of patients though the system is 39, and the duration of clinic open hours is 502.7 minutes (8.37 hours).

● $T_r = 75$ minutes

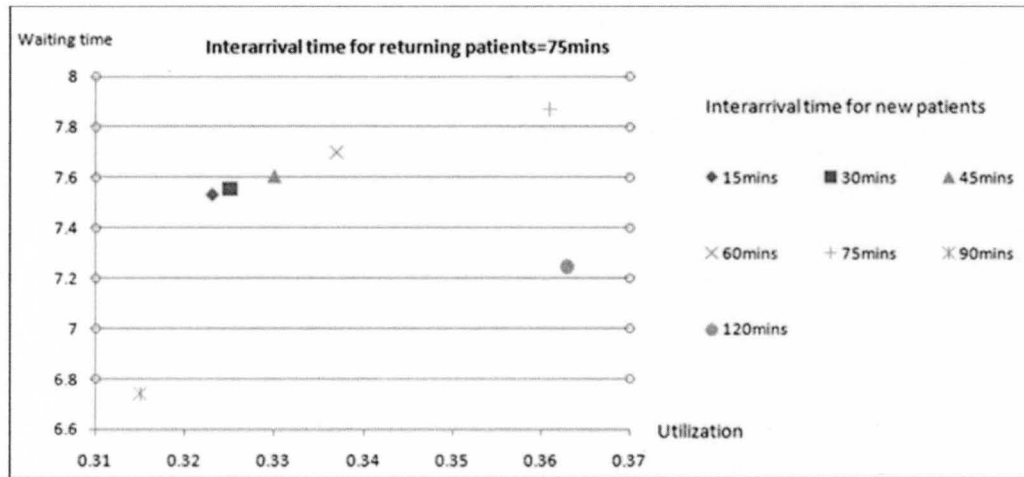


Figure 31 - Interarrival Time for Returning Patients = 75 minutes

From Figure 31, we find that the system utilization and the patient's total waiting time are not very sensitive to the change in T_r and T_n . We study the highest utilization point when T_r and T_n are 75 and 120 minutes, respectively. In this case, the average utilization of the staff is 0.363, the waiting time for patients is 7.245 minutes, the total time for patients staying in the clinic is 87.512 minutes (1.46 hours), the number of patients served is 30, and the duration of clinic open hours is 391.92 minutes (6.5 hours).

