ANALYSIS OF A HOSPITAL CALL CENTER

A THESIS
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MASTER OF SCIENCE

by
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August, 2012

I certify that I have read this thesis and that in my opinion it is full adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

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In this thesis, we study the call center operations of a particular hospital located in Ankara, namely Güven Hospital. The hospital call center takes role as a medical consulting and appointment center and also domestic call traffic flows over the call center. These three types of calls are classified as consulting, appointment and domestic calls. The arriving call rate to the call center vary depending on hours and each agent is capable of giving service to each type of calls.(i.e. Agents are multi-tasking). Different types of calls have different exponential service time distributions. Regardless of call type calls may abandon during their waiting time in the call center. Abandonment rate and arrival rates of the calls are assumed to be exponential. Call center directs some percent of appointment calls to a doctor who gives service in the call center and some percent of consulting calls to hospital units depending on customers' requests. A domestic call only receives service from the call center. Some percent of these diverted calls to doctor and hospital units return to call center. This diverting and returning process among call center, doctor and hospital units constitutes the call center network of the hospital. The aim of this study is to model this call center network as to reflect the properties of the analyzed system. Accordingly, the system is modeled with queuing network and simulation approaches. Different models are developed with different divert and return rates and different number of agents being multi-tasking or dedicated to give service to a specific call type. These models are compared in terms of systems performance metrics and related numerical analyses are reported.

Keywords: Hospital Call Center, Queuing, Simulation, Multi-Type Customers

ÖZET

HASTANE ÇAĞRI MERKEZİ ANALİZİ

Ezel Ezgi Budak
Endüstri Mühendisliği, Yüksek Lisans
Tez Yöneticisi: Prof. İhsan Sabuncuoğlu
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Ağustos, 2012

Bu tez çalışmasında, Ankara' da hizmet veren Güven Hastanesi'nin çağrı merkezi sistemi çalışılmıştır. Toplanan veriler ile yapılan analizler sonucunda hastane çağrı merkezinin hasta ve hasta yakınlarından gelen tıbbi danışmanlık ve randevu isteği aramaları ile hastane içi bağlantı kurmak isteyen personele hizmet vermekte olduğu görülmüştür. Bu üç arama tipi danışma, randevu ve iç hat aramaları olarak sınıflandırılmıştır. Çağrı merkezine gelen çağrı oranı saatler bazında değişmekte ve çağrı merkezi çalışanları tüm arama tiplerine hizmet verebilmektedirler. Farklı arama tipleri farklı üstel servis zamanlarına sahip olup arama tipinden bağımsız olarak kuyruktaki müşterilerin sabretme sürelerine göre, bazı aramalar abandone olmaktadırlar. Çağrıların abandone olma oranı ve çağrıların geliş hızının üstel dağıldığı kabul edilmiştir. Çağrı merkezi belli olasılıklarla danışma aramalarını hastane içi birimlere, randevu aramalarını ise çağrı merkezinde hizmet veren danışman doktora yönlendirmekte iç hat aramalarına ise sadece kendi hizmet vermektedir. Yönlendirilen danışma ve randevu aramaları belli bir yüzde ile çağrı merkezine geri dönmektedir. Tüm bu yönlendirilen ve geri dönen aramalar doktor, hastane birimleri ve çağrı merkezinden oluşan bir kuyruk ağını oluşturmaktadır. Çalışmanın amacı bu çağrı merkezi ağının sistemin özelliklerini yansıtacak şekilde modellenmesidir. Bu doğrultuda sistem, kuyruk ağı ve simülasyon yaklaşımları ile modellenmiştir. Sonrasında, simülasyon yöntemi ile çalışanların her arama tipine ya da belirli bir arama tipine hizmet verdiği, farklı sayıda çalışan içeren ve yönlendirilme ve geri dönüş yüzdelerinin farklılaştığı modeller sistem performans metrikleri bazında karşılaştırılmıştır ve sayısal çalışmalar rapor edilmiştir.

Anahtar Sözcükler: Hastane Çağrı Merkezi, Kuyruk Problemleri, Simülasyon, Farklı Müşteri Tipleri

To my family…

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Chapter 1

Introduction

A call center is the first contact point of businesses with customers. It is the central point of any organization from which all customer contacts are managed. Through a right organized call center, companies are able to create more accessible and dependable information for customers which not only adds significant value to the image of the company but also generates an interactive environment for the company to manage customer relationship in an effective manner. Call centers work as front desks of any organization, which is a channel to provide information, service or product etc. for customers transforming these to benefit in the form increased customer satisfaction for the company.

Being an efficient channel for business environment, call centers are becoming more important with technological improvements. However, these improvements also cause challenges in management and planning of the call centers. The primary challenge in designing and managing any call center is to achieve a balance between operational efficiency and service quality which leads to customer satisfaction.

Maintaining customer satisfaction in healthcare area is harder than any other service area since needs of people is urgent and sometimes vital. Healthcare call centers are carrying out increasingly broader array of services to callers. In addition to receiving and directing telephone calls, healthcare call centers are becoming medical contact centers, also handling electronic communications, such as email and text messages. More customers are demanding medical information online, asking basic records, managing insurance claims, reports etc. In her study Stroher (2006) mention two thirds of US hospitals employ call centers for vast variety of purposes starting from traditional switchboard operators that triage calls to relevant provider to more sophisticated centers that manage billing operations, nurse advice lines, marketing campaigns etc. Since the healthcare industry handles a vast variety of calls at high volumes, the quality of healthcare service given is getting harder and there will be a corresponding need of medical providers and talented agents to handle issues more effectively and efficiently. Crow et.al. (2003) discuss the issue of customer satisfaction and measurement of satisfaction in health care area. We are not going to dig the concepts of customer satisfaction and customer loyalty in health care management however, the reflection of these concepts to call center is not deniable since it is a branch in healthcare theme. Moving from here, we can conclude that a well-conducted call center giving service in health care area play an important role in balancing service quality and operational efficiency.

A central characteristic of a call center is whether it handles inbound or outbound traffic. An inbound call center only handles the calls which are initiated by the customer but an outbound call center is one in which agents make calls to customers on account for a business. Hospital call centers can be categorized as inbound call centers since customers make the calls to consult medical issues, to make appointments, to ask for their medical reports or test results etc. Another significant difference between any call center and a hospital call center is the customer profile. The customers are mainly composed of patients or patients' relatives who are more sensitive. Patients are less willing to stay on the line therefore abandonment issue is relatively high since people are impatient and it is hard to satisfy them. Therefore operational efficiency is also extremely important in order to achieve an acceptable level of customer satisfaction with less abandonment and high response rate.

This study mainly analyzes the call center of a particular hospital located in Ankara, namely Güven Hospital. This hospital has 250 beds capacity with 10 operating rooms, one of the largest private hospitals in the city, with its highly specialized team of 1000 employees, including 200 doctors and 350 nurses. The call center of the hospital receives thousands of calls a day. Incoming call types vary since hospital provides service with many units and people. The hospital call center takes role as a medical consulting and appointment center and also domestic call traffic flows over the call center too. Those calls can be classified in three categories: Consultancy, Appointment and Domestic.

Consultancy Calls are made by patients and are mainly to collect information about treatments, doctors, prices of operations, talk to inpatients, learn results of tests, etc. Appointment Calls are made by patients again, to make an appointment from a medical unit. Domestic Calls are internal calls made by the hospital staff to get connected to another unit in the hospital.

The major concern of the hospital management is to achieve a service level where patients calling for an appointment can make their appointment in a reasonable time without abandoning the call due to long waiting times and a patient calling for consultancy can reach to his/her destination unit. According to the data collected by the center, between 7% - 15 % of the calls are being abandoned due to long waiting times. There are several issues which make this call center busy and create a necessity for an effective design of its operations as explained below.

Appointment calls are made by patients directly to make appointments for consultation or treatment. Call center staff has the authority to make the appointment directly via software tool that all hospital is connected to. There are currently 12 agents working in shifts and a consulting doctor to whom patients calling to make an appointment but not sure from which unit they should make the appointment are directed to.

A great proportion of consultancy calls are directed to hospital units and others are handled by the call center staff. Those which are directed to other units are either “followed transfers” or “un-followed transfers”. A call is followed if the agent waits on the line until the unit picks up the phone and is an un-followed call if the only dials the number of relevant unit and does not wait for the unit to pick up the phone, therefore directed customer can either receive a busy signal from the hospital unit or gets an answer. Patients calling for consultation complain if their call cannot be connected to the directed unit, as they wait on the line for somebody to pick up the line, but if nobody picks up the line at the directed unit's counter, then this call returns back to the automatic call distributor and the patient re-enters the queue where all process starts over.

Domestic calls are made by hospital personnel, especially by doctors, who do not have access to internal phone numbers or who cannot wait on the phone while treating a patient but need to contact another doctor or nurse immediately. Such domestic calls are also creating a considerable traffic in the call center and keeps agents busy. Despite its negative role on call center performance the hospital has to provide such a service. The call traffic of the call center is pictured below. Incoming Calls are first received by Automatic Call Diverter (ACD) which diverts calls to available agents. Then calls follow probabilistic routes based on their call types. (See Figure 1.1)

Besides achieving an acceptable level of customer satisfaction, the hospital also wants to manage call center in an efficient way since appointment and consulting calls are important when they return to requests of medical treatments or decisions of having operations in the hospital. Abandonment of such calls simply decreases the customer satisfaction which will also bring a profit loss for a private hospital.

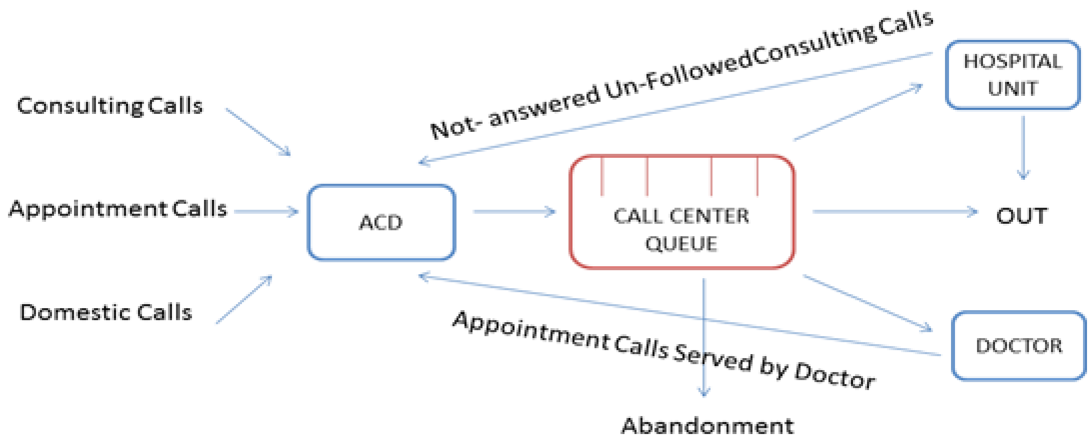

Figure 1.1: Call Traffic

The main performance criterion of the call center set by the hospital management is to make as many appointments as possible. In the mean time, consultancy calls not reaching to their destination is not desirable as they create extra traffic and dissatisfaction of the patients. We can easily conclude that domestic and consulting calls generate extra burden to the call center if they cannot be handled in a right and timely manner. The hospital management has complaints on several issues. They have the perception that, high volume of domestic calls is the biggest defect of the call center as well as the busy signals received from internal units where consulting calls are diverted to.

As rapid changes occur in communications technology, many studies are carried out to understand the call center management problems. Analytical approaches such as stochastic processes, queuing theory, and simulation are used to find alternative answers in optimizing a call center system. Our objective is to analyze the system in detail to picture call center's call traffic based on call types, returning call percentages and abandonment; and compare the performance of different configurationsof the call center based on measures related to customer satisfaction and number of appointment calls received. We analyze the system thoroughly and model it explicitly to examine this perception and reveal the performance of the call center in terms of customer satisfaction. We first attempt to model this complicated environment of the call center with a queuing network approach but then resort to a simulation modelsince our queuing modelhas a large state space which makes it impractical to solve and accommodates some simplifying assumptions.

Our main objective is to make a complete analysis of the system and propose methods to improve performance metrics of the hospital call center. Motivated by these, we first have collected data in the call center to understand internal dynamics of the call center. Therefore we observed that hospital units are also attached to call center system since calls are diverted to and returned from the units, necessary observations are also made in hospital units to have a better understanding of the call center network. In addition to the data collected from the call center by and the units, observation, automatically generated call center reports are also used to comprise several information such as output information of arrival rates, service rates, call type percentages, abandonment rate and diverting probabilities. We have used Rockwell Arena Simulation Software to analyze the system based on the data collected and the data provided by the hospital. The system is analyzed with different protocols in terms of number of agents, call-type based assignments, and different flexibility levels to compare system performance under different situations. The main performance measures used in this comparison are percentage of calls that are turned into an appointment, number of calls that are not abandoned due to long waiting times in the queue, number of consultancy calls that are answered by the units, and average waiting times in the queue. The computational results are reported and the best policies among alternatives are given.

The remainder of the thesis is organized as follows:

In Chapter 2, we provide a review of the literature on call center problems and modeling issues. In the first part of this chapter, qualitative studies are mentioned and in the second part, the quantitative studies on the design and analyze of general call center problems are reviewed. The reviewed studies on call center problems ranges from single server queues with one type of customers to network of queues with multiple servers and customer types including one or more of the issues of abandonment, retrials, time varying arrivals, service times etc. since our problem includes all of the mentioned.

In Chapter 3, we will provide description of the call center characteristics in detail. We initialize the analysis with data collection process then the analysis of the collected data will be demonstrated, simultaneously taking assessment of the executives into account, we construct the profile of the call center, and call center metrics based on mathematical analysis.

In Chapter 4, we will propose modeling approaches to the system we analyze in Chapter 3. This section is organized as two parts. In the first part, we will discuss on modeling the system with queuing network approach and in the second part, we will discuss the simulation model and the latter approach will be analyzed in detail as if the output of the models coincide with the system itself, i.e. validation of the simulation model will be shown.

In Chapter 5, we will discuss alternative approaches to optimize the system of management, and then we report the computational results of our modeling approaches. The best policy among alternative approaches is evaluated under different circumstances like varying arrival times and differing agent numbers.

In Chapter 6, we conclude the thesis by giving an overall summary of the study and our contribution to the existing call center literature and suggestions of possible future research directions.

Chapter 2

Literature Review

The literature on the call center modeling and optimization is extensive. The studies are based on varying approaches and comprise many different disciplines. This multi-disciplinary research is ranging from Statistics, through Operations Research, Industrial Engineering, Informatics and Quality Management, to Psychology and Sociology. In spite of various resources to review, there exist rare sources on call centers in health care area. There exist studies on health care management which actually focus on queuing networks inside medical centers not specifically to healthcare call center networks. (Fomundam and Hermann, 2007). Our aim is to give a brief summary of what is researched and studied on this area from the general to the specific based on multi-disciplinary research range. From this point, we have classified the studies on call center under qualitative and quantitative titles. First group of studies are generally empirical and originated in Social Sciences, Marketing and Management. Second group is typically analytical and our modeling approaches of queuing and simulation models are focus of this group.

We will start our review with qualitative studies to understand the general aspects in call center literature and healthcare literature related then we will continue with queuing systems approaches and simulation modeling literature. There exist many studies on literature of call center simulation modeling, however since those studies generally based on specific data, the resulting model and performances are only related to that data. Although, it is sufficient to view a study to gain a point of view on simulation modeling of call centers.

2.1. Qualitative Studies

Feinberg et. al. (2007) specifies operational determinants in achieving customer satisfaction by a call center. Their motive in the study is the lack of literature to suggest variables to improve customer satisfaction in a call center. They focus on determining this literature based on predicting the relationships between variables, i.e. metrics based on collected data from different industry call centers. With regression analysis, they try to predict operational determinants of caller satisfaction. They only find two relevant metrics which are strongly significant however; they conclude that with only two variables "average abandonment" and "percentage of calls closed in first contact" predictions are not strong enough.

Stroher (2006) study the effect of call centers on patient satisfaction. She states that call centers role in healthcare system is getting important day by day with sophisticated changes in call center process based on technological improvements. She claims that call centers are now not only represented by switchboard operations but also with nursing advice lines, marketing health-related programs, disease management programs etc. She analyzed a healthcare call center in the aspect of customer satisfaction by analyzing the questionnaires both employee and customer based.

2.2. Quantitative Studies

In their study, Gans et. al.(2003) review the call center literature, under the titles of busy signals and abandonment, time varying arrival rates, staff scheduling within the base example of homogenous customers and agents. Mandelbaum (2006) in his bibliography reviewed the call center literature based on different research fields consisting studies from marketing and human resource management to operations research and queuing. Studies on call center queuing problems ranges from single server queues with one type of customers to network of queues with multiple servers and customer types including one or more of the issues of abandonment, retrials, time varying arrivals, service times etc.

Koole and Mandelbaum (2002) review queuing models of call centers. Starting with reviewing the literature of single type customers, single skilled agents typical M/M/s models, they continue with more technological call center queue systems of multi-type/ multi skill call centers with IVRs (Interactive Voice Response) and e-mails etc. especially on busy signals and abandonment and skill based routing. They also examine how performance measures of a call center change under different patience times of customers and, with different number of agents from summarized data sheet of ACD. They conclude that using the queuing models which includes abandonments should be chosen.

Collings (1974) study a queuing problem which customers have different service distributions. Collings assume arrivals follow a Poisson distribution and service time distribution is exponential. His motive is the problems in Health Service. He states that patients at hospitals visiting consultants often have service times closely approximates to exponential but average service times are varying between different groups of patients since length of stay in hospital is related to diagnosis, age etc. He used state notation of (N, i); N is the number in the system at time t and i stands for the customer group whose being served. He calculates the equilibrium probabilities as the recurrence relations between the states of the system with a method called "cuts" where a "cut" is composed of (N, i) and neighbor states. He showed that approximation of a group of exponential distributions by a single exponential distribution having a mean equal to the group of exponential distributions causes underestimation of queue sizes. Kelly (1975) extends the study to a network of queues problem with customers of different types which a customer can choose his own path through the network and his service time distribution at each queue.

Garnett. O et. al. (2002) study mathematical queuing model M/M/s+M (also called Erlang A) in which customer's abandonment is included and the inter-arrival time distribution, service time distribution and abandonment time distribution follow an exponential distribution. They state that the models which does not include abandonments cannot reflect system's performance realistically and can cause under or over-staffing. For this purpose, they analyze the abandonment based on customers' patience where the system's capacity is unlimited. Since ACD outputs contain summary data of averages, not call by call data, they use a balance equation of the form:

$\theta * E[\#Waiting\ in\ te\ Queue] = \lambda * P\{Abandonment$ to estimate the abandonment rate θ or average patience of the customers ($1/\theta$). This is the steady state balance of abandonment rate of customers and the rate which abandoning customers enter the system. Then through simplifications based on Little's Theorem, they come up with a formula $\theta * E[W] = P\{Abandonment\}$ which holds under exponentially distributed patience.

Mehrotra & Fama (2003) study the call center system with simulation modeling. Their motive is that, the simulation models are good at reflecting increased complexity in call center with technological improvements. They state that simulation models for call centers are valuable in the terms of operational efficiency. In the study, they state the ways of simulation models can be used by call centers to improve performance metrics and then they provide a modeling framework for the simulation with the inputs of different agent skill definitions, abandonment, and agent schedules. They model a call center with respect to those issues and share related numerical results.

Chapter 3

System Analysis

Despite similar dynamics, call centers take shape according to the corporations' characteristics that they serve, thus we keep a close watch on the call center process to collect necessary information to understand and then to model the system. With the advantage of having a close look to the system, we realize many remarkable characteristics of the center. This process helps us to better understand what type of data is needed, how to analyze such data and how to construct appropriate models.

In our case, the call center' s resources are comprised of an ACD with capacity of 16 trunk lines, 12 agents working in shifts, a doctor for counseling. Trunk line capacity is not used as a metric to optimize since the cost of a trunk line is trivial and call center management wants to focus on the traffic between the hospital units and the call center. Call center works 24 hours a day; however we observed the operations of the call center agents for several days from 9:00 am to 6:00 pm to understand the details of the operations. Observing the operations for this 9 hours is reasonable since 90 percent of the calls are coming in this interval and also doctor and the supervisor works between these hours, thereby for a complete analysis, data are collected in this interval.

As it operates, a large call center generates vast amounts of data. In general, call centers do not store the records of individual call data since to store such amount of data; needs very large databases which incurs high costs. Instead, most of the call centers often summarize data as averages calculated in short time intervals such as 30 minutes in length. In our case the call center keeps data in 5 minute intervals. In Table-3.1, a sample data collection sheet of the call center is shown.

Table 3.1: Sample Call Center Data Sheet (03.01.2011)

	Abandoned at			Session Summary			Longest Queue Time		Average Queue	
Interval	**Queuing**	**Alerting**	**Abandoned**	**Queuing**	**Offered**	**Answered**	**Answered**	**Abandoned**	**Answered**	**Abandoned**
09:00 - 09:05	0	0	0	1	17	17	00:00:26	00:00:00	00:00:26	00:00:00
09:05 - 09:10	1	3	4	2	22	18	00:00:05	00:00:03	00:00:05	00:00:03
09:10 - 09:15	5	0	5	13	19	14	00:00:35	00:01:09	00:00:18	00:00:19
09:15 - 09:20	11	0	11	29	32	21	00:01:56	00:00:44	00:00:48	00:00:13
09:20 - 09:25	0	1	1	6	21	20	00:00:29	00:00:00	00:00:14	00:00:00
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
17:55 - 18:00	0	1	1	2	6	5	00:00:23	00:00:00	00:00:20	00:00:00
Total	327	101	428	1433	2717	2289	-	-	00:40:26	00:24:34
Average	3	1	4	13	25	21	-	-	00:00:22	00:00:14

First column indicates start and end times of the calls, second and third columns show abandoned and alerting calls during those 5 minutes. Under Session Summary, the third column “offered” indicates the total number of calls incoming in this 5 minute, and in last column total number of “answered” calls are shown among “offered“ calls where “abandoned” calls among those offered calls is shown in the first column. Second column indicates the number of queuing calls before getting an answer or abandon. Total of answered and abandoned calls gives offered calls. Last two rows give the summarized information on “total” and “averages” of all columns. Last two columns of the table gives how long an abandoned call waits on average before abandonment.

We have used the data available from the call center to estimate inter-arrival times and abandonment rates of customers in call center system. We are able to calculate inter-arrival time of the calls using “total number of offered calls” and abandonment rate from the data of average abandon time and abandoned call number from hospital data sheet. However the data sheet of hospital does not provide sufficient information to calculate neither service times of the customers nor the traffic between units and call center. But we need those data in order to model the system, therefore a data collection process is conducted by us to observe missing data. Firstly, we are going to mention our derivations from the data sheet given by hospital and secondly the derivations from the collected data will be discussed.

3.1. Inter-Arrival Time

Before estimating inter-arrival rate of received calls, we analyze the data whether incoming call rates differ based on hours in a day. 9 hours between 9:00 am to 6:00 pm are compared based on offered call numbers. One hour intervals are ordered from 1 to 9 as slot 1 stands for the interval 09:00 am-10:00 am and 9 stands for 05:00 pm-06:00 pm. The relevant analysis made with SPSS 11.5. and the null hypothesis of

$H_{01,}$*: The effect of time intervals on arrivals is not meaningful. (I.e. there exists no difference between arrivals according to time intervals)* is tested.

Null Hypothesis H_{01} is tested with rejection probability of 5%. The analysis shows that there exists significant difference among time intervals. Using One Way Analysis Of Variance, according to Student Newman Keuls Test (SNK) observed from SPSS, the intervals are divided into 3 groups based on arrival rates of calls during 9 hours. Most of the calls are received from 10:00 am to 12:00 am which correspond to slots 2 and 3. Another group of similar slots are 1, 4, 5, 6, 7, 8 i.e. 09:00 am to 10:00 am in addition to 12:00 am to 05:00 pm. Towards evening hours, incoming call number decreases significantly since slot 9 i.e. 05:00 pm to 06:00 pm the least number of calls received. Result of the analysis coincides with experiences of the call center management, and also reasonable by rational expectations point of view. [See Appendix A]

From this point, to calculate inter-arrival rates of different intervals $(1/\lambda_t)$ the offered call number average is taken with respect to related time interval length to estimate the arrival rate. The calculation is given as;

$N_{t,i}$: *Total offered call number in time interval t, day i, t*=1, 2, 3, *j*=1, 2... , 30

(30 days of data collection sheets are received from the call center)

T_t=Number of slots in interval t=1 T_t=6, t=2 T_t=2, t=3 T_t=1

$\beta_t = \frac{\sum_{j=1}^{30} N_{tj}}{30*60*T_t}$ $\forall$i, $\forall$j ; Average offered call number in a minute in interval t

$1/\lambda_t = 60/\beta_t$; Inter-arrival time of calls in a minute in time interval t

$\lambda_t =$ Arrival rate of calls in a second

Table 3.2: Hour-Based Inter- Arrival Times

Time Intervals (t)	Inter-Arrival Times ($1/\lambda_t$)
1/4/5/6/7/8	15
2/3	11.1
9	20

Under general acceptances we have assumed the inter arrival times are distributed as exponential with the rate estimated as above; since arrivals to a call center queue is a typical Poisson process.

3.2. Abandonment Rate

Second main estimation from the available data is the abandonment rate of customers. The direct data we gathered from call center data sheet is given in 5 minute intervals and the data only contains averages, as opposed to call-by-call measurements. In order to be able to calculate abandonment rate we have assumed that all abandoned customers wait in queue with average queue time in relevant time interval.

We observed that average queue time of abandoned customers takes values from interval [0,130] (in seconds). From this point it is perceptible to split [0,130] interval in 5 second sub intervals to observe how many of the customers are waiting and then abandoning between these sub intervals. There exist very few customers that wait more than 115 seconds therefore, we limit the upper limit to 115 and added the data in 115,130 to the last sub interval [110, 115]. To this end we suggest a method for estimating the average time to abandon that customers endure before abandon i.e. patience duration of the customers, based on the given equation below;

A_i= number of sub intervals i=1, 2.., 23

$[\ l_i, u_i]$ =lower and upper bounds of sub interval *i*

T_{ij} =Total numbers of people waiting in queue before abandon in day j and in sub interval *i*

$$1/\rho \ = \frac{\sum_{i=1}^{n}(\sum_{j=1}^{30} T_{ij}\ (l_i+u_i)/2)}{\sum_{i=1}^{n}\sum_{j=1}^{30} T_{ij}}$$; Average time to abandon

$\rho =$ Abandonment rate of customers

Abandonment rate ρ is calculated as above, and abandonments of the customers are assumed to be exponentially distributed with that rate. We inspire the term "patience" and the possible way of estimating abandonment rate in the system from the study of Garnet et.al. (2002).