- $T_r = 90$ minutes

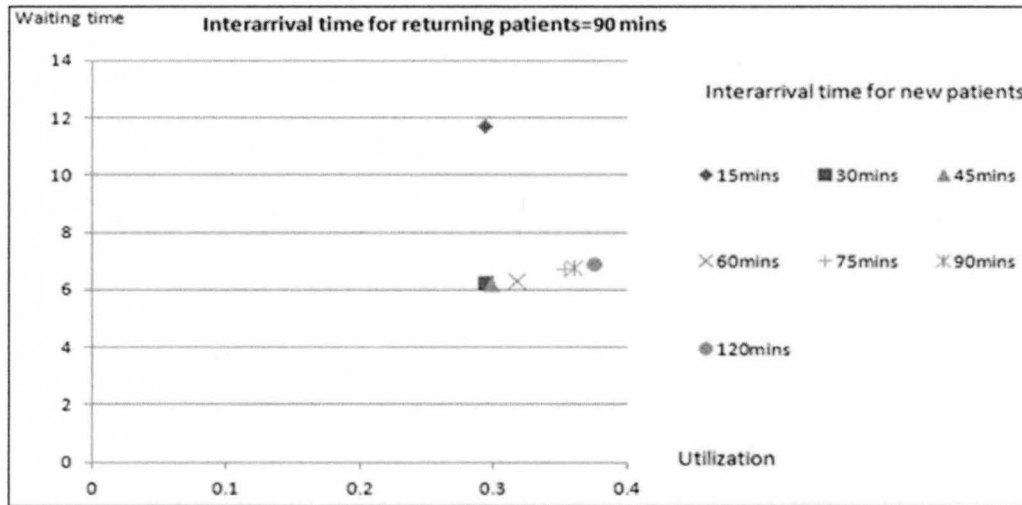


Figure 32 - Interarrival Time for Returning Patients = 90 minutes

From Figure 32, we find that the system utilization and the patient's total waiting time are not very sensitive to the change in T_r and T_n except the point at T_n is 15 minutes. When T_n is 15 minutes, the waiting time is longer than the others, but the utilization is nearly the same with others. We study the highest utilization point when T_r and T_n are 90 and 120 minutes, respectively. In this case, the average utilization of the staff is 0.376, the waiting time for patients is 6.832 minutes, the total time for patients staying in the clinic is 87.764 minutes (1.45 hours), the number of patients be reserved is 27, and the duration of clinic workday is 356.18 minutes (5.9 hours).

● Tr = 120 minutes

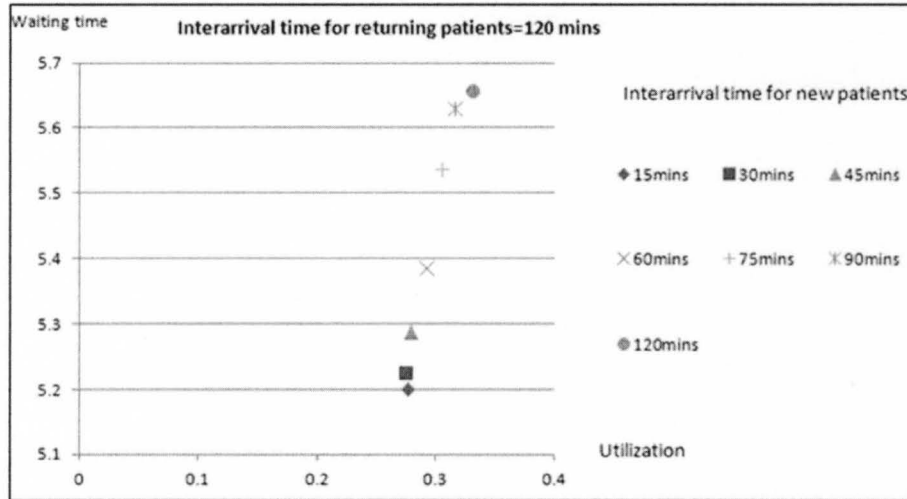


Figure 33 - Interarrival Time for Returning Patients = 120 minutes

Figure 33 shows that the point with the highest utilization occurs when T_r and T_n are both 120 minutes. In this case, the average utilization of the staff is 0.332, the waiting time for patients is 5.654 minutes, the total time for patients staying in the clinic is 81.561 minutes (1.36 hours), the number of patients served is 23, and the duration of clinic open hours is 344.27 minutes (5.75 hours).

A.4 Conclusions on Interarrival Time For Returning Patients:

From Figures 27 to 33, we find that the number of patients served and utilization of staff are improved when overbooking takes place, but the latter also causes increase in both

patient waiting time and clinic opening time. We compile the following Table VI, consisting of selected data points from figures 27 through 33, to study the tradeoff between the utilization and the waiting time. Our goal is to choose a set of parameter settings that yields higher utilization and shorter waiting time. In addition, we target the duration of clinic open hours to be near 8 hours (8am to 4 pm) or 480 minutes.

Table VI
DATA OF HIGH AND MEDIAN UTILIZATION POINTS

Interval time for returning patients	Interarrival time for new patients	Utilization	Waiting time for patients	Total time in clinic for patients	# of patients	Duration of Clinic Workday
15mins	30mins	0.509	30.08	122.9	121	1299.33
15mins	60mins	0.461	22.897	111.703	105	1202.54
30mins	45mins	0.477	22.276	111.127	69	822.64
45mins	60mins	0.452	16.954	103.265	51	635.49
60mins	75mins	0.402	11.118	94.403	39	502.7
75mins	120mins	0.363	7.245	87.512	30	391.92
90mins	120mins	0.376	6.832	87.764	27	356.18
120mins	120mins	0.332	5.654	81.561	23	344.27

As it turns out, the combination of the interarrival time for returning patients who see psychologist being 60 minutes and

the interarrival time for patients being 75 minutes meets these criteria. Particularly, for this setting, the average utilization is 40.2%, the average waiting time is 11.118 minutes, the average total time for patients in clinic is 94.403 minutes (1.57 hours), the number of patients served is 39, and duration of the clinic workday is 502.7 minutes (8.38 hours).