3.3. Data Collection Process

From the available data, we could estimate the interarrival and abandonment rates , fro the rest of the required parameters we directly made observations. Call center management arranged the system appropriately for us to listen to the calls simultaneously with an agent via a headphone connected to that agents line to collect data. We first listened to several calls, to get acquainted with the system then we have built a data collection sheet. We have seen that, when a call arrives to agent, he/she listens to customer, understands the need of the customer, decides to divert the call according to the need or handle herself/himself and then decides to divert followed or un-followed.

Starting from here, the sheet is designed to have “start-end times “of the calls, “the unit the call is directed to”, and whether the “call transfer is followed or un-followed” those information corresponds to “Call Arrival-Call End”, “Directed” and “Followed-Un-followed” titles in data sheet respectively. In addition to those, based on subject of the call and the caller, call types are classified in three categories: Consulting, Appointment and Domestic. Data regarding this category is titled as “Call Type” in data collection sheet. After the call type is determined as an Appointment Call then under “Appointment“title the information of which unit the appointment taken is kept under “Appointment To” title. With “Diverted To” data we observe to which units a Consulting Call is diverted. Some of the diverted calls may return if customers cannot receive service from the diverted unit then in order to keep the time between diverting and returning of the calls, we keep phone numbers of related Consulting Calls. In Table 2.3 sample of the data sheet is shown.

Table 3.3: Sample Call Center Data Collection Sheet

CALL TYPE	CALL ARRIVAL TIME	CALL END TIME	SERVICE TIME	PHONE NUMBER	APPPOINTMENT TO	DIRECTED TO	FOLLOWED/UNFOLLOWED CALL
C	10:08:46	10:09:36	00:00:50	2154478		2771	F
D	10:09:47	10:10:14	00:00:27	-		4731026	F
C	10:10:20	10:11:10	00:00:50	3264596			
C	10:11:18	10:12:21	00:01:03	3583677		4572781	F
A	10:12:40	10:14:13	00:01:33	-	CHEST DISEASES		
C	10:14:24	10:15:03	00:00:39	4132565		3800	U
C	10:15:09	10:16:04	00:00:55	-		2547	F
C	10:16:17	10:16:43	00:00:26	2801532		2157/2154	U
C	10:16:48	10:17:13	00:00:25	6766739		2157	U
C	10:17:20	10:18:07	00:00:47	2556844		2547	U
C	10:18:14	10:19:06	00:00:52	3604117			U
A	10:19:22	10:21:00	00:01:38	-	PEDIATRICS		
C	10:21:11	10:22:46	00:01:35	4351385		2517	U
D	10:22:53	10:23:05	00:00:12	-			F
A	10:23:13	10:24:22	00:01:09	-	GYNAECOLOGY		

3.4. Service Time Distribution and Divert Probabilities

Having start and end times of the calls service time is calculated as “End Time of the Call - Start Time of the Call”*;* however service times can differ based on call types. A statistical analysis is conducted to understand whether there exists a significant difference in the service times among call types. [Appendix B]. Relevant analysis is performed with SPSS 11.5. and using One Way Analysis Of Variance.

H_{02}*: The effect of call types on service times is not meaningful. (I.e. there exists no difference between service times according to call types)*

Null Hypothesis H_{02} is tested with rejection probability of 5%. The analyses show that significant difference on service time exists among call types; based on ANOVA analysis.

The call center system studied here consists of three main processors; these are call center itself, doctor and other hospital units. As it is mentioned, the three types of calls have different routes to follow probabilistically between those main processors and since the call types’ service times are significantly different, our system is challenged with multi-type customers.

We used ARENA Input Analyzer to fit distribution to service times of three significantly different call types. We observe that the service time distributions can be modeled with exponential distribution under acceptable square errors. [Appendix C].

We are also capable of calculating the percentages of different call types received and percentage of calls diverted to every unit. [Appendix D]

Domestic calls are shown in column “Call Type” with “D” on data sheet and they constitute 13% of all calls which is the least received call type among all. Domestic call service time is 6 + EXPO (42.1).

Consulting calls which constitutes the highest percentage of incoming calls, 69% and shown in column “Call Type” with “C”. Those calls are finalized in two ways either the call is diverted to relevant unit or the agent answers the questions without diverting the call. However, if agent diverts the call un-followed to the unit, and in case customer receives a busy signal from that unit, he/she will return to call center queue retry to connect the unit which customer could not achieve in previous trial. This reprocess creates extra traffic in call center and also causes customer dissatisfaction indeed. Call center answers 73.5 percent of the consulting calls itself or direct to other units in a followed manner, but the remaining 26.5 percent is directed in a not-followed manner to a hospital unit. A consulting call service time is distributed with 0.999 + EXPO (56.5).

After observing the hospital units which receives most of the diverted calls using “Diverted To” data, we see that calls are mainly diverted to pediatrics and polyclinics. Later, likewise listening to an agent in the call center, we have collected data in these heavy-traffic centered units to observe the proportions of times that these units do not pick up a Consulting Call.

As we observe the hospital unit we make a data sheet which is comprised of two columns, first column is to determine whether the call is coming from the call center to the unit and the second is to view whether it is answered or not. Hence the probability of the unit to answer a consulting call diverted from call center is estimated. (See Table- 3.4)

Table 3.4: Sample Hospital Unit Data Collection Sheet

FROM CALL CENTER/ NOT	OPENED/ NOT OPENED
Y	Y
Y	Y
N	Y
Y	N
Y	N
Y	Y
N	N

The followed or not-followed situations are occurring according to agents' workload at the call time and customers' compliances. If a customer calling to call center complains about not getting a connection to other hospitals units and waiting for some amount of time, agent generally directs the customer in a followed manner. However agents are not always careful or do not have enough time to perform a followed call since it consumes more time than a not-followed call. In not-followed case, 75 percent of the calls fail to get an answer from the hospital unit and come back to robotic system queue of the call center to try a connection after some amount of time. This is because customers wait the unit to answer. Since we know the diverted phone number of the calls then we are able to calculate the times between diverting time of the call to a unit and returning time of the call from that unit. We estimate this return time as EXPO (15). This situation is not only creating rework but also decreases the customer satisfaction since returning customers becomes more impatient which causes more abandonment.

Appointment calls, constitutes 19% of incoming calls, and shown in column "Call Type" with "A". An appointment call in the system can be handled by call center itself without directing the call, agents can manage the appointments of the patients, then calls leave the system or the patient wants to consult to the doctor about the appointment in case of not knowing where to be treated .Then call center directs the patient to the doctor. 15 percent of the patients want to consult to doctor, remaining takes appointments from call center directly. An appointment call service time is having distribution 34+EXPO (89). Doctor's service time is realized as 40 seconds and assumed to be exponentially distributed. Abandonment from doctor's queue is not modeled since observed customers are patient about consulting the doctor, and only 15 percent of the calls are diverted to doctor who does not cause high workload for the doctor.

Both call center and hospital units are monitored for a week and different agents are listened to collect unbiased data. Consequently 950 calls in call center and 400 calls in hospital units are listened and relevant data is recorded. The information generated from the data is used to estimate call center and the agents' service time distributions and the call traffic between call center and the hospital units. Significant influences of call type parameter on service times and time parameter on arrival rates are observed. It has been shown that the service times can be modeled with exponential distribution under acceptable significance levels for call center, doctor's service time and the abandonment rate distribution are exponential and arrival rates of customers are assumed to follow Poisson process. The system is analyzed and inputs are generated to model the system. All input variables estimated are tabulated below.

Table 3.5: Input Variables

	Call Type(i)		
	i=1 **Appointment Call**	i=2 **Consulting Call**	i=3 **Domestic Call**
Arrival Probabilities (p_i)	0.19	0.69	0.13
***General Arrival Rates $\lambda_i = (\lambda * p_i)$**	(1/14.93)*0.19	(1/14.93)*0.69	(1/14.93)*0.13
***Time Interval Based Arrival Rates ($\lambda_t * p_i$)**			
Slots 1/4/5/6/7/8 (t=1)	(1/15)*0.19	(1/15)*0.69	(1/15)*0.13
Slots 2/3 (t=2)	(1/11.1)*0.19	(1/11.1)*0.69	(1/11.1)*0.13
Slot 9 (t=3)	(1/20)*0.19	(1/20)*0.69	(1/20)*0.13
Abandonment Rate (ρ)	0.07	0.07	0.07
Divert Probabilities (q_i)	0.15	0.265	0
Return Probabilities (r_i)	1	0.75	0
Service and Delay Times			
Doctor (α)	EXPO(40)		
Call Center (μ_i)	34+EXPO(89)	0.999+EXPO(56.5)	6+EXPO(42.1)
Hospital Units (β)		EXPO(15)	

Times are based on seconds.

* The general arrival rate λ=1/14.93 and general arrival rates of each call type λ_i are also estimated to be used in following chapters for further analysis.

Chapter 4

Model Development

In this chapter, we present our models developed for the system described in system analysis in the previous chapter. In the system that we have analyzed, different types of customers have different service times, arrivals rates of customers vary in time and customers tend to leave the queue (i.e. abandon) unless they do not get service for some of amount of time. In addition to those, a customer who cannot connect the relevant units for once, twice etc. creates rework and centre loses reputation in customer service. To sum up, we confront with a challenged system of a call center with multiple servers and different types of customers who have different service times and varying arrival rates in addition to retrials and abandonment.

We focus on modeling the system with two approaches. Since call centers can be viewed as a queuing system our first approach is to visualize the system as a queuing network. However as Koole & Mandelbaum (2002) mention measuring the service operations by queuing models is not straightforward when many dimensions like abandonment, retrials, bulking etc. are considered. Queuing models are not as flexible as requested. Many researchers study call centers as queuing networks whereas most of the studies are based on modeling a specific problem or some of them simplifies the problem via assumptions to base upon a existing queuing theory which cause the problem or the system modeled to lose natural characteristics. We first model the system as a queuing network under some mild assumptions.

4.1. A Queuing Modelling Approach

The call center system studied here consists of three main processors; these are call center itself, doctor and other hospital units. As it is mentioned, the three types of calls have different routes to follow probabilistically between those main processors. This call traffic between those processors can be modeled as a queuing network under appropriate assumptions. Ignoring time varying arrivals and abandonment, we can model the call center as M/M/s/K queue, since call arrivals follow a Poisson distribution and service times are exponentially distributed and call center have multiple servers *s*, and the center is capacitated with its trunk line number *K*. Doctor and the hospital units receive diverted calls from the call center with different probabilities since the arrival process to the call center follows Poisson distribution, doctor and hospital unit will also receive exponential inter-arrival times. Call center directs followed and un-followed calls to hospital units, followed calls are opened by hospital unit since call center agents wait the phone to be answered then direct the call, however 75 percent of the un-followed calls return back to the call center. Therefore we are only interested in un-followed calls since followed calls reach their destinations and are disposed by hospital units after served. However an un-followed call can either receive a busy signal or take service if the hospital unit is idle. This situation lets us model the hospital units' queuing system as M/M/1/1 since arriving calls finds the system busy cannot connect to units' line. This helps us to model a capacitated resource which creates a random delay in the system. Similarly doctor's queue is modeled as M/M/1/1 We propose to model the system based on below state definitions under the assumption of system reaches the steady state. (See Figure- 4.1)

State Definition and Possible Transitions

We define the state of the system with six variables.

Suppose at time *t* we have;

N: # of people in the system (# in queue + # in service in the call center)

a: number in service of the call center for Appointment Call

c: number in service of the call center for Consulting Call

d: number in service of the call center for Domestic Call

r: number in service of doctor

u: number in service of hospital unit

Therefore our state vector can be represented as: (N, a, c, d, r, u) *where*

$0 \leq N \leq$# of trunk line, 0≤ (a+c+d) ≤ # of agents, 0 ≤ a ≤ # of agents, 0≤ c ≤ # of agents,

0≤ d ≤ # of agents, $0 \leq r \leq 1$, $0 \leq u \leq 1$

If the system is in state (N, a, c, d, r, u) at a time instance of t then after δ_t time, with a possible transition, the system can move to another possible state according to the first event occurred. The [0 ,# trunk line] interval is split into 3, in order to show all possible states to reach and calculate the recurrence probabilities of that transitions are given based on the values of N to model the system. Since total transition rate differs depending on values of N.

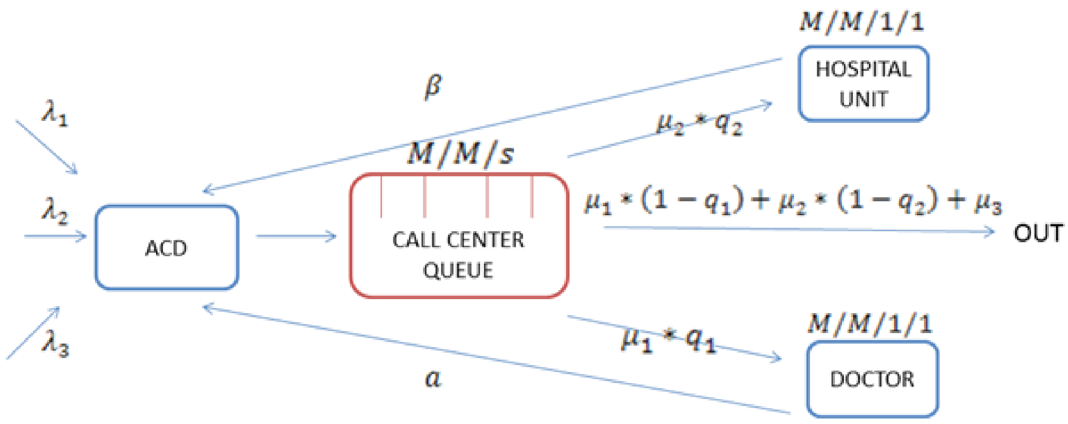

Figure 4.1: Call Center Queuing Network with Related Rates

For all states, we need to calculate the rate of leaving that state and let Q represent this state. Later we should identify the states that can be reached from this state and the probabilities of reaching to such states. Below, show the calculation of Q for an arbitrary state (N, a ,c ,d ,r ,u) and probabilities of leaving the state depending on some values of state variables N, a ,c ,d ,r ,u . Inputs in Table 3.5 are used to estimate the probabilities.

i) For $N \in$ **[0, 1,2,…, *# of agents*)**

$Q = \sum_{i=1}^{3} \lambda_i + a * \mu_1 + c * \mu_2 + d * \mu_3 + r * \alpha + u * \beta$; *Transition rate from state (N, a, c, d, r, u)*

(1) $(N, a, c, d, r, u) \rightarrow (N+1, a+1, c, d, r, u)$ with probability: $\left(\frac{\lambda_1}{\mathrm{Q}}\right)$. This would occur when appointment type customer arrives and seize an available agent in call center.

(2) For r=1: $(N, a, c, d, r, u) \rightarrow (N+1, a+1, c, d, r-1, u)$ with probability: $\left(\frac{\alpha}{\mathrm{Q}}\right)$. This would occur when doctor finishes service of appointment type customer and directs the customer to call center.

(3) $(N, a, c, d, r, u) \rightarrow (N+1, a, c+1, d, r, u)$ with probability:

$(\frac{\lambda_2}{Q})$. This would occur when consulting type customer arrives and seize an available agent in call center.

(4) For *u*=1: $(N, a, c, d, r, u) \rightarrow (N+1, a, c+1, d, r, u-1)$ with probability: $(\frac{\beta}{Q})$. This would occur when a return call of consulting type customer comes from hospital unit and seize an available agent in call center.

(5) $(N, a, c, d, r, u) \rightarrow (N+1, a, c, d+1, r, u)$ with probability: $(\frac{\lambda_3}{Q})$. This would occur when domestic type customer arrives and seize an available agent in call center.

(6) For *a*>0: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c, d, r, u)$ with probability: $(\frac{a*\mu_1}{Q} * (1-q_1))$. This would occur when appointment type customer being served left.

(7) For *a*>0, *r*=0: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c, d, r+1, u)$ with probability: $(\frac{a*\mu_1}{Q} * q_1)$. This would occur when appointment type customer being served is directed to doctor.

(8) For a>0, r=1: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c, d, r, u)$ with probability: $(\frac{a*\mu_1}{Q} * 1))$. This would occur when appointment type customer being served left.

(9) For *c*>0 :$(N, a, c, d, r, u) \rightarrow (N-1, a, c-1, d, r, u)$ with probability:

$(\frac{c*\mu_2}{Q} * (1-q_2))$. This would occur when consulting type customer being served left.

(10) For *c*>0, *u*=0: $(N, a, c, d, r, u) \rightarrow (N-1, a, c-1, d, r, u+1)$ with probability:

$(\frac{a*\mu_2}{\mathrm{Q}} * q_2)$. This would occur when consulting type customer being served is directed to hospital unit.

(11) For *c*>0, u=1: $(N, a, c, d, r, u) \rightarrow (N-1, a, c-1, d, r, u)$ with probability:

$(\frac{a*\mu_2}{\mathrm{Q}} * 1))$. This would occur when consulting type customer being served left.

(12) For *d*>0 : $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d-1, r, u)$ with probability:

$(\frac{d*\mu_3}{\mathrm{Q}} * 1))$. This would occur when domestic type customer being served left.

ii) For ***N*** **∈ [#** ***Agents, #Trunk Line*****)**

$Q = \sum_{i=1}^{3} \lambda_i + a*\mu_1 + c*\mu_2 + d*\mu_3 + r*\alpha + u*\beta$; Transition rate from state *(N, a, c, d, r, u)*

(1) $(N, a, c, d, r, u) \rightarrow (N+1, a, c, d, r, u)$ with probability:

$(\frac{\lambda}{\mathrm{Q}})$. This would occur when a customer arrives and waits for service in call center queue.

(2) For *r*=1: $(N, a, c, d, r, u) \rightarrow (N+1, a, c, d, r-1, u)$ with probability

$(\frac{\alpha}{\mathrm{Q}})$. This would occur when doctor finishes service and directs the customer to call center.

(3) For *u*=1: $(N, a, c, d, r, u) \rightarrow (N+1, a, c, d, r, u-1)$ with probability

$(\frac{\beta}{Q})$. This would occur when a return call comes from hospital unit to call center queue.

(4) For *a*>0 : $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_1}{\sum_{i=1}^{3}\lambda_i} * (1-q_1))$ This would occur if the present appointment type customer being served left and the next person to be served is appointment type customer.

(5) For *a*>0, *r*=0 : $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_1}{\sum_{i=1}^{3}\lambda_i} * q_1)$ This would occur if the present appointment type customer being served directed to doctor and the next person to be served is appointment type customer.

(6) For *a*>0, *r*=1: $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_1}{\sum_{i=1}^{3}\lambda_i} * 1)$ This would occur if the present appointment type customer being served left and the next person to be served is appointment type customer.

(7) For *a*>0 : $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c+1, d, r, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * (1-q_1))$ This would occur if the present appointment type customer is being served left and the next person to be served is consulting type customer.

(8) For *a*>0, *r*=0: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c+1, d, r+1, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * q_1)$ This would occur if the present appointment type customer being served is directed to doctor and the next person to be served is consulting type customer.

(9) For a>0, r=1: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c+1, d, r, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * 1)$ This would occur if the present appointment type customer being served is directed to doctor and the next person to be served belongs to customer group 2.

(10) For a>0: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c, d+1, r, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * (1-q_1))$ This would occur if the present appointment type customer is served left and the next person to be served is domestic type customer.

(11) For a>0, r=0: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c, d+1, r+1, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * q_1)$ This would occur if the present appointment type customer being served is directed to doctor and the next person to be served belongs to customer group 3.

(12) For a>0, r=1: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c, d+1, r, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * 1)$ This would occur if the present appointment type customer being served left and the next person to be served is domestic type customer.

(13) For c>0: $(N,a,c,d,r,u) \rightarrow (N-1,a,c,d,r,u)$ with probability

$(\frac{c*\mu_2}{Q} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * (1-q_2))$ This would occur if the present consulting type customer being served left and the next person to be served is consulting type customer.

(14) For c>0, u=0: $(N,a,c,d,r,u) \rightarrow (N-1,a,c,d,r,u+1)$ with probability

$(\frac{c*\mu_2}{Q} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * q_2)$ This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is consulting type customer.

(15) For c>0, u=1: $(N,a,c,d,r,u) \rightarrow (N-1,a,c,d,r,u)$ with probability

$(\frac{c*\mu_2}{Q} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * 1)$ This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is consulting type customer.

(16) For c>0 : $(N,a,c,d,r,u) \rightarrow (N-1,a+1,c-1,d,r,u)$ with probability

$(\frac{c*\mu_2}{Q} * \frac{\lambda_1}{\sum_{i=1}^{3}\lambda_i} * (1-q_2))$ This would occur if the present consulting type customer being served left and the next person to be served is appointment type customer.

(17) For c>0, u=0: $(N,a,c,d,r,u) \rightarrow (N-1,a+1,c-1,d,r,u+1)$ with probability

$(\frac{c*\mu_2}{Q} * \frac{\lambda_1}{\sum_{i=1}^{3}\lambda_i} * q_2)$ This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is appointment type customer.

(18) For c>0, u=1: $(N, a, c, d, r, u) \rightarrow (N-1, a+1, c-1, d, r, u)$ with probability

$\left(\frac{c*\mu_2}{Q} * \frac{\lambda_1}{\sum_{i=1}^{3} \lambda_i} * 1\right)$ This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is appointment type customer.

(19) For c>0: $(\mathrm{N}, \mathrm{a}, \mathrm{c}, \mathrm{d}, \mathrm{r}, \mathrm{u}) \rightarrow (\mathrm{N}-1, \mathrm{a}, \mathrm{c}-1, \mathrm{d}+1, \mathrm{r}, \mathrm{u})$ with probability

$\left(\frac{c*\mu_2}{Q} * \frac{\lambda_3}{\sum_{i=1}^{3} \lambda_i} * (1-q_2)\right)$ This would occur if the present consulting type customer being served left and the next person to be served is domestic type customer.

(20) For c>0, u=0: $(N, a, c, d, r, u) \rightarrow (N-1, a, c-1, d+1, r, u+1)$ with probability

$\left(\frac{c*\mu_2}{Q} * \frac{\lambda_3}{\sum_{i=1}^{3} \lambda_i} * q_2\right)$ This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is domestic type customer.

(21) For c>0, u=1: $(N, a, c, d, r, u) \rightarrow (N-1, a, c-1, d+1, r, u)$ with probability

$\left(\frac{c*\mu_2}{Q} * \frac{\lambda_3}{\sum_{i=1}^{3} \lambda_i} * 1\right)$ This would occur if the present consulting type customer being served is left and the next person to be served is domestic type customer.

(22) For $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ with probability

$\left(\frac{d*\mu_3}{\mathrm{Q}} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * 1\right)$ This would occur if the present domestic type customer being served is left and the next person to be served is domestic type customer.

(23) For d>0: $(N, a, c, d, r, u) \rightarrow (N-1, a+1, c, d-1, r, u)$ with probability

$\left(\frac{d*\mu_3}{\mathrm{Q}} * \frac{\lambda_1}{\sum_{i=1}^{3}\lambda_i} * 1\right)$ This would occur if the present domestic type customer being served is left and the next person to be served is appointment type customer.

(24) For d>0: $(N, a, c, d, r, u) \rightarrow (N-1, a+1, c, d-1, r, u)$ with probability

$\left(\frac{d*\mu_3}{\mathrm{Q}} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * 1\right)$ This would occur if the present domestic type customer being served left and the next person to be served is consulting type customer.

iii) For *N*= ***# Trunk Line***

$Q = a*\mu_1 + c*\mu_2 + d*\mu_3$; Transition rate from state (N, a, c, d, r, u)

(1) For a>0: $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ with probability

$\left(\frac{a*\mu_1}{\mathrm{Q}} * \frac{\lambda_1}{\sum_{i=1}^{3}\lambda_i} * (1-q_1)\right)$ This would occur if the present appointment type customer being served left and the next person to be served is appointment type customer.

(2) For a>0, r=0: $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ with probability

$(\frac{a*\mu_1}{\mathrm{Q}} * \frac{\lambda_1}{\sum_{i=1}^{3} \lambda_i} * q_1)$ This would occur if the present appointment type customer being served directed to doctor and the next person to be served is appointment type customer.

(3) For a>0, r=1: $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ with probability

$(\frac{a*\mu_1}{\mathrm{Q}} * \frac{\lambda_1}{\sum_{i=1}^{3} \lambda_i} * 1)$ This would occur if the present appointment type customer being served left and the next person to be served is appointment type customer.

(4) For a>0 : $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c+1, d, r, u)$ with probability

$(\frac{a*\mu_1}{\mathrm{Q}} * \frac{\lambda_2}{\sum_{i=1}^{3} \lambda_i} * (1-q_1))$. This would occur if the present appointment type customer being served left and the next person to be served belong to customer group 2.

(5) For a>0, r=0: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c+1, d, r+1, u)$ with probability $(\frac{a*\mu_1}{\mathrm{Q}} * \frac{\lambda_2}{\sum_{i=1}^{3} \lambda_i} * q_1)$.This would occur if the present appointment type customer being served is directed to doctor and the next person to be served is consulting type customer.

(6) For a>0, r=1: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c+1, d, r, u)$ with probability

$(\frac{a*\mu_1}{\mathrm{Q}} * \frac{\lambda_2}{\sum_{i=1}^{3} \lambda_i} * 1)$. This would occur if the present appointment type customer being served is directed to doctor and the next person to be served is consulting type customer.

(7) For a>0: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c, d+1, r, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * (1-q_1))$. This would occur if the present appointment type customer being served left and the next person to be served is domestic type customer.

(8) For a>0, r=0: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c, d+1, r+1, u)$ with probability$(\frac{a*\mu_1}{Q} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * q_1)$. This would occur if the present appointment type customer being served is directed to doctor and the next person to be served is domestic type customer.

(9) For a>0: $(N, a, c, d, r, u) \rightarrow (N-1, a-1, c, d+1, r, u)$ with probability

$(\frac{a*\mu_1}{Q} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * 1)$. This would occur if the present appointment type customer being served left and the next person to be served is domestic type customer.