A.5 Conclusions on the Overbooking Model

The simulation shows that when the time between appointments decreases, the total number of served patients increases, the utilization of staff increases and the patient waiting time increases. We need to trade-off between the waiting time and utilization. We conclude from all the plots (from Figure 20 to Figure 33), that a good combination calls for the interarrival time for returning patients who see the psychologist to be 30 minutes and the interarrival time for other returning patients to be 60 minutes, and the interarrival time for new patients to be 75 minutes. This yields the system utilization of 0.411 and the average patient's waiting time of 10.909 minutes. Additionally, the

total time for patients is 93.893 minutes (1.56 hours) ,
numbers of patients served is 43 , and duration of the Clinic
open hours is 543.65 minutes (9.06 hours).

B. Multiple Resource Model

B.1 Analyze the Data of Multiple Resource Model

In healthy for life, returning patients can choose to see one or two staff during one visit. This is implemented in our simulated model. In this regard, there are 11 types of patients.

- New patients
- Returning patients who see the physician
- Returning patients who see the nutritionist
- Returning patients who see the psychologist
- Returning patients who see the exercise physiologist
- Returning patients who see the physician and the nutritionist
- Returning patients who see the physician and the exercise physiologist
- Returning patients who see the physician and the psychologist

- Returning patients who see the nutritionist and the exercise physiologist
- Returning patients who see the nutritionist and the psychologist
- Returning patients who see the exercise physiologist and the psychologist

We set the interarrival time for all patients to be 30 minutes, 60 minutes and 90 minutes. In addition, we carefully control the maximum number of patients to be seen every day. For example, when the interarrival time is 30 minutes, we set maximum number of new patients to be 14, the maximum number of returning patients see only one staff to be 16, the maximum number of returning patients who see two staff to be 8.

Table VII displays the system performance with various interarrival time. The performance includes: the maximum number of appointments for various types of patients, the average utilization of individual staff, the total waiting time for patients, and the total numbers of patients served.

Table VII
OUTPUT FROM SIMULATION OF MULTI-RESOURCE VISITS

	Time between arrival		
	90 mins	60 mins	30 mins
#max of appointments for new patients	4	7	14
#max of appointments for RP see nutritionist	5	8	16
#max of appointments for RP see Exercise Physiologist	5	8	16
#max of appointments for RP see Psychologist	5	8	16
#max of appointments for RP see Doctor	5	8	16
#max of appointments for RP see Doctor and Exercise Physiologist	3	5	8
#max of appointments for RP see Doctor and Nutritionist	3	5	8
#max of appointments for RP see Nutritionist and Exercise	3	5	8
#max of appointments for RP see Nutritionist and Psychologist	3	5	8
#max of appointments for RP see Doctor and Psychologist	3	5	8
#max of appointments for RP see Psychologist and Exercise	3	5	8
Utilization of Doctor	0.68	0.55	0.61
Utilization of Exercise Physiologist	0.78	0.87	0.91
Utilization of Nurse	0.67	0.58	0.69
Utilization of Nurse Practitioner	0.41	0.47	0.52
Utilization of Nutritionist	0.45	0.48	0.58
Utilization of Psychology	0.69	0.64	0.76
Utilization of Registration	0.77	0.74	0.88
Waiting time for new patients	123.74	175.31	282.85
Waiting time for RP see nutritionist	64.7	116.51	244.15
Waiting time for RP see Exercise Physiologist	94.67	194.26	409.66
Waiting time for RP see Psychologist	116.12	152.62	317.38
Waiting time for RP see Doctor	123.25	179.75	238.11
Waiting time for RP see Doctor and Exercise Physiologist	150.64	324.51	451.6
Waiting time for RP see Doctor and Nutritionist	86.89	129.14	269.03
Waiting time for RP see Nutritionist and Exercise	177.17	345.38	514.27
Waiting time for RP see Nutritionist and Psychologist	137.12	205.9	403.4
Waiting time for RP see Doctor and Psychologist	125.32	187.98	372.27
Waiting time for RP see Psychologist and Exercise	164.31	298.66	423.78
Total time for new patients	259.74	311.31	418.85
Total time for RP see nutritionist	120.7	172.51	300.15
Total time for RP see Exercise Physiologist	150.67	250.26	465.66
Total time for RP see Psychologist	177.12	213.62	378.38
Total time for RP see Doctor	219.25	275.75	334.11
Total time for RP see Doctor and Exercise Physiologist	286.64	460.51	587.6
Total time for RP see Doctor and Nutritionist	202.89	245.14	385.03
Total time for RP see Nutritionist and Exercise	273.17	441.38	610.27
Total time for RP see Nutritionist and Psychologist	238.12	306.9	504.4
Total time for RP see Doctor and Psychologist	266.32	328.98	513.27
Total time for RP see Psychologist and Exercise	265.31	399.66	524.78
total # of patients served	51	76	129