(10) For c>0 : $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ with probability

$(\frac{c*\mu_2}{Q} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * (1-q_2)$. This would occur if the present consulting type customer being served left and the next person to be served is consulting type customer

(11) For c>0, u=*0:* $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u+1)$ with probability

$(\frac{c*\mu_2}{Q} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * q_2)$. This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is consulting type customer.

(12) For *c*>0, *u*=1: $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ with probability

$\left(\frac{c*\mu_2}{\mathrm{Q}} * \frac{\lambda_2}{\sum_{i=1}^{3} \lambda_i} * 1\right)$. This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is consulting type customer.

(13) $(N, a, c, d, r, u) \rightarrow (N-1, a+1, c-1, d, r, u)$ *c>0:* with probability

$\left(\frac{c*\mu_2}{\mathrm{Q}} * \frac{\lambda_1}{\sum_{i=1}^{3} \lambda_i} * (1-q_2)\right)$. This would occur if the present consulting type customer being served left and the next person to be served is appointment type customer.

(14) $(N, a, c, d, r, u) \rightarrow (N-1, a+1, c-1, d, r, u+1)$ *c>0, u=0:* with probability $\left(\frac{c*\mu_2}{\mathrm{Q}} * \frac{\lambda_1}{\sum_{i=1}^{3} \lambda_i} * q_2\right)$. This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is appointment type customer.

(15) $(N, a, c, d, r, u) \rightarrow (N-1, a+1, c-1, d, r, u)$ *c>0, u=1:* with probability

$\left(\frac{c*\mu_2}{\mathrm{Q}} * \frac{\lambda_1}{\sum_{i=1}^{3} \lambda_i} * 1\right)$. This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is appointment type customer.

(16) $(N, a, c, d, r, u) \rightarrow (N-1, a, c-1, d+1, r, u)$ *c>0:* with probability

$\left(\frac{c*\mu_2}{\mathrm{Q}} * \frac{\lambda_3}{\sum_{i=1}^{3} \lambda_i} * (1-q_2)\right)$ This would occur if the present consulting type customer being served left and the next person to be served is domestic type customer.

(17) $(N, a, c, d, r, u) \rightarrow (N-1, a, c-1, d+1, r, u+1)$ *c>0, u=0:* with probability $\left(\frac{c*\mu_2}{\mathrm{Q}} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * q_2\right)$ This would occur if the present consulting type customer being served is directed to hospital unit and the next person to be served is domestic type customer.

(18) $(N, a, c, d, r, u) \rightarrow (N-1, a, c-1, d+1, r, u)$ *c>0, u=1:* with probability

$\left(\frac{c*\mu_2}{\mathrm{Q}} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * 1\right)$. This would occur if the present consulting type customer being served is left and the next person to be served is domestic type customer.

(19) $(N, a, c, d, r, u) \rightarrow (N-1, a, c, d, r, u)$ *d>0:* with probability

$\left(\frac{d*\mu_3}{\mathrm{Q}} * \frac{\lambda_3}{\sum_{i=1}^{3}\lambda_i} * 1\right)$. This would occur if the present domestic type customer being served is left and the next person to be served is domestic type customer.

(20) $(N, a, c, d, r, u) \rightarrow (N-1, a+1, c, d-1, r, u)$ *d>0:* with probability

$\left(\frac{d*\mu_3}{\mathrm{Q}} * \frac{\lambda_1}{\sum_{i=1}^{3}\lambda_i} * 1\right)$. This would occur if the present domestic type customer being served is left and the next person to be served is appointment type customer.

(21) $(N, a, c, d, r, u) \rightarrow (\mathrm{N}-1, \mathrm{a}+1, \mathrm{c}, \mathrm{d}-1, \mathrm{r}, \mathrm{u})$ *d>0:* with probability

$\left(\frac{d*\mu_3}{\mathrm{Q}} * \frac{\lambda_2}{\sum_{i=1}^{3}\lambda_i} * 1\right)$ .This would occur if the present domestic type customer being served is left and the next person to be served belong to customer group 2.

All possible states and probabilities of reaching those states from $(\mathrm{N}, \mathrm{a}, \mathrm{c}, \mathrm{d}, \mathrm{r}, \mathrm{u})$ in one transition are presented above. Given these state transition rates the steady state probability that the system is in state (N, a, c, d, r, u) can be found by standard techniques. Once these probabilities are found, all necessary performance measures can be derived. However, this way of modeling the system has some drawbacks.

First of all, having a state with six variables brings curse of dimensionality. In this representation, there exist excessively possible states and the system of equations to be solved is very large. Secondly, with this way of modeling, steady state probabilities can be found but it can be argued that the system might not reach to steady state in 9 hours. Note that every new day is a clean start in this system therefore the results obtained will not cover the transient phases of the system. In addition to those, some features of the system like abandonment and time varying arrival rates cannot be reflected in such a model.

Hence, such a model can be contrasted with simulation techniques, since analytical alternatives troubled in mathematical skills and in contrast simulation tools have higher elasticity. As modern call centers are improved by technology, complexity in modeling the systems increases. Therefore, we choose to model the system with simulation to capture all features of the system and develop a satisfactory model by all means.

4.2. A Simulation Modeling Approach

We simulate the call center queuing network using Rockwell's Arena Simulation Software. We use terminating simulation since we observe call center operations for 9 hours in a day. The system starts with a clean state initially. The input variables in Table 3.5 are used to develop the model. The Arena model is provided in Appendix E. In the first part, we describe the simulation model based on this layout in three stages as Part 1: Incoming calls, Part 2: Abandonment and Part 3: Service. Later in this secton, we explain the key points in a simulation modelling approach which are validation of the model and the determination of number of replications.

4.2.1. Simulation Model

Part 1: Incoming Calls

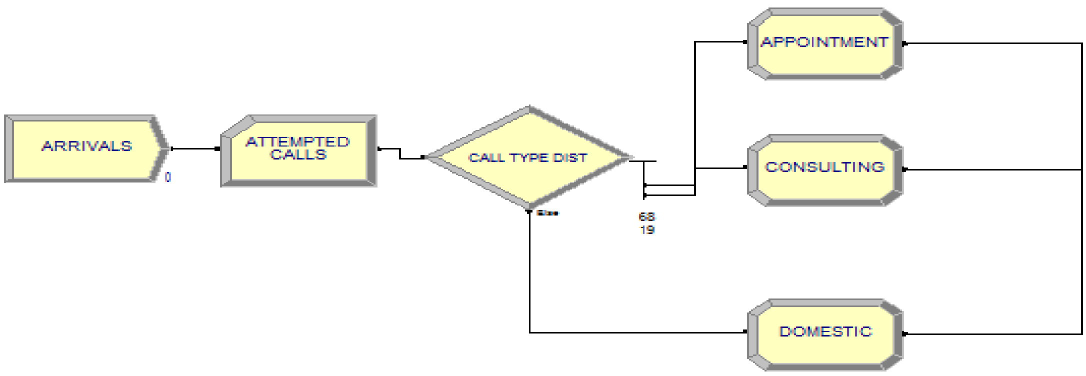

Figure 4.2: Arena Layout Part 1: Incoming Calls

Arrival process can be followed from Figure 4.2 Incoming calls enter the system using Create module called "ARRIVALS" then number of attempted calls are counted with Record module called "ATTEMPTED CALLS". A Decide module called "CALL TYPE DIST" is used to divide calls into three categories of Appointment, Consulting and Domestic depending on incoming probabilities (p_i) of each type of call. With three Assign modules we named "APPOINTMENT", "CONSULTING" and "DOMESTIC"; entity assignments of calls are made. The challenging part here is to define inter-arrival time inside the "call arrival" module since the call center receives calls that vary based on hours during the 9-hour day.

The inter-arrival times ($1/\lambda_t$) between calls are changing during specific slots that we mentioned in system analysis. To model time varying arrivals in Arena software, we define a 9 rowed variable set called "Ratesbyhour" to keep inter-arrival rates by hours, with a Variable module, and we use Calhour function of Arena to build appropriate expression inside the Create module. The function Calhour returns the integer hour portion of the simulation time. Then the expression used in the module is: Ratesbyhour (Calhour (Tnow) +1); where function Tnow gives the current simulation time and Calhour gives the integer portion by hour (0 to 23). The "+1" adjusts the subscript upward since Arena arrays, unlike C or C++ arrays, begin with subscript 1, not 0. (PMC Forums 2012)

Part 2: Abandonment

Incoming calls enter the call center queue to seize an available agent. If all agents are busy then the calls wait in the queue. The calls may abandon or wait until an agent becomes available. Abandoned calls leaves the call center queue and dispose from the system whereas calls which wait for service continue to be processed by “call center service”. In Figure 4.3, the relevant modules are visualized. With a Decide module abandoned call types are defined, and number of abandoned calls is recorded with Record modules.

We have used assign modules before and after the call center queue in order to find total queuing time of the arriving entity. We have also generated “random number” with UNIF (0, 1) and compare the probability of abandonment with the random number generated. If the probability of abandonment is higher than that random number, the customer will abandon otherwise customer will continue to get service from an available agent. The abandonment rate (ρ) is exponential than the following probability calculation will be $P(X \leq x) = 1 - e^{\rho x}$ where x denotes the queuing time which we calculate as the difference of Tnows in Assign modules of “ENTER TIME” and “END TIME”. Then the expression entered in Decide module of “ABOND?” is: “random number $\leq (1 - e^{\rho x})$”. If this expression is “true” then the entity will abandon and counted with Record modules. Otherwise the entity continues and arrives to call center receive service in Process module “CALL CENTER SERVICE”.

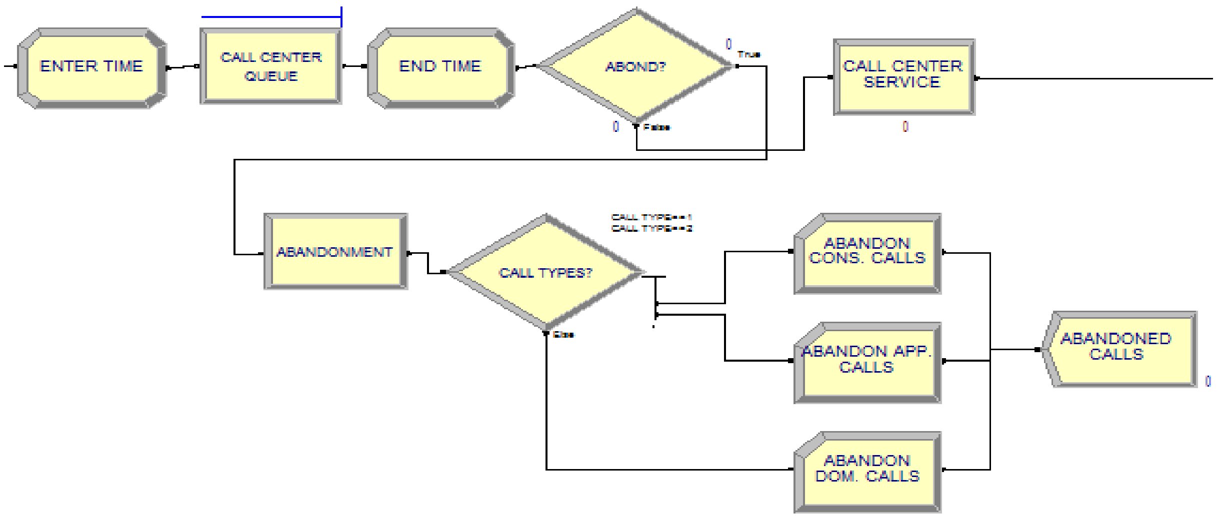

Figure 4.3: Arena Layout Part 2: Abandonment

Part 3: Service

Calls that do not abandon continue to Process module of "CALL CENTER SERVICE" as it can be followed from Figure 4.4. The call center processes the calls and diverts 26.5% (q_2) of Consulting Calls to units and 15% (q_1) of Appointment Calls to doctor. Domestic Calls, Appointment Calls that are not directed to doctor and Consulting Calls that are not directed to hospital units or directed in a followed manner are disposed from the system. The calls diverted to "DOCTOR" are directed back to the call center queue after served. The Un-followed Consulting Calls directed to hospital units will spend EXPO (15) seconds of time in Delay module "UNITS DELAY" while waiting for service. After delay, the calls may receive service with probability 0.25 (1-r_2) or return back to call center queue with probability 0.75 (r_2).

Each call type has different service times, then to define call center service time in "CALL CENTER SERVICE" ; we define two 3 rowed variable sets which are called "call lengths" to keep exponential parts of the service times and "array" to keep constant parts of the service times (μ_i). We also use attribute “call type” to define the type of call.

Then, we build expression of “EXPO (call lengths (call type)) +array (call type)” as the service time in the call center process. We ensure that the call center will give service based on the call type.

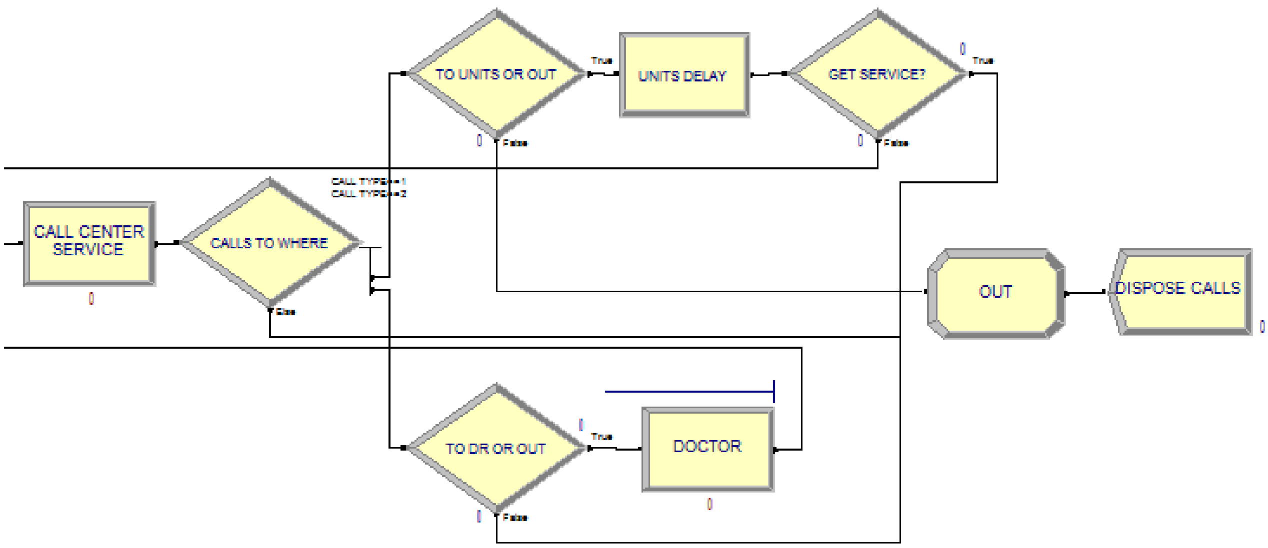

Figure 4.4: Arena Layout Part 3: Service

4.2.2. Replication Number Decision and Model Validation

In order to reflect system statistics with minimal error, we run multiple replications of the simulation model and compute estimates for performance measures based on the average of the run length. When more than one replication is made, ARENA gives a half width value which is 95% confidence interval on the expected value of the output result. The half width, value *h* is calculated as below:

$h = t_{n-1,\alpha/2} * \frac{s}{\sqrt{n}}$ where n is number of replications, and s is the standard deviation. (Kelton D., Sadowsk P. and Sturrock T., 2008)

To determine the number of runs, we focused on value of attempted calls as statistic of interest. After each run, we would examine overall half width of this statistic across all runs. We have calculated the required number of replications needed to decrease the value of half width to a desired level which we have set as our confidence threshold. After deciding the replication number based on the desired half width value, we have checked whether the observed averages of performance metrics attempted calls, queuing time, number of abandonment differ significantly or not when a higher replication number is set. Starting with 20 replications and fixed number of 8 agents we have;

Table 4.1: Average Number of Attempted Calls in 20 Replications

	Average	Half Width	Confidence Interval
# Attempted Calls	2176	28.97	2176 ∓ 28.97

To estimate a rough approximate number of replications the formula below is used (Kelton D., Sadowsk P., and Sturrock T., 2008)

$n = n_0 * \frac{h_0^2}{h^2}$ where n_0: initial number of replications and h_0: half width value of n_0 replications. We have set target $half\ width \leq 10$ in order to catch desired confidence interval. Then the number of replications, n, to be made is roughly 160. After setting replication number to 160, realized half width of attempted calls is 7.6 is shown in below table with other necessary metrics to be compared with system's real metrics.

Table 4.2: Performance Metrics in 160 Replications

	Average	**Half Width**	**Confidence Interval**
# Attempted Calls	2162	7.6	(2154.4, 2169.6)
# Abandoned Calls	181	3.73	(177.27, 184.43)
Queuing Time of Call Center*	1.4236	0.04	(1.3836, 1.4636)
* in seconds			

Table 4.3: Real System Statistics

	Average
# Attempted Calls	2155.2
# Abandoned Calls	240
Queuing Time of Call Center*	1.4486
* in seconds	

The resulting averages of 160 replications are compared with the results of 200 numbers of replications to observe whether there exists a significant difference with Two Sample Independent T Test. We observed that sample means of the metrics in two replications are not different with 95% confidence. To validate the model, we compare Table 4.2 with table 4.3 we see that except total number of abandoned calls, the real system statistics are between the confidence intervals of the realized statistics with simulation model. The observed abandonment number is less than the real average because of underestimating the rate with taking average waiting time to be the average of the sum of lower and upper bounds of waiting times.$((l_i + u_i)/2))$. There exist no problem in system validation however; the input data validation is defected. The problem emerges from the way of keeping the abandonment data. Observed total abandonment rate with simulation underestimates the value but it is in the range of the real abandonment number since the total abandonment number in real system takes values between 154 and 355.

Chapter 5

Numerical Analysis

In this Chapter, we present the resultsof our numerical analysis. In this analysis, we basically have two targets. Our First target is to demonstrate how the simulation model can be used to analyze the system dynamics based on a given configuration of the call center and how a decision maker can use this analysis to determine number of agents employed in any given time of the day. Note that, currently the call center has a staff of 12 agents who work in schedule and the call center management intuitively decides the number of agents to work during the day. Our analysis here can be a toolfor the management to determine the schedules based on the desired performance measures.

Our second target is to investigate possible configurations for rhe call center. Currently all calls are served by each agent regardless of the call type. In other words, there is a pool of servers who are dedicated to pick any type of call that drops into this pool. However, all call types have different routes to follow in call center system and the call traffic generated by these calls is also different. Due to possible returns, some calls generate extra traffic that impacts the performance for the other calls. Moreover, the domestic calls are only generating extra traffic for the servers whose main is to serve appointment and consulting calls. Consequently, we analyze the possibility of dedicating servers to specific call types by separating the ppoling of call types to all servers so that the service level provided for more important call types could be increased with the same level of resources.

5.1. Agent Schedule Decision

According to our observations call center receives most of the calls from 10:00 am to 12:00 am (Slots 2, 3). Between 05:00 pm to 06:00 pm, (Slot 9) incoming call number decreases significantly. To reflect the effect of varying arrival rate to call center system we take fixed number of 8 agents and observe the changes in utilization rate and total abandonment number based on time intervals.

Table 5.1 Time Varying Arrivals

TIME INTERVALS	ARRIVAL RATE (SECOND)	UTILIZATION	ABANDONMENT	CUMULATIVE ABANDONMENT	CHANGE
09:00 am-10:00 am	1/15	0.6334	11		
10:00 am-11:00 am	1/11.1	0.6377	29	40	264%
11:00 am-12:00 am	1/11.1	0.6381	27	67	68%
12:00 am-01:00 pm	1/15	0.6445	24	91	36%
01:00 pm-02:00 pm	1/15	0.6395	23	114	25%
02:00 pm-03:00 pm	1/15	0.6390	22	136	19%
03:00 pm-04:00 pm	1/15	0.6382	20	156	15%
04:00 pm-05:00 pm	1/15	0.6385	14	170	9%
05:00 pm-06:00 pm	1/20	0.6345	13	183	8%

As we observe from the Table 5.1, utilizations do not change in high-arrival intervals however abandonments of customers are significantly differ based on time intervals. Although an increase observed in utilizations passing from 09:00-10:00 interval to 10:00-11:00 interval, the effect of return rates and the way we model the abandonments cause utilizations to not significantly change. Although, we observe that number of abandonments are higher than any other slot in slots 2 and 3 and change based on previous hour in cumulative abandonments are much higher in time slots 2 and 3 consistent with higher arrival rate of the calls in these slots. We can say that allocating more agents in slots where more abandonments are encountered would result with a better scheduling to lessen abandoned number of calls. We do not further analyze different schedules but we show that the decision makers can decide on the number of agents to allocate to each time slot by conducting similar analysis by using our simulation model.

5.2. Comparison of Multi-Tasking Agents to Dedicated Agents

Our baseline scenario is one with 9 agents who answers all types of calls. We have compared this system with 9 multi-tasking agents to agents dedicated to answer a specific type of calls to analyze whether allocating specific number of servers would provide better service to more important call types such as appointment and consulting. We know that pooling all call types and diverting them to al servers will bring the highest utilization fort he whole system. But separating some of the calls, we might provide better service for some types and worse service to the others. Such configurations might be preferred by the decision makers.

Models are compared based on agents' utilizations, waiting times in queue, number of abandoned calls for each call type. We do not propose to allocate dedicated agents for Domestic Calls since arrivals of those calls are relatively rare and service provided for these calls are not the focal point of the decision makers.. The following notation in Table 5.2 will be used to determine models.

Table 5.2: Notation Used

NOTATION	EXPLANATION
CDA9	Multi Tasking 9 Agents
CDx/Ay	x agents dedicated to Consulting and Domestic Calls/ y agents dedicated to Appointment Calls where x+y=9
DAX/Cy	x agents dedicated to Domestic and Appointment Calls/ y agents dedicated to Consulting Calls where x+y=9

Table 5.3: Simulation Results of the Models

	AVERAGE WAITING TIME (seconds)	UTILIZATION	ABANDONED # OF CALLS APPOINTMENT	CONSULTING	DOMESTIC	TOTAL
CDA9	0.7440	0.59	15	65	22	102
CD8/A1	63.6160	0.462	264	15	2	281
CD7/A2	19.872	0513	147	36	6	189
CD6/A3	4.028	0.54	70	84	13	167
CD4/A5	5.457	0.51	10	307	52	369
CD3/A6	10.299	0.455	3	510	87	600
CD2/A7	21.622	0.385	1	762	133	896
DA8/C1	51.1660	0.368	1	1090	0	1091
DA7/C2	20.844	0.45	3	767	2	772
DA6/C3	10.01	0.512	9	493	5	507
DA5/C4	3.219	0.553	25	290	13	328

Table 5.3 summarizes the results of the metrics being evaluated from each model. We have come up with 11 models since models which are dominated by other models in all areas are excluded. Based on the output in Table 5.3, we can observe that, the multi-tasking agent model out-performed in many metrics compared to the models with dedicated agents. We will examine all models based on each performance metric in the following parts. The models with low abandoned rate of Appointment calls are good in case of improving Appointment calls service level, however the abandoned number of consulting calls increase dramatically in those models. CDA9 model is better depending on present parameters of the call center.

Average Waiting Time

Table 5.4 shows that the total average wait time for the multi-tasking agent model is lower than any other model. However based on agent number dedicated to answer a specific type of call will result with less waiting time for that type of customer group. The comparison of average waiting times as both total and call type based are given in Figure 5.1.

Table 5.4: Average Waiting Times

	WAITING TIMES			
	Appointment Call	Consulting Call	Domestic Call	Average Waiting Times
CDA9	1.635	0.9160	0.786	0.744
CD8/A1	67.962	0.2320	0.183	63.616
CD7/A2	22.453	0.5900	0.486	20.00
CD6/A3	8.538	1.4700	1.232	4.00
CD4/A5	1.658	6.4650	5.527	5.021
CD3/A6	1.033	12.5420	11.390	10.127
CD2/A7	0.876	23.967	22.181	22.351
DA8/C1	1.604	54.505	1.621	51.166
DA7/C2	1.606	23.341	1.636	21.426
DA6/C3	2.065	11.693	1.9910	10.237
DA5/C4	3.1910	5.903	3.162	3.257

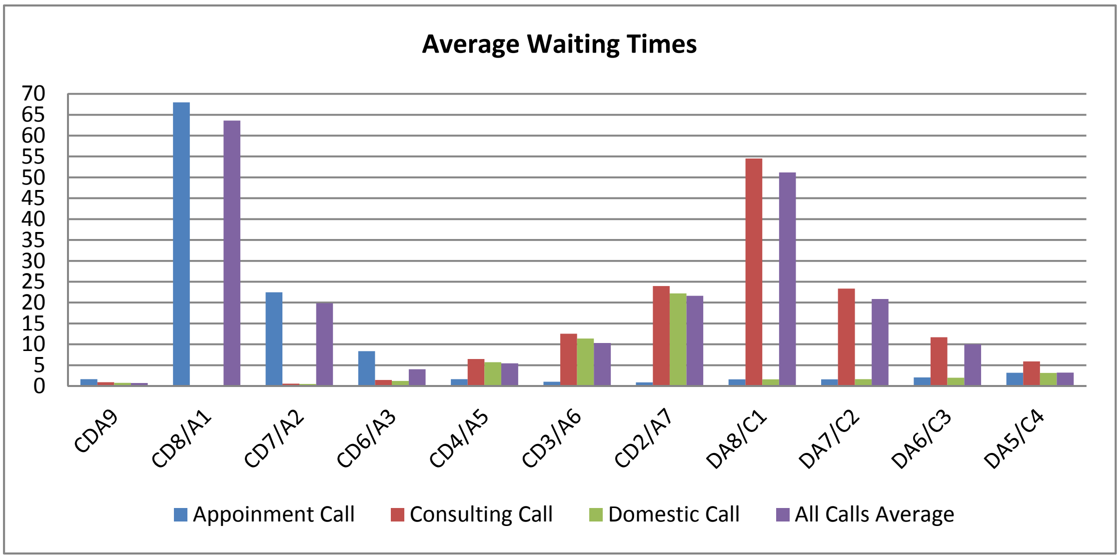

Figure 5.1: Average Waiting Times

Utilization

Agent Utilization is compared among models is depicted in Figure 5.2, as it is observed; the highest utilization rate is in model CDA9. The models which allocates high number of agents to call type Consulting are better in terms of utilization rate. The lowest utilization rated model is DA8/C1. Scheduling many agents to domestic type and appointment type of calls cause less utilization rates since excessive resources are allocated to those calls.