Let T_1 = patients' interarrival time

Table VII indicates that the total times for new patients staying in the clinic are approximate 259 minutes, 360 minutes, 311 minutes, for $T_1 = 90, 60, 30$ minutes, respectively. They all exceed 4 hours, which is not acceptable to patients. Compared to the single-resource model, the gain in staff utilization for multi-resource model is very minimal. For example, when $T_1 = 90$ minutes, the system utilization for the single resource model is 48%, nearly 50%. The same is true for $T_1=60$ minutes and $T_1 = 30$ minutes. However, the increase in waiting time for the multi-resource model is enormous. For example, when $T_1= 30$ minutes, the waiting time is 356.95 minutes (5.95 hours) which is more than half day.

To solve the above issue of excessively long waiting time, we first drop the option of $T_1 = 30$ minutes. Secondly, we limit the max number of patient served. The results are displayed in Table VIII.

Table VIII

REDUCE THE INTERARRIVAL TIME FOR MULTI-RESOURCE

	Time between arrival	
	60 min	90mins
#max of appointments for new patients	7	4
#max of appointments for RP see nutritionist	8	5
#max of appointments for RP see Exercise Physiologist	8	5
#max of appointments for RP see Psychologist	8	5
#max of appointments for RP see Doctor	8	5
#max of appointments for RP see Doctor and Exercise Physiologist	6	1
#max of appointments for RP see Doctor and Nutritionist	6	1
#max of appointments for RP see Nutritionist and Exercise	6	1
#max of appointments for RP see Nutritionist and Psychologist	6	1
#max of appointments for RP see Doctor and Psychologist	6	1
#max of appointments for RP see Psychologist and Exercise	6	1
Utilization of Doctor	0.678	0.55
Utilization of Exercise Physiologist	0.875	0.63
Utilization of Nurse	0.72	0.49
Utilization of Nurse Practitioner	0.59	0.52
Utilization of Nutritionist	0.57	0.42
Utilization of Psychology	0.76	0.45
Utilization of Registration	0.85	0.74
Waiting time for new patients	224.32	33.3
Waiting time for RP see nutritionist	123.37	35.9
Waiting time for RP see Exercise Physiologist	202.32	50.07
Waiting time for RP see Psychologist	179.09	67.01
Waiting time for RP see Doctor	240.77	27.76
Waiting time for RP see Doctor and Exercise Physiologist	338.27	167.07
Waiting time for RP see Doctor and Nutritionist	159.36	0
Waiting time for RP see Nutritionist and Exercise	366.3	0
Waiting time for RP see Nutritionist and Psychologist	258.76	10
Waiting time for RP see Doctor and Psychologist	252.86	101.85
Waiting time for RP see Psychologist and Exercise	308.51	0
Total time for new patients	360.32	169.3
Total time for RP see nutritionist	179.37	91.9
Total time for RP see Exercise Physiologist	258.32	106.07
Total time for RP see Psychologist	240.09	128.01
Total time for RP see Doctor	336.77	123.76
Total time for RP see Doctor and Exercise Physiologist	474.27	303.07
Total time for RP see Doctor and Nutritionist	275.36	0
Total time for RP see Nutritionist and Exercise	462.3	0
Total time for RP see Nutritionist and Psychologist	359.76	111
Total time for RP see Doctor and Psychologist	393.86	242.85
Total time for RP see Psychologist and Exercise	409.51	0