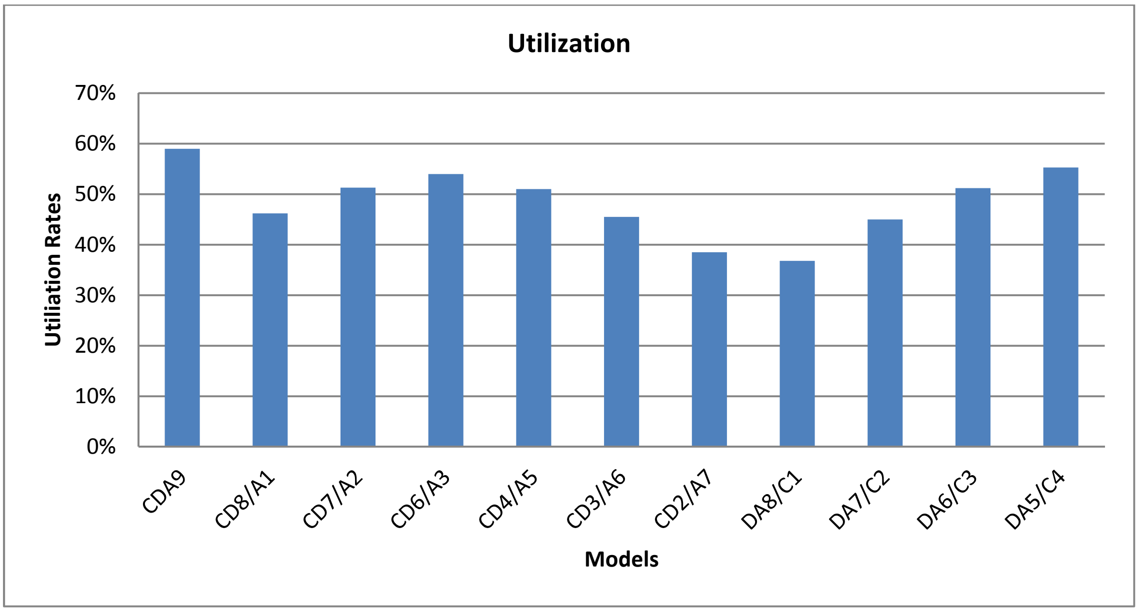

Figure 5.2: Utilization Rate

Abandonments

In dedicated models which specialize to give service to Appointment Calls with agents more than 5, realizes less abandonment in those calls. These models are good on behalf of having Appointment Call customers more satisfied however, the overall abandonment number is still higher than the multi-tasking agent model. The models CD6/A3 and CD7/A2 are coming after CDA9 model having less abandonment number than the other models. This is reasonable since Consulting Calls are the most received call type among 3, allocating more agents to that type of call will lessen the number of lost calls. The comparison of abandonment number as both total and call type based are given in following figure.

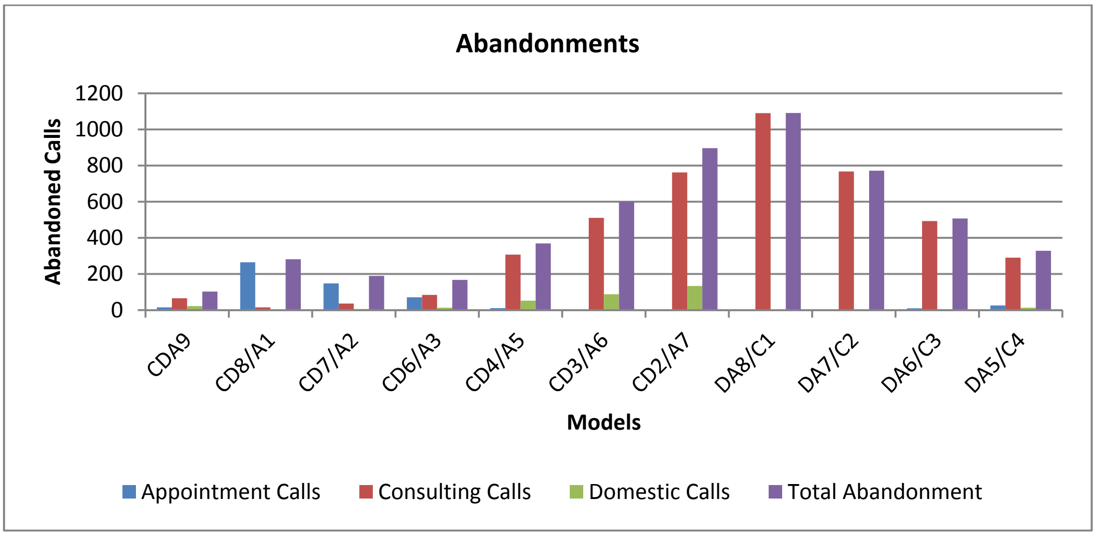

Figure 5.3: Abandoned Calls

5.3. Comparison of Multi-Tasking Agents to Dedicated Agents With Increased Divert Probability of Consulting Calls to Hospital Units

Table 5.5: Simulation Results of the Models with Increased Divert Rate

			ABANDONED # OF CALLS			
	WAITING TIMES	UTILIZATION	APPOINTMENT	CONSULTING	DOMESTIC	TOTAL
CDA9	2.16	0.761	50	271	30	351
CD8/A1	64.87	0.675	264	165	18	447
CD7/A2	22.15	0.691	147	255	28	430
CD6/A3	10.32	0.673	70	370	43	483
CD4/A5	9.35	0.566	10	655	86	751
CD3/A6	14.31	0.487	3	833	116	952
CD2/A7	13.18	0.4	1	1019	154	1174
DA8/C1	53.61	0.373	1	1260	0	1261
DA7/C2	23.31	0.466	3	1052	2	1057
DA6/C3	13.50	0.551	9	858	5	872
DA5/C4	10.43	0.622	25	673	13	711

We will compare the model CDA9 with dedicated agents models to observe whether performance metrics improved under increased rates of diverting the calls. Under the increased divert probability Consulting Calls to units, the models will be compared based on performance metrics. The probability (q_2) is increased 2 times to observe significant changes. Since increasing diverts probability 2 times will increase return traffic 30 times. As we observe from Table 5.5 waiting times of all types of calls, total abandonment numbers and utilizations are increased. CDA9 model still gives better performance metrics when compared to other models. However, abandoned Consulting call numbers are less than CDA9 model in models CD8/A1 and CD7/A2, since more agents are allocated to answer Consulting Calls.

Average Waiting Time

Table 5.6 shows that the all calls average wait time for the multi-tasking agent model is still lower than any other model. However, based on agent number dedicated to answer a specific type of call result with less waiting time for that type of customer group. But all waiting times are increased due to increased Consulting Call traffic in the system. The comparison of average waiting times as both total and call type based are given in Figure 5.4.

Table 5.6: Average Waiting Times With Increased Divert Rate

	WAITING TIMES			
	Appointment Call	Consulting Call	Domestic Call	All Calls Average
CDA9	3.431	4.258	2.483	2.16
CD8/A1	67.9620	2.647	1.552	64.87
CD7/A2	22.4530	4.297	2.527	22.15
CD6/A3	8.3580	6.624	4.046	10.32
CD4/A5	1.6530	14.118	9.608	9.35
CD3/A6	1.0330	20.799	15.376	14.31
CD2/A7	0.8760	32.183	25.470	13.18
DA8/C1	1.6040	63.808	1.6210	53.61
DA7/C2	1.6060	32.028	1.6360	23.31
DA6/C3	2.0650	20.628	1.9910	13.50
DA5/C4	3.1910	13.891	3.1620	10.43

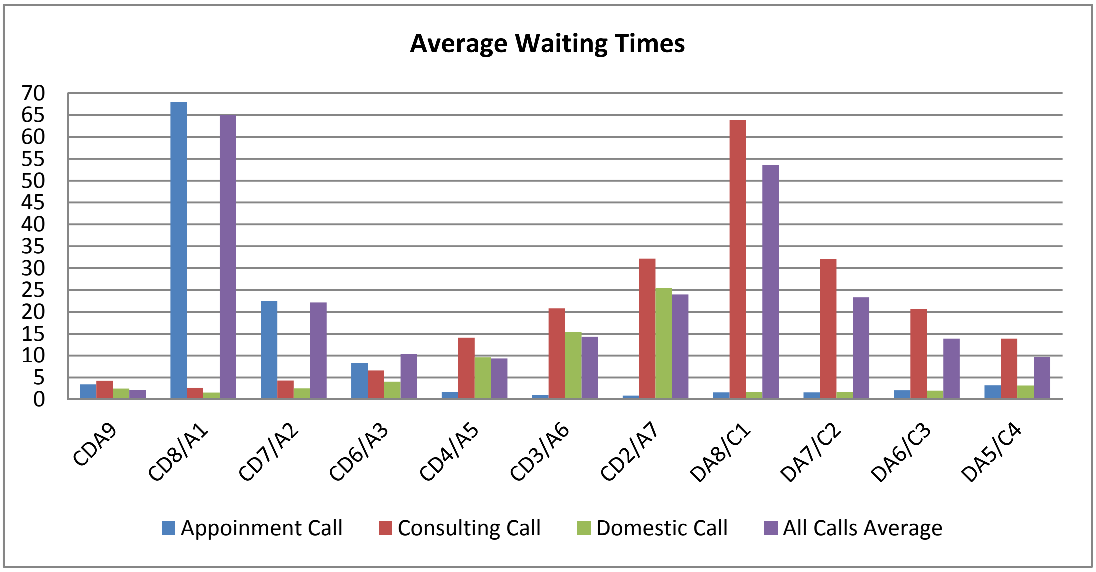

Figure 5.4: Average Waiting Times With Increased Divert Rate

Utilization

Agent Utilization is compared among models is depicted in Figure 5.5, as it is observed; the highest utilization rate is in model CDA9. The models which allocates high number of agents to call type Consulting are better in terms of utilization rate. The lowest utilization rated model is still DA8/C1. The utilization of models which allocates more agents to Consulting calls are increased significantly according with the increase in divert probability.

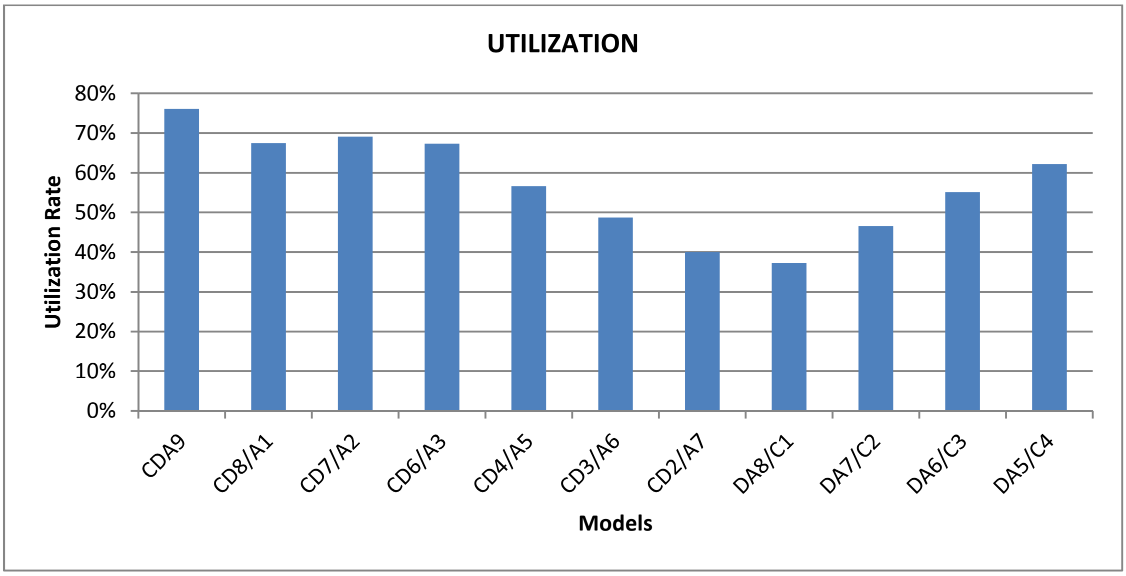

Figure 5.5: Utilizations With Increased Divert Rate

Abandonments

In dedicated models which specialize to give service to Consulting Calls with agents more than 5, realizes less abandonment in this type of calls. Models CD8/A1 and CD7/A2 are coming after multi-tasking agent model CDA9 in total abandonment number. The comparison of abandonment number as both total and call type based are given in following figure.

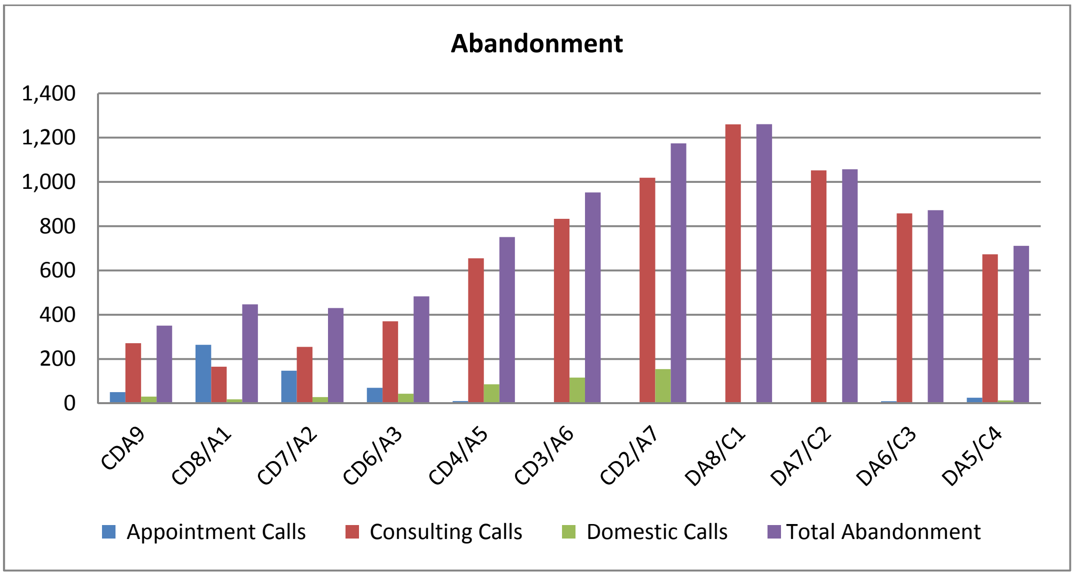

Figure 5.6: Abandonment With Increased Divert Rate

We have compared the system with multi-tasking agents who can give service to all types of calls to the models with varying number of agents dedicated to answer specific types of calls. In queuing models, combining the resources gives better results on operational efficiency however depending on the properties of the systems, allocating dedicated agents to specific customers may end with higher customer satisfaction since abandonments and queuing times will be lower for that type of customers. We have checked all models depending on performance metrics specified and we have observed that the model with multi-tasking agents is more efficient in overall statistics. However, the models which allocates more agents to specific types of calls gives better results in abandonment and queuing times of that types of customers. We also checked that; how performances metrics are affected if the call traffic is increased via boosting Consulting Call divert probability 2 times. We have seen that multi-tasking agent model still gives better results in the most performance metrics. Therefore, optimal model depends on call center's attitude under these circumstances. Call center can choose a model depending on its targets.

Chapter 6

Conclusion and Future Research

In this thesis, a call center queuing network of a hospital is studied. Using real data generated by the center, call traffic of the hospital is analyzed. It is observed that, call center receives 3 different types of calls which we grouped as *Appointment*, *Consulting* and *Domestic Calls*. The routes followed by these calls create the network of the call center. Those processors other than the call center are hospital units and consultant doctor. We observed that some percent of *Appointment Calls* are diverted to doctor whereas *Consulting Calls* are diverted to hospital units. Those calls return to call center unless the directed units answered them. Therefore, not answered calls create rework and dissatisfaction of customers which causes abandonments of the customers. With appropriate analysis we observed that, all call types have different exponentially distributed service times and inter-arrival times of the calls changes according to hours in a day. All of these features create the challenging structure of the hospital call center network. We study this system based on queuing and simulation approaches.

Queuing Approach

The system modeled as a queuing network comprised of M/M/S/K and 2 M/M/1/1 queues representing call center, doctor and hospital units respectively. The state space is composed of all possible transitions from a arbitrary state of (N, a, c, d, r, u). The related transition probability equations are given according to possible transitions from this state to a possible state in δt time. The system can be modeled and solved under the assumption of system reaches steady state. However there exist halting points of the queuing model. First of all, the system is not demonstrated as it is since we have ignored time varying arrivals and abandonment to model the system. Secondly the resulting state space is too large and number of equations to be solved is very high. A possible solution could be a state reduction as to join ***a, c*** and ***d*** to decrease number of states. The state will be (N, A, r, u) with ***A*** being total of ***a, c*** and ***d***. Since ***A*** represents all type of calls, the probability of which type of call leaves first and the rate of leaving cannot be estimated as told. Since all service times are exponentially distributed then with appropriate probability, the service time distribution of the calls become *Hyper-Exponential*. As a future research direction the model can be solved with new state definition based on Hyper-Exponentially distributed service times.

Simulation Approach

As the complication of the call center systems increased, analytical models are troubled to compensate the gap between modeled and realized. Those models tries to approach the system with assumptions, however they fall further back from reflecting the system nature. It is hard to reflect the properties of a system with analytical models however they can be simulated. We use Rockwell Simulation Software to analyze and model the system. Resulting model outputs are compared with real call center statistics to validate the model. The systems of multi-tasking agents and dedicated agents are compared based on output statistics of queuing times, utilization and abandoned call numbers of call types. It is realized that, the flexible system in which all agents can handle all types of calls gives better results in general. We observe that, with appropriate dedicated models, service level of appointment and consulting calls can be increased. The models in which more than or equal to 4 agents are specialized to answer *Appointment Calls* only, can be preferred by call center management since lower abandonment number of this type of calls helps hospital finances. The similar situation for Consulting Calls is also preferable to ensure customer satisfaction. In contrast to Hospital Management's point of views, it is observed that domestic calls do not create extra traffic for he center.It is clear that whole analysis depend on the data observed and generated, if there occurs any suspicion on the accuracy of the data, the models should be revised and the system should be reanalyzed.

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APPENDICES

Appendix A: SPSS Output 1: Arrival Rate Difference Based on Hours

SNK Test

Table A.1: Arrival Rate SPSS Output SNK Test

CALL_ARRIVALS			Subset for alpha = .05		
	SLOTS	N			
			1	2	3
Student-Newman-Keuls*	9	30	176.1		
	4	30		215.6	
	8	30		234.9	
	5	30		240.95	
	7	30		245.1	
	6	30		246.3	
	1	30		248.6	
	2	30			312.55
	3	30			320.35
	Sig.		1	0.2934	0.6206

Means for groups in homogeneous subsets are displayed.
*Uses Harmonic Mean Sample Size = 30

Appendix B: SPSS Output 2: Service Times Difference Based on Call Types

SNK Test

Table B.1: Service Time SPSS Output SNK Test

	CALL TYPE	N	Subset for alpha = .05		
			1	2	3
Student-Newman-Keuls	2	77	3.57		
	1	413		3.84	
	3	116			4.68
	Sig.		1	1	1

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares The Error Term is Mean Square Error=0.424
The group sizes are unequal. The harmonic mean of the group sizes is used.
Type I error levels are not guaranteed.

Alpha = .05

*The Test is made over 606 calls.

Appendix C: Arena Input Analyzer Output: Service Times Distributions

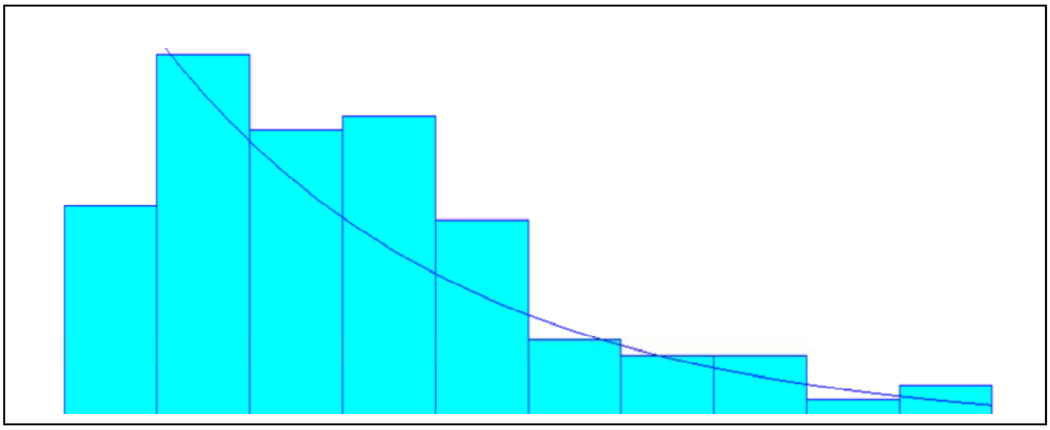

Figure C.1: Appointment Calls Histogram and Distribution Summary

Distribution Summary

Distribution: Exponential

Expression: 34 + EXPO(89)

Square Error: 0.027383

Chi Square Test

Number of intervals = 6

Degrees of freedom = 4

Test Statistic = 16.9

Corresponding p-value < 0.005

Kolmogorov-Smirnov Test

Test Statistic = 0.165

Corresponding p-value < 0.01

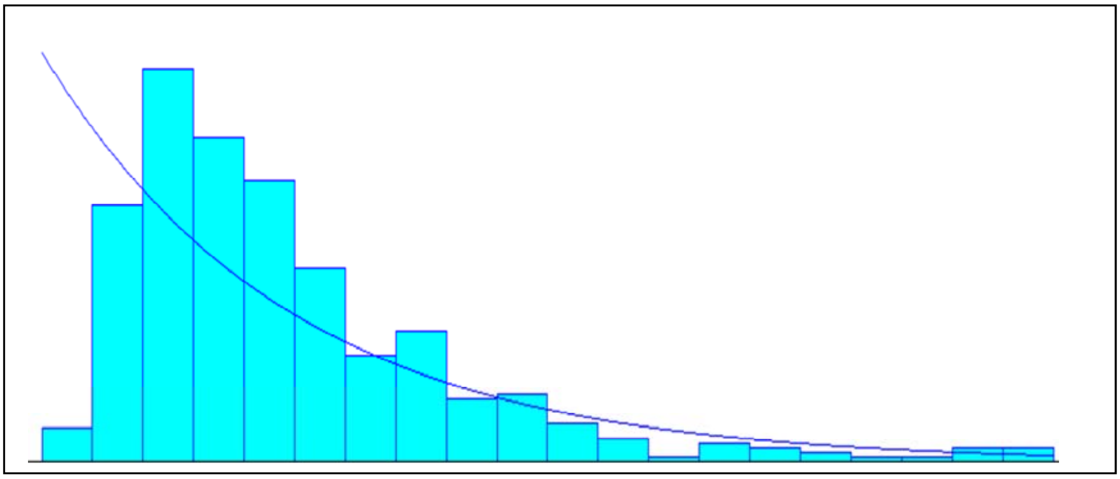

Figure C.2: Consulting Calls Histogram and Distribution Summary

Distribution Summary

Distribution: Exponential

Expression: 0.999 + EXPO(56.5)

Square Error: 0.043149

Chi Square Test

Number of intervals = 13

Degrees of freedom = 11

Test Statistic = 135

Corresponding p-value < 0.005

Kolmogorov-Smirnov Test

Test Statistic = 0.215

Corresponding p-value < 0.01

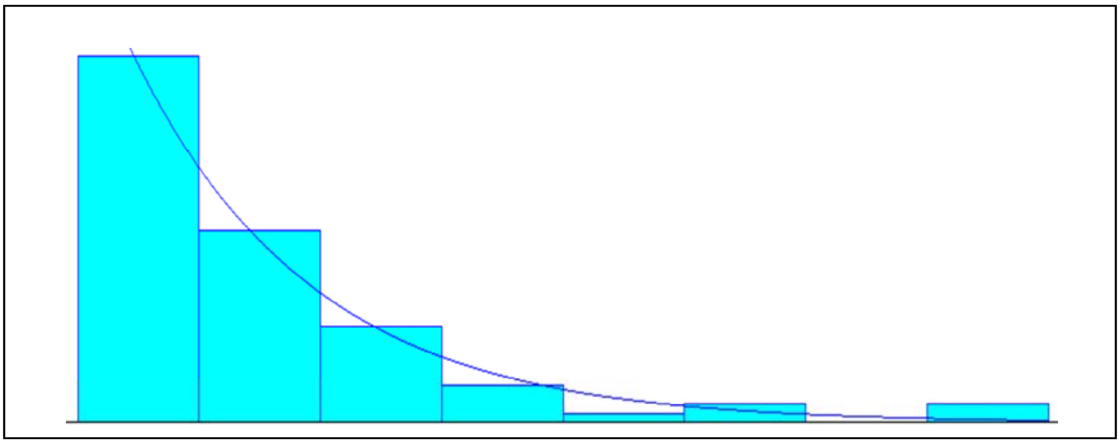

Figure C.3: Domestic Calls Histogram and Distribution Summary

Distribution Summary

Distribution: Exponential

Expression: 6 + EXPO(42.1)

Square Error: 0.001302

Chi Square Test

Number of intervals = 4

Degrees of freedom = 2

Test Statistic = 0.482

Corresponding p-value >0.75

Kolmogorov-Smirnov Test

Test Statistic = 0.0971

Corresponding p-value >0.15

Appendix D

Table D.1: The Percentage of Calls Diverted to Units

Hospital Units	Telephone Extensions	Call Percentage
Pediatrics	2157/2152/2154/2547	30%
Polyclinics	3828/3801	14%
Price Unit	2517/2560	16%
Internal Diseases	2158	2%
Chest Diseases & Cardiology	2162/2255/2256	7%
Endocrinology	2151	7%
Gastroenterology	2250	7%
Urology	2163	5%
Gynecology	2155/2156	4%
Radiology and Laboratory	2252	2%
Orthopedics	2251	5%

* Relevant data is based on 655 Consulting Calls over 950 calls listened in the call center

Appendix E:

Figure E.1: Simulation Model Layout