Table VIII indicates that the total times for new patients staying in the clinic are approximate 360 minutes, 170 minutes for $T1 = 60$ and 90 minutes, respectively. They are better than those in Table VII, but it is still not acceptable to patients. Compared to the data in Table VII, the utilization decreased a little bit, and the waiting time also decreased some. For example, in Table VIII, the average utilization for $T1 = 90$ minutes is 0.54 while in Table VII, it is 0.64. On the other hand, the waiting time in Table VIII is 61 minutes compared to the 123 minutes in Table VII.

B.2 Conclusions on the Multiple-Resource Model:

Tables VII and VIII suggest that compared to the single-resource model, multiple-resource scheduling leads to a significant increase in the total time that patients stay in the clinic, and only marginal gains on both the staff utilization and numbers of patients served. We conclude that the multiple-resource is not effective at this point. Our future interest is to study if multi-resource scheduling helps with the multi-day simulation model.

V CONCLUSIONS

The clinic Healthy for Life faces a big problem that the no-show rate is very high. Patients make appointments, but they do not show up. This problem has many negative effects. First, the staff in the clinic cannot work efficiently, for they have to wait for the patients. Second, patients who want to make appointments in certain time period cannot do so, for others have been scheduled for this time but indeed do not show up. Third, the clinic cannot make a good profit for the high no-show rate.

To solve this problem, we propose two methods. One is the overbooking method. In overbooking, the number of patients scheduled is larger than what the clinic can handle. This method is compensated for patients who do not show up for appointments. Ideally, overbooking can help increase the staff utilization and the number of patients reserved without much sacrifice on the patients' waiting time. The second method is the multiple-resource model, in which we can allow

patients to see two staff in one visit if they would like to.

We build a simulation model to simulate one day of the clinic operations while assuming every staff works five days in a week. We vary the interarrival time of patients from 30 minutes to 120 minutes to study the effects of overbooking. From the simulation results, we observe that overbooking leads to increase in both the utilization of staff and the number of patients reserved per day. However, it also causes the waiting time for patients to increase. Considering this trade-off, we conclude that the interarrival time for returning patients who see the psychologist being 30 minutes, the interarrival time for other returning patients being 60 minutes, and the interarrival time for new patients being 75 minutes is the best option overall. We hope this recommendation can help Healthy for Life to schedule patients more efficiently and to achieve maximal staff utilization and profit.

In the second method of multiple-resource, simulation results suggest that the total time for patients to stay in the clinic is unacceptably high due to the multi-resource scheduling. Therefore, we suggest the clinic does not consider

this method.

Finally, we offer some other suggestions. First, Healthy for Life can make appointments one week in advance, and this may help them to reduce the no show rate. Second, patients would feel more comfortable to visit the psychologist in the future if they get to meet him/her during their very first visit with the clinic.

VI FUTURE RESEARCH

In this thesis, a one-day simulation model is developed to study the daily operations at a clinic of the University of Louisville, Healthy for Life. There are several directions for future research. First, the present model assumes that all the staff in the clinic work on five days in a week. However, in reality, not all staff work every day. So, an extension of a multi-day model with various staffing each day is worth investigating. Second, we plan to collect additional data to develop a long-term model, which categorizes patients and assigns different no-show rates to different categories of patients. This will help to increase the accuracy of the overbooking model significantly. For example, ways to categorize patients include whether or not they show up, which staff they see, which staff they make appointments for next month, whether they use public or private transportation, what type of insurance they have, etc. We can then investigate overbooking for these specific categories of patients. Third,

we would also like to develop a longer-term model. For example, we like to simulate at least three months for patients who come to the clinic once every month. Finally, in this thesis, the multiple-resource method does not show much benefit to the clinic. We like to further investigate how multiple-resource scheduling performs in a multi-day or long-term model.

